

UPPER EXTREMITY KINEMATICS AND
JOINT COORDINATION OF FLY-CASTING

by

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ABSTRACT

Little research exists that focuses on the motions and coordination common to fly-casting. It was hypothesized that kinematic parameters of casting (peak and total range of motion, timing of peak joint angular velocity, and magnitude of peak joint angular velocity) would increase in order to cast lines of greater length. Also, it was hypothesized that when greater length of line is cast, the time between peak angular velocities would decrease. The purpose of this study was to determine the kinematic and joint coordination changes necessary to cast lines of different length. Eighteen male subjects participated in the study. Experience ranged from intermediate to expert, with a number of the subjects being professional fly-fishing guides. Twenty three reflective markers were tracked by a 6-camera Vicon® digital capture system. Shoulder motion was calculated with respect to the trunk. The elbow was modeled as a uni-axial pin joint and the wrist as a bi-axial pin joint. Subjects performed casts at conditions of 20, 40, 60, and 80 ft. A MANOVA was used to assess effect of line length. The fly casting motion was divided into three primary phases; back cast, pause, and forward cast. Overall, total ROM increased with increased length of line cast. However, wrist radial/ulnar deviation (RD/UD) total ROM changed little across all distances and wrist flexion/extension (F/E) total ROM decreased with increased line length. Peak angular velocity exhibited a proximal-to-distal trend during the forward cast; first peak shoulder internal rotation, then elbow extension and lastly, wrist ulnar deviation. Time between peak angular velocities did not decrease with increased line length. Time between peak shoulder and elbow angular velocities actually increased ($p = 0.037$) as line length increased. Findings indicate that significant changes in total ROM were needed to accommodate the demands of casting greater lengths of line. Also, joint velocity coordination patterns of fly-casting appear to follow a proximal-to-distal pattern.

CHAPTER ONE

INTRODUCTION

Development of the Problem

The overhand throw is a common movement that has long been used as a method of creating velocity and/or precision in various athletic settings. Throwing motions for a variety of overhand sports (baseball, cricket, American football, etc.) have been well researched and documented in previous literature (Cook and Strike, 2000; Dillman, Fleisig, and Andrews, 1993; Escamilla, Fleisig, Barrentine, Andrews, and Moorman, 2002; Fleisig, Barrentine, Escamilla, and Andrews, 1996). However, little research exists that focuses on the motions and coordination common to fly-casting. Fly-casting instructors reported shoulder and elbow pathologies (associated with the repetitive, high velocity, overhand movements common to fly-casting) in a nationwide survey study (McCue, Guse, and Dempsey, 2004). In light of reported upper extremity (UE) pain and injury specific to fly-casting, the need exists for a biomechanical research study that will accurately describe the fly-casting stroke.

In fly-fishing, the fisher uses a rod of approximately 3 meters in length to cast the line out onto the water. An artificial fly is attached to the end of the line by a leader (a thinner section of line). In one complete cycle of the cast, the caster raises the line out of the water in front, to throw it behind so that it straightens out, roughly parallel to the water. The rod is then returned, in order to propel the line forward and land the fly gently down onto the water (Robson, 1998). Based on qualitative observation and pilot data, the

fly-casting motion appears to have kinematic and coordination patterns similar to overhand throwing motions.

A solid understanding of throwing technique can lead to improvements in throwing performance. As a result, many investigators have studied kinematic and kinetic parameters of the throwing motion. These studies have enabled researchers to predict throwing mechanics that facilitate maximum performance outcomes while minimizing risk of injury (Feltner and Dapena, 1986; Fleisig et al., 1996). The outcome of this study could similarly help to improve fly-casting performance while minimizing risk of UE injury.

Background

Once the sport of fly-fishing is taken up, it is often continued throughout a lifetime. Fly-fishing has long been a popular form of recreation among outdoor enthusiasts and is increasing in popularity. In 2001, 34 million anglers spent an average of 16 days or more fishing. That is equal to 16% of the US population 16 years old and older who went fishing (U.S. Fish and Wildlife Service, 2001). In light of increased participation in fly-fishing, a recent survey of licensed casting instructors revealed shoulder and elbow pathologies associated with repetitive, high velocity, overhand movements common to fly-casting (McCue et al., 2004).

Surprisingly, although a common incidence of pain has been reported by fly-casters, no previous study has formally documented UE movement and coordination patterns during fly-casting. Thus, there is a need for formal research that accurately

describes the fly-casting stroke, possibly allowing for eventual recommendations in relation to performance enhancement and injury prevention in fly-casting.

In fly-casting, as with any other throwing activity, different types of casts are used according to surrounding conditions and desired result. An accurate cast with little power could be needed to reach a location that is in close proximity (eg. less than 40 ft.) to the caster. Or, the caster might need a powerful cast to reach a desired location that is farther away (eg. greater than 40 ft). An increase in line length is needed to reach greater casting distances. The increased line would move through the air during the cast, providing an increased load on the rod and arm. This effect may be similar to throwing objects with different masses. One biomechanical study of overload pitching (Castagno, P., Richards, J., and Axe, M., 1995) noted that an increase in mass of the projectile directly affected ROM and throwing patterns of subjects. Whereas, Fleisig et al. (1996) found no significant ROM difference between baseball pitching and football throwing, despite the difference in mass of a baseball (5 oz) and football (13-14 oz). Hence, there was a need to address ROM and joint coordination changes that would occur in response to increased load (due to greater length of line for distance casts) during fly-casting.

In summary, determining biomechanical parameters specific to fly-casting may allow greater understanding of the underlying mechanisms of UE pathologies in this specific population.

Statement of Purpose

Previous researchers have reported that the repetitive, high-velocity nature of fly-casting can lead to UE pain (McCue et al., 2004). However, there has been no published

research specifically relating to the kinematics of fly-casting. The overall goals of this research were to document kinematic patterns and determine joint timing patterns common to fly-casting. With respect to those goals, the purpose of this study was to determine the kinematic and joint coordination changes necessary to cast lines of different length.

Information provided through this research on fly-casting may provide a foundation from which to explain UE pain associated with casting fly rods (McCue et al., 2004). In future research, the resulting kinematic and timing patterns may then be analyzed and interpreted in hopes of establishing a link between casting styles, injury, and/or performance enhancement.

Hypotheses

Two major hypotheses were tested. First, it was hypothesized that kinematic parameters (peak and total range of motion, timing of peak joint angular velocity, and magnitude of peak joint angular velocity) of casting will increase in order to cast lines of greater length:

$$\mathbf{H}_{o1}: \mu_1 = \mu_2 = \mu_3 = \mu_4$$

$$\mathbf{H}_{a1}: \mu_1 < \mu_2 < \mu_3 < \mu_4$$

Where, the notations of μ_{1-4} are the parameter specific sample means of casting with 20, 40, 60, and 80 ft of line, respectively. Second, it was hypothesized that when greater length of line is cast, the time between peak angular velocities will decrease:

$$\mathbf{H}_{o2}: \mu_1 = \mu_2 = \mu_3 = \mu_4$$

$$\mathbf{H}_{a2}: \mu_1 > \mu_2 > \mu_3 > \mu_4$$

Where, the notations μ_{1-4} represent the respective times between peak angular velocities (from shoulder to elbow to wrist) for the 20, 40, 60, and 80 ft casts. A decrease in timing of peak velocities about the shoulder, elbow, and wrist would allow for a more efficient translation of velocity down the kinematic chain of the arm.

Total timing between peaks was defined as time between peak shoulder velocity and peak wrist velocity. Time between peak shoulder velocity and peak elbow velocity, as well as time between peak elbow and wrist velocity were analyzed.

Assumptions

Assumptions in this study were:

- The lab environment was similar to the field environment of fly-casting
- The rod used was a typical rod used by a large proportion of the specific population

Limitations

Limitations of this study were:

- Replication of the field environment in the lab setting
- Subject number and availability
- The recruited sample may not have represented the general population of fly fishers

Operational Definitions

- Frontal Plane – bisects an object into anterior and posterior portions
- Transverse Plane – bisects an object into superior and inferior portions
- Sagittal Plane – bisects an object into medial and lateral portions
- Longitudinal Axis – an axis about which rotational movements occur; also known as superior/inferior (coincides with the transverse plane)
- Mediolateral Axis – an axis about which flexion/extension movements occur (coincides with the sagittal plane)
- Anterior/Posterior Axis – an axis about which adduction/abduction movements occur (coincides with the frontal plane)
- Shoulder External Rotation (ER) – rotation of the humerus externally, about its long axis, in the transverse plane
- Shoulder Internal Rotation (IR) – rotation of the humerus internally, about its long axis, in the transverse plane
- Shoulder Flexion – movement of the upper arm with respect to the trunk, toward the anterior, in the sagittal plane, about a mediolateral axis
- Shoulder Extension – return from shoulder flexion; movement of the upper arm with respect to the trunk, toward the posterior, in the sagittal plane, about a mediolateral axis
- Shoulder Abduction – movement of the upper arm away from the midline of the body, with respect to the trunk, in the frontal plane, about an anterior/posterior axis

- Shoulder Adduction – movement of the upper arm toward the midline of the body, with respect to the trunk, in the frontal plane, about an anterior/posterior axis
- Shoulder Horizontal Abduction – movement of the upper arm away from the midline of the body, with respect to the trunk, in the transverse plane, about a superior/inferior axis
- Shoulder Horizontal Adduction – movement of the upper arm toward the midline of the body, with respect to the trunk, in the transverse plane, about a superior/inferior axis
- Elbow Flexion/Extension (F/E) – movement of the distal arm segment about a mediolateral axis of the elbow, effectively bending and straightening the elbow
- Wrist Flexion/Extension (F/E) – movement of the hand about a mediolateral axis of the wrist
- Wrist Radial/Ulnar Deviation (R/U) – movement of the hand about an anterior-posterior axis of the wrist
- Angular Velocity – a vector quantity (ω) that describes the time rate of change of angular position
- End-point Velocity – linear velocity of the distal end-point of an anatomical system
- Degree of Freedom (DOF) – a type of motion structurally allowed by the anatomical joints (maximally: three rotational and three translational)

CHAPTER TWO

REVIEW OF THE LITERATURE

Introduction

The throwing motion has long been used in various athletic settings as a method of displacing an object with high velocity and precision. The kinematics of numerous overhand sports have been well documented in previous literature (Cook and Strike, 2000; Dillman et al., 1993; Escamilla et al., 2002; Fleisig et al., 1996). These studies have served to identify important variables relating to throwing performance.

A nationwide survey study of licensed fly-casting instructors revealed shoulder and elbow pathologies associated with repetitive, high velocity, overhand movements common to fly-casting (McCue et al., 2004). Pains in the shoulder (50%), elbow (39%), and wrist (36%) were reported. Also, Berend (2001) revealed shoulder and elbow pain in a portion of respondents to a national fly-fishing survey. The basic motions and joint coordination common to fly-casting have never been researched or documented in a three-dimensional movement analysis study. Thus, a biomechanical study is needed that will accurately describe the fly-casting stroke, allowing for eventual injury prevention and performance enhancement recommendations.

Injury History

The powerful nature of throwing has been implicated in UE injuries. Examples of UE pathologies related to throwing are rotator cuff injuries, SLAP (Superior Labral tear

from **A**nterior to **P**osterior) lesions, and tendonitis (Fleisig et al., 1996). As a result of UE injuries, many investigators have studied kinematic and kinetic parameters of the overarm throw. Throwing motions for baseball (Dillman et al., 1993; Escamilla et al., 2002; Fleisig et al., 1996), football (Fleisig et al., 1996), volleyball hitting (Kugler, Kruger-Franke, Reininger, Trouillier, and Rosemeyer, 1996) and cricket (Cook and Strike, 2000) have been previously documented. These studies enabled researchers to predict throwing mechanics that achieve maximum performance outcomes while minimizing risk of injury. Effective injury management strategies have been utilized as a result of this research.

UE pain has also been reported in fly-fishermen. A national survey by Berend (2001) revealed shoulder pain (28%) and elbow pain (18%) in respondents to an online fly-fishing survey. McCue et al. (2004) stated that recommendations of certain fly-casting techniques may be useful in alleviating pain symptoms in the upper extremity. Similar to previous pitching/throwing studies, the information revealed by this study will help to improve fly-casting performance while minimizing risk of UE injury.

Based on qualitative observation and pilot data, the fly-casting motion appears to have kinematic and coordination patterns similar to common throwing motions. This chapter will examine those similarities by first reviewing basic overhand throwing kinematics, followed by a review of the coordination of UE joints during overhand throwing tasks. Also included will be a brief review of fly-casting pilot data.

Kinematics

Dillman et al. (1993) was the first group to publish a 3-D analysis of pitching. High speed (200 Hz) video analysis was used to calculate specific parameters of throwing focusing on the shoulder joint. Fleisig et al. (1996) reviewed baseball overhand pitching motions in great detail. They also compared the primary kinematic descriptions of the baseball throwing motion with similar throwing motions (American football, volleyball, and javelin).

Escamilla, Fleisig, Zheng, Barrentine, and Andrews (2001) used data collected on baseball pitchers at the 1996 Summer Olympics to compare kinematics between countries. Escamilla (2001) also used anthropometric and kinematic measurements to determine ball velocity. Escamilla et al. (2001) and Fleisig et al. (1996) divided the pitching motion into five phases: lead foot contact, arm cocking, arm acceleration, ball release, and arm deceleration. Although the throwing motion has been divided into phases, it is important to notice that a discontinuous action is not suggested. The purpose of the divisions of the throwing motion is to identify key mechanical parameters within each phase. Refer to Table 2.1 for kinematic descriptions of throwing reported by various authors.

For baseball pitching, arm cocking has been defined as the time from lead foot contact to maximum shoulder external rotation (ER). Arm acceleration has been defined as the time from maximum shoulder ER to ball release (Fleisig et al., 1996; Escamilla et al., 2001). It is important to note that the fly-casting stroke does not utilize a wind-up approach as in baseball pitching.

Table 2.1: Throwing kinematics presented by various authors (maximum degree); mean (SD)

Reference/Sport	n=	Elbow Flexion	Shldr Abd (@ foot contact)	Shldr ER	Shldr H Add [†]
Fleisig et al. (1996) – baseball	26	100 (13)	93 (12)	173 (10)	18 (8)
Fleisig et al. (1996) – football	26	113 (10)	96 (13)	164 (12)	32 (9)
Sakurai et al. (1993) – fastball	6	116 (19)	83 (12)	181 (7)	11 (12)
Sakurai et al. (1993) – curveball	6	114 (17)	78 (10)	181 (6)	14 (13)
Feltner & Dapena (1986) - baseball	8	91 (8)	76 (9)	170 (10)	N/A
Rash & Shapiro (1995) – football	12	110 (10)	96 (7)	164 (11)	12 (9)

[†]Shldr=Shoulder, Abd=Abduction, ER=External Rotation, H Add=Horizontal Adduction

A recent pilot study demonstrated that the fly-casting motion may be divided into three primary phases (Allen, O’Keefe, McCue, and Hahn, 2005). The first phase, the “back cast,” is a movement from anterior to posterior, displacing the fly line behind the caster (See Figure 2.1). Primary motions during Phase 1 included flexion, abduction, and ER of the shoulder; flexion of the elbow; and radial deviation of the wrist. At the end of the back cast, there is a pausing phase (Phase 2) in which the caster waits for the line to load the rod prior to the forward cast. Phase 3, the “forward cast,” serves to move the rod anteriorly, sending the line toward the desired target (see Figure 2.1). Primary motions during phase 3 included internal rotation and extension of the shoulder, combined with extension of the elbow and ulnar deviation of the wrist. For further reference the casting stroke will be referred to in terms of Phases 1, 2, and 3 (P1, P2, and P3).

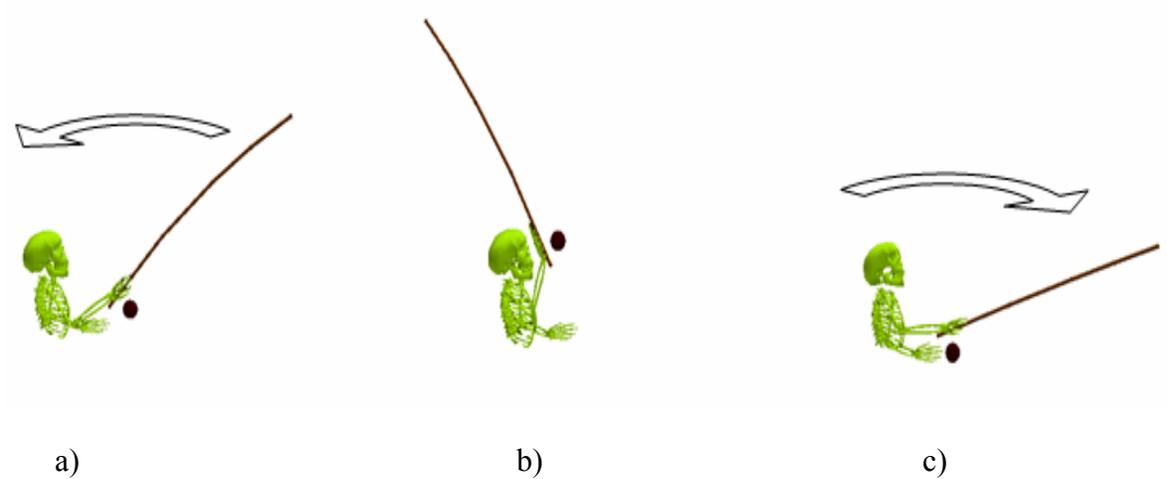


Figure 2.1: An example of the motions of the a) Back cast (P1), b) Pause (P2), and c) Forward cast (P3). Adapted from pilot data (Allen et al., 2005).

Throughout the cocking phase of overhand throwing the shoulder remains abducted approximately 90° , and at the end of the cocking phase the shoulder is externally rotated between 150° and 180° (Fleisig et al., 1996). For the current study, the amount of ER was expected to be less than that of pitching, and the degree of abduction was expected to be similar to pitching. During fly-casting, the caster stands somewhat stationary while casting and exhibits little anterior/posterior trunk movement, effectively limiting ER. During pitching, inertial characteristics of the arm/hand/ball system during arm cocking and anterior trunk movement combine to produce high degrees of ER.

Little joint motion is expected during P2 of the cast. This brief pause allows the line to continue traveling behind the caster, in effect “loading” the rod.

The acceleration phase of throwing consists of internal rotation, horizontal adduction, and extension of the shoulder, and extension of the elbow (Escamilla et al., 2002). For the current study, the amount of IR and elbow extension was expected to be

less than that of pitching. During fly-casting, the forward motion does not result in release of the projectile from the hand (as in pitching), effectively limiting the amount of IR and elbow flexion needed to cast.

Pilot data collected to support the current project indicated P3 to have similar motions to throwing. The greatest ROM for all joints occurred during P3, followed by P1. The greatest ROM during P1 and P3 was external/internal rotation of the shoulder, followed by elbow flexion/extension. Shoulder flexion/extension and ab/adduction also exhibited substantial ROM during the forward cast. Average ROM values for the pilot study by Allen et al. (2005) are presented in Table 2.2.

Table 2.2: ROM during each phase (degrees); mean (SD), n = 6.

Joint Motion [†]	Phase 1	Phase 2	Phase 3
Sh. F/E	26.1 (3.1)	3.6 (2.3)	27.9 (17.1)
Sh. Ab/d	19.2 (9.6)	6.9 (5.3)	22.1 (21.0)
I/E Rot	63.4 (11.8)	6.6 (3.7)	53.0 (17.7)
F/E	31.0 (6.1)	3.4 (2.2)	41.1 (17.0)
F/E	21.9 (5.8)	3.6 (1.8)	21.9 (12.4)
R/U Dev	12.7 (1.5)	5.1 (3.7)	11.9 (6.5)

[†] Sh = shoulder, Elb = elbow, Wr = wrist, F/E = flex/extension, Ab/d = ab/adduction, I/E = int/external rotation, R/U = radial/ulnar deviation.

Time to Peak Angular Position within each phase is presented in Table 2.3. In general, substantial variation was seen in the relative timing of peak displacements (most likely due to low sample size). However, two patterns showed consistency. Peak shoulder external rotation of $71.6^\circ (\pm 17.0^\circ)$ occurred at 4% ($\pm 6\%$) of P3, and peak elbow flexion of $101.7^\circ (\pm 14.6^\circ)$ occurred 19% ($\pm 22\%$) into P3. The early external rotation in P3 may

indicate the effect of anterior trunk motion and inertial delay in the arm and rod segments, similar to the acceleration phase of a baseball pitch.

Table 2.3: Relative time to peak displacement (% of phase); mean (SD).

Joint Motion [†]	Phase 1	Phase 2	Phase 3
Sh. F/E	22 (25)	42 (30)	64 (29)
Sh.Ab/d	59 (27)	38 (33)	52 (28)
Sh. I/E Rot	78 (25)	46 (36)	4 (6)
Elb. F/E	65 (29)	38 (34)	19 (22)
Wr. F/E	54 (42)	50 (38)	35 (25)
Wr. R/U Dev	56 (39)	53 (34)	55 (24)

[†] Sh = shoulder, Elb = elbow, Wr = wrist, F/E = flex/extension, I/E Rot = int/external rotation, R/U Dev = radial/ulnar deviation.

Findings from this pilot study indicated moderate consistency of basic movement patterns between subjects during fly-casting. The proposed study provided increased consistency in those patterns (due to increased sample size) and thoroughly described the UE kinematics relating to fly-casting.

Joint Coordination

The concepts of sequential joint timing patterns are common in previous throwing research. The ability to produce large hand or foot speed, maximizing velocity of the distal segment, is essential for success in most sporting activities. Specific coordination of bodily segments can result in maximal acceleration of the distal segment (Hirashima, Kadota, Sakurai, Kudo, and Ohtsuki, 2002). Two opposing theories have resulted from this research. The first theory lends to proximal to distal (P-D) timing that is required in

order to achieve a high end-point velocity during a throwing task. The second theory suggests use of a simultaneous or non-sequential timing pattern in order to achieve desired throwing performance. The two theories will be reviewed in greater detail in this section.

Proximal-to-distal (P-D) Timing

A number of authors have suggested P-D sequencing is necessary to achieve maximal projectile speed or distance (Chowdhary and Challis, 2001b; Herring and Chapman, 1992). Authors who examined baseball pitching (Barrentine, Fleisig, Whiteside, Escamilla, and Andrews, 1998; Dillman et al., 1993; Feltner and Dapena, 1986; Fleisig et al., 1996), javelin throwing (Best, Bartlett, and Morriss, 1993), and American football (Fleisig et al., 1996; Rash and Shapiro, 1995) have presented a P-D sequencing theory for high velocity throwing actions.

The P-D sequence has also been justified by mathematical models of throwing mechanics (Chowdhary and Challis, 2001a; Herring and Chapman, 1992). Chowdhary and Challis (2001a) used a mechanical model to scrutinize past throwing models that validated P-D sequencing. A two-segment, two-joint throwing model was utilized to project balls of different masses. In throws for maximum distance of the projectile, a P-D sequencing of muscular activations was determined to be ideal. Herring and Chapman (1992) utilized a uni-planar shoulder joint throwing model to determine if P-D sequencing and/or maximal muscular torque was necessary for maximal performance. Torques about the shoulder, elbow, and wrist were inputs to the model. Maximal velocity of the endpoint of the distal segment and maximal distance of a projectile were

recorded. Results from this study supported P-D sequencing in order to achieve maximal endpoint velocity and projectile displacement.

Several authors have further added support to the P-D theory. In a study of bowling in cricket, Cook and Strike (2000) reported that an ordered series of joint motion (namely P-D) is optimal to produce high end-point velocities during overhand throwing. The study was on a single professional male cricket bowler. Relevant literature review from Cook and Strike (2000) confirmed the designation of “phases” for throwing tasks. Peak segment endpoint velocities were used to determine timing of activity for the UE. The P-D theory was validated, with the segments of the arm being coordinated in a sequential fashion, proximal-to-distal, such that the endpoint yielded a high velocity at release.

Hirashima et al. (2002) used electromyography (EMG) to record activation of muscles used for throwing in nine subjects (three baseball players, one American football quarterback, and two tennis players). In doing so, they reported a P-D sequence in muscular activity during overarm throws. These researchers provided alternative means to validate results that had only previously been presented as a result of motion analysis data. Similarly, Chowdhary and Challis (2001b) noted that throws for maximal distance used a P-D sequencing of muscle activations, as recorded by electromyography.

Non-Sequential Timing

Other authors have shown that there are differences in the sequence of peak joint velocity based on the skill and/or power required for the task at hand (McDonald, Van Emmerik, and Newell, 1989; Van Den Tillaar and Ettema, 2003). These researchers have

determined that a difference in P-D sequencing may occur as a function of the desired result of the throw. For instance, when power is the goal of the throwing motion, P-D sequencing may be the best option. When accuracy is desired from the throwing motion, the P-D sequence fades, in order to yield accurate propulsion of the projectile.

Van Den Tillaar and Ettema (2003) sampled nine experienced team handball players from Norway to determine if different joint timing strategies are used for overarm throws with different purposes (accuracy vs. velocity). They noted that a non-sequential timing pattern was utilized for overarm handball throws; such that maximal linear velocity of the elbow occurred before maximal linear velocity of the shoulder. Similarly, Fradet et al. (2003) suggested that non-P-D sequencing is standard for handball players. Injury prevention was suggested as a possible reason for the non-P-D sequencing found in the study. Gowitzke and Milner (1980) proposed that simultaneous peaks in angular velocity of all joints are required when maximal projectile speed is desired. This proposal was based upon a simulation model for overhand throwing.

In a study of tennis players at the 2002 Summer Olympics, it was reported that P-D sequence of maximum angular velocities was not evident during the tennis serve (Fleisig, Nicholls, Elliot, and Escamilla, 2003). In fact, maximum angular velocity for shoulder internal rotation occurred after maximal elbow and wrist angular velocity. This is in opposition to results presented in a throwing study involving baseball and American football (Fleisig et al., 1996). Late shoulder velocity in the tennis study by Fleisig et al. (2003) is consistent with patterns shown for the serve of college level tennis players and the forehand drive used by squash players (Marshall and Elliot, 2000). Extension of the

elbow slightly before internal rotation of the shoulder allows the athlete to reduce the inertia and reach greater shoulder internal rotation angular velocity (Dillman et al., 1993)

Throwing vs Casting

Fly-casting is similar to other throwing tasks in that the desired result is accurate placement of a projectile at some distance away from the body. Researchers, based on pilot data, indicated that P-D sequencing for angular velocities may exist in fly-casting (O'Keefe, Allen, McCue, and Hahn, 2005). The study was focused on relative timing of peak angular velocities for the shoulder, elbow, and wrist during P3. The relative time to peak angular velocity for the shoulder, elbow, and wrist was found to be $80.5\% \pm 8.5$, $86.3\% \pm 6.3$, $89.1\% \pm 8.8$, respectively.

While there may be differences in proper throwing mechanics for various sports, certain similarities are found in all overhand throws (Fleisig et al., 1996). Describing kinematic parameters and establishing the joint coordination patterns of fly-casting will enable comparisons to past throwing research. This will provide a basis for further development of performance and injury prevention guidelines.

CHAPTER THREE

METHODOLOGY

Subjects

A convenience sample of nineteen subjects was recruited to participate in the study. Subjects were recruited from local guide shops as well as from Montana State University. Subjects were required to have at least minimal fly-casting experience, defined as those who have casted, on average, at least 10 days/year for the past 3 years. Subject skill and experience range was between intermediate and expert, excluding beginners and professionals (certified instructors). In accordance with Van Den Tillar and Ettema (2003), excluding beginner subjects will assist in avoided the effects of under-developed coordination patterns. In contrast, professional fly-casters (defined as certified instructors) are often exceptions to the norm in terms of technique and susceptibility to injury, thereby not representing the general population.

O'Keefe et al. (2005) observed that the magnitude of UE peak angular velocities during the forward motion (P3) of fly-casting were largely dependent on the experience level of the subject. Therefore, those who fished 10 days/year or less were more likely to have high angular velocities about the wrist, compared to the elbow and shoulder; whereas, more experienced subjects had a much greater shoulder angular velocity. These data supported limiting the subject pool to those who fish 10 days/year or more. Including subjects in the study who fish very infrequently would have added variability of results. The results would have been less generalizable to the majority of fly-fishermen who fish consistently.

To correctly assess and report fly-casting mechanics, the subjects were required to be healthy. Healthy subjects were defined as those who were not currently injured or recovering from an injury, and who had not had surgery in the past 12 months. Subjects who had undergone surgery (> 12 months post-surgery) were not considered healthy if they are not yet back to 100% performance (adapted from Dillman et al., 1993). The subject pool was not limited by sex or age.

Protocol

Prior to data collection, subjects signed an IRB approved informed consent and completed a brief questionnaire describing past fly-fishing experience. The questionnaire was utilized to provide a brief medical history for each subject, and for exclusion of beginners and professionals. The subjects were asked to qualify themselves as beginner, novice, intermediate, advanced, expert, or professional. They were also asked the duration and frequency of their fly-casting experience. These variables served to categorize subjects, allowing for the possibility of future data analysis that may include comparisons between levels of expertise. See Appendix A for the subject questionnaire.

Each subject was given 5-10 minutes to familiarize themselves with the equipment and setting. Then, each subject was asked to perform multiple casting trials. For this study, casting style was limited to overhand casting, illustrated in Figure 3.1.

Athletes in throwing sports often need to throw different distances according to the desired result of the throw. A maximal throw may not always yield success; in some cases, the accuracy of the throw may be of most importance (Cook and Strike, 2000). Similarly, while fly-casting, the desired result of the cast will dictate the type of cast

used. An accurate cast with little power could be needed to reach a location that is in close proximity (i.e., less than 40 ft.) to the caster. Or, the caster might need a powerful cast to reach a desired location that is farther away (i.e., greater than 40 ft.) from the caster. Thus, subjects performed 20 casts in total; five casts at each of four designated distances (20 ft., 40 ft., 60 ft., and 80 ft). The three middle casts at each distance were analyzed. Each distance was controlled for (by wrapping the line around the reel) once the desired line length had been measured out.

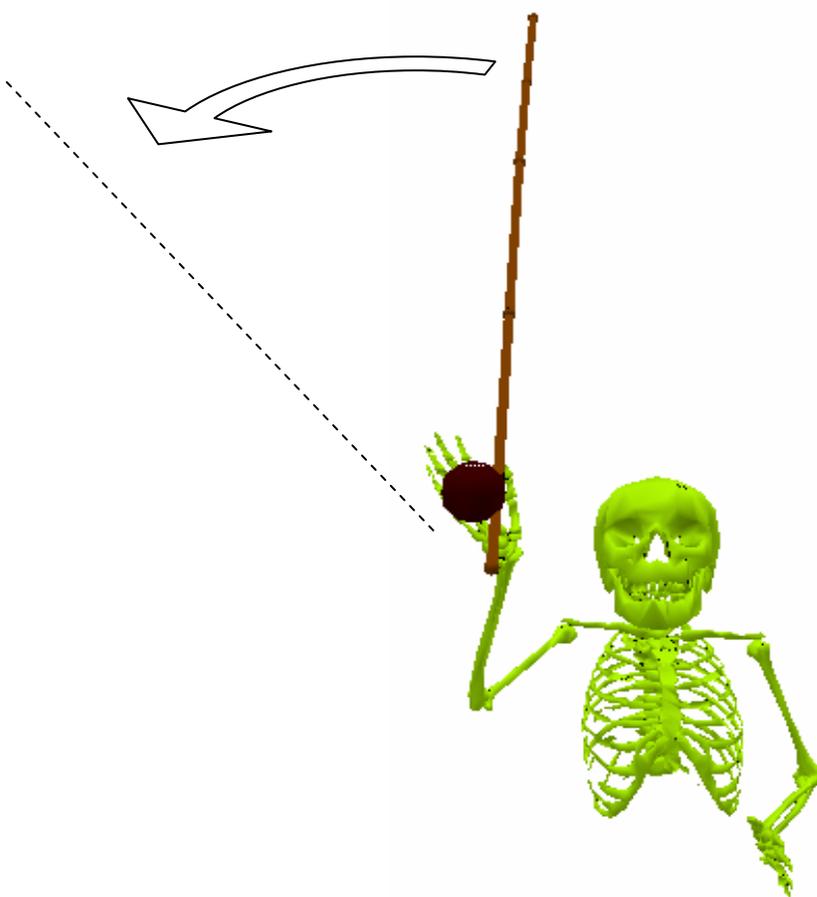


Figure 3.1: An illustration of desired casting angle. The current study collected data on only overhand casters. Any subject who repeatedly casted below that of approximately 45° from vertical (dashed line) was excluded.

The goal of each cast was to cast the desired distance. No accuracy component was involved. The order of distance conditions was controlled using a Latin Square design in order to eliminate a learning effect that could occur if all subjects were to cast in sequential distances. A total of 20 casts was significantly below the amount of casting that would occur during a normal day fly-fishing effectively limiting a possible confounding effect of fatigue.

For each trial, subjects were instructed to perform a series of “false casts” (usually 1-2), followed by the actual “shooting cast.” The purpose of the false cast is to give the caster a sense of rhythm and allow for familiarity of the required casting distance. The shooting cast refers to the cast in which the end of the line is placed out onto the water. Data were analyzed on only the shooting cast of each trial. Each subject was allowed to rest between casts, while data processing occurred for the previous trial (usually 1-2 minutes), reducing the risk of fatigue.

Instrumentation

Twenty-three spherical reflective markers were placed on prominent bony landmarks of the upper body that are easily identifiable and reproducible (adapted from Rab, Petuskey, and Bagley, 2002). Marker locations were as follows: head (4), vertebral (C7 and T10), right scapula, suprasternale, infrasternale, acromion process, lateral upper arm, lateral epicondyle of the elbow, forearm (mid-radius), radial and ulnar styloids of the wrist, and dorsal aspect of distal 3rd metacarpal. Markers were adhered with double sided adhesive tape. See Figure 3.2 for an example of marker placement.

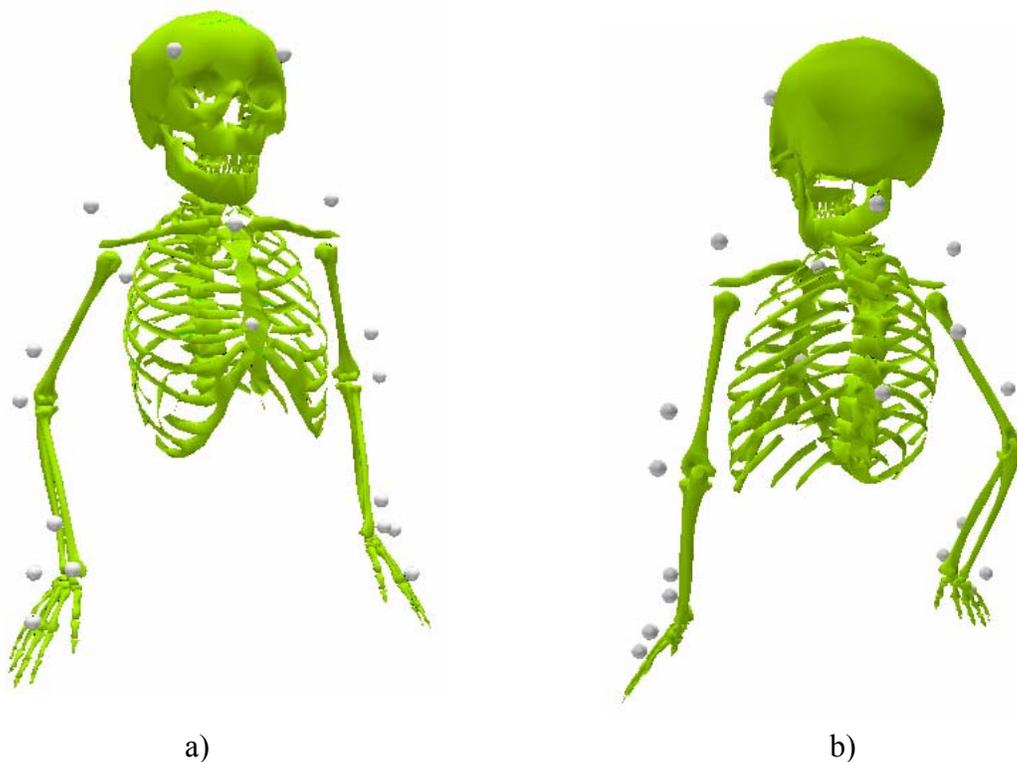


Figure 3.2: Marker locations from a sample static trial during pilot data collection; a) right anterior oblique; b) left posterior oblique.

A six camera Vicon® 460 system (Vicon Motion Systems Inc., Lake Forest, CA) was utilized to collect reflective marker position data at a frequency of 200 Hz. This allowed for precise three dimensional reconstructions of the fly-caster and fly rod. Specific calibration methods were followed prior to each data collection session.

A medium stiffness fly rod (Redington Rods, Bainbridge Island, WA) was used by all subjects for all trials. The rod had retro reflective tape markers spaced along the length of the rod and on the reel. Reflective markers along the rod provided more accurate three dimensional representation of the fly rod, allowing for future data analysis that might include dynamics of the interaction between the hand segment and the rod.

Measurements

Anthropometric measurements were taken for each subject in order to identify joint centers and axes of rotation. The upper extremities were modeled as a system of rigid bodies. Vicon Workstation (v4.6) software was used for all UE calculations; including representations of 3-D joint angles, using Euler sequence calculation techniques. For each trial, phases were designated by manual marking of the following time events: start of casting motion, end of back cast, start of forward cast, and end of casting motion. ROM and peak angular positions were calculated for all three phases of the fly-cast. Peak joint angular velocities were calculated for P3 only.

Shoulder motion was calculated with respect to the trunk segment; modeled as having three rotational degrees of freedom (DOF). Order of rotation for the shoulder was calculated as sagittal, frontal, and transverse. The elbow was modeled as a single-axis pin joint (1 DOF), and the wrist as a two-axis pin joint (2 DOF). See Figure 3.3 for rotation axes of the UE that were used.

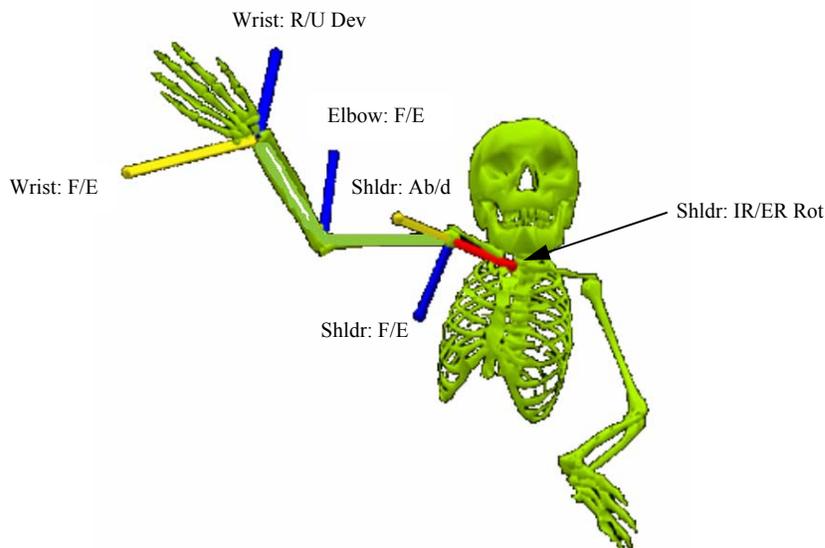


Figure 3.3: Rotation axes of the UE. The shoulder was modeled with 3 DOF (rotations about the F/E, Ab/d, and IR/ER axes); the elbow with 1 DOF (rotation about the F/E axis); and the wrist with 2 DOF (rotation about the F/E, and R/U axes).

Table 3.1: Dependent variables.

Joint	Action [†]	Variable 1	Variable 2	Variable 3 (P3 only)	Variable 4 (P3 only)
Shoulder	F/E	Tot. ROM	Peak Ang. Displacement	Peak Ang. Vel.(ω)	TT Peak ω
	Ab/d	Tot. ROM	Peak Ang. Displacement	Peak Ang. Vel.(ω)	TT Peak ω
	I/E Rot	Tot. ROM	Peak Ang. Displacement	Peak Ang. Vel.(ω)	TT Peak ω
Elbow	F/E	Tot. ROM	Peak Ang. Displacement	Peak Ang. Vel.(ω)	TT Peak ω
Wrist	F/E	Tot. ROM	Peak Ang. Displacement	Peak Ang. Vel.(ω)	TT Peak ω
	R/U Dev	Tot. ROM	Peak Ang. Displacement	Peak Ang. Vel.(ω)	TT Peak ω

[†]F/E = flex/extension, Ab/d = ab/adduction, I/E Rot = internal/external rotation, R/U Dev = radial/ulnar deviation

Total range of motion (ROM), Peak Angular Position and time to peak displacement were examined for phase patterns, focusing on the following motions: shoulder flex/extension (F/E), ab/adduction (Ab/d), int/external (I/E) rotation; elbow F/E; wrist F/E and radial/ulnar (R/U) deviation. Joint timing patterns were calculated with respect to timing of peak endpoint angular velocity. Time and magnitude of peak angular velocities were examined during the forward cast only. Angular velocities were calculated using the central difference method and smoothed with a 4th order Butterworth low pass filter (cutoff = 2Hz). Peak velocities of shoulder internal rotation, elbow extension, and wrist ulnar deviation were examined for joint coordination patterns.

Data Analysis

The independent variable in this study was the distance of line cast (20, 40, 60, and 80 ft). The dependent variables consisted of the kinematic parameters for each joint. For each degree of freedom per joint, the following parameters were analyzed: ROM (peak and total) and peak joint angular velocity (timing and magnitude). Refer to Table 3.1 for a summary of independent variables. A single factor MANOVA was used to assess the condition effect of line distance (significance at $p < 0.05$) on the independent kinematic variables. A post-hoc pair-wise t-test was used to assess for differences between distance conditions (Bonferroni adjusted $\alpha = 0.016$).

Reliability

Reliability measures were performed at the 20 ft distance condition for three subjects. Those three subjects were marked with reflective markers as mentioned previously and asked to perform 5 casts. After which, the reflective markers were totally removed from the subject. The markers were re-applied, after which, each subject then performed 5 more casts at the 20 ft condition. Similar to the previously mentioned casting protocol, data analysis from the set of 5 casts was performed on the middle three casting trials only. A test/re-rest correlation was performed to assess reliability in marker placement and casting style repeatability.

CHAPTER FOUR

RESULTS

Subject Characteristics

A total of 19 participants were recruited for this study. Exclusion criteria were such that subjects were required to be of at least intermediate casting experience. Such experience allowed subjects to adequately perform casts at all four distance conditions. One subject was unable to consistently cast over 40 feet, thereby failing to meet the criteria, and was excluded from the final data analysis. Subject characteristics are presented in Table 4.1.

All 18 subjects utilized an overhand casting style which was defined as any casting angle consistently above 45° from horizontal. Seven subjects categorized themselves as “professional” on the questionnaire (see Appendix A). These seven were professional fly-fishing guides, but not licensed as fly-casting instructors. All 18 subjects were right-handed casters, with 13 using their left arm as their reeling arm. Subjects reported an average of approximately 99 days fishing per year, and had casted for almost 20 years, on average.

Table 4.1: Subject characteristics, n = 18.	Mean (SD)	Range
Age	32.7 (8.4)	22-48
Height (cm)	180.1 (6.4)	170-193
Weight (kg)	80.2 (7.9)	65-95
Days fishing per year (past 5 years)	98.9 (70.2)	15-200
Previous fly-fishing experience (years)	19.4 (10.4)	3-40
Reeling Arm [†]	5R/13L	n/a
Self described experience level [‡]	3I/8A/7P	n/a

[†] R = right, L = Left

[‡] I = intermediate, A = advanced, P = professional

Dependent variables included (for each DOF): Total ROM, Peak Angular Position for P1-P3, and peak angular velocity for P3 only. Dependent variables were analyzed for conditions 1-4 (distances of 20 ft, 40 ft, 60 ft, and 80 ft, respectively). Many of the changes across conditions were significant ($p < 0.05$) and will be reported in the following sections.

Reliability

Test-retest reliability showed generally strong correlation between test sessions. For Peak Angular Position, strong correlation (R value > 0.83) was found for all DOF. For Total ROM, strong correlation (R value > 0.82) was found for all DOF except shoulder ab/d (R value = 0.57). For peak angular velocity, strong correlation (R value > 0.87) was found for all DOF and most of the time-to-peak velocity values. The exceptions were time-to-peak shoulder internal rotation (R value = 0.49) and peak elbow extension (R value = -0.35).

Total ROM

Total ROM about the shoulder increased significantly ($p < 0.001$) with greater length of line cast (Table 4.2 and Figure 4.1). Post-hoc analysis revealed a significant condition effect on Total ROM for shoulder F/E, Ab/d, I/E rot between the 20 and 40 ft conditions. Similar condition effects were noted for shoulder Ab/d between 40 and 60 ft, and shoulder I/E rot between 60 and 80 ft.

Total ROM for axes about the elbow and wrist showed no significant increases (Table 4.2) across conditions for elbow F/E, wrist F/E, or R/U deviation. However, post-hoc analysis revealed a significant increase in total ROM for the elbow F/E axis between conditions 1 to 2. The wrist R/U axis showed little change in total ROM across conditions. Wrist F/E decreased slightly in total ROM with increased line length (Figure 4.2).

Table 4.2: Total ROM (deg) across distance conditions; mean (SD).

Joint Action [†]	Distance Condition (ft)				p-value
	20	40	60	80	
Sh. F/E	21.5 (10.8) _a	33.1 (10.4) _a	37.7 (13.8)	38.2 (12.0)	< 0.001
Sh. Ab/d	15.2 (11.4) _a	31.2 (16.9) _{ab}	44.4 (18.9) _b	55.2 (24.9)	< 0.001
Sh. I/E rot	45.0 (21.9) _a	67.3 (14.1) _a	72.4 (14.7) _c	80.7 (19.5) _c	< 0.001
Elb. F/E	32.1 (9.4) _a	41.3 (15.9) _a	44.2 (18.7)	43.6 (20.3)	0.111
Wr. F/E	26.1 (14.5)	21.5 (16.1)	18.0 (11.8)	16.2 (8.4)	0.117
Wr. R/U dev	29.2 (11.4)	29.2 (9.8)	29.1 (10.4)	28.3 (10.4)	0.994

[†]F/E = flex/extension, Ab/d = ab/adduction, I/E Rot = int/external rotation, R/U Dev = radial/ulnar deviation. Sub-script notations of a, b, and c indicate significant post-hoc differences between paired conditions (Bonferroni adjusted alpha = 0.016).

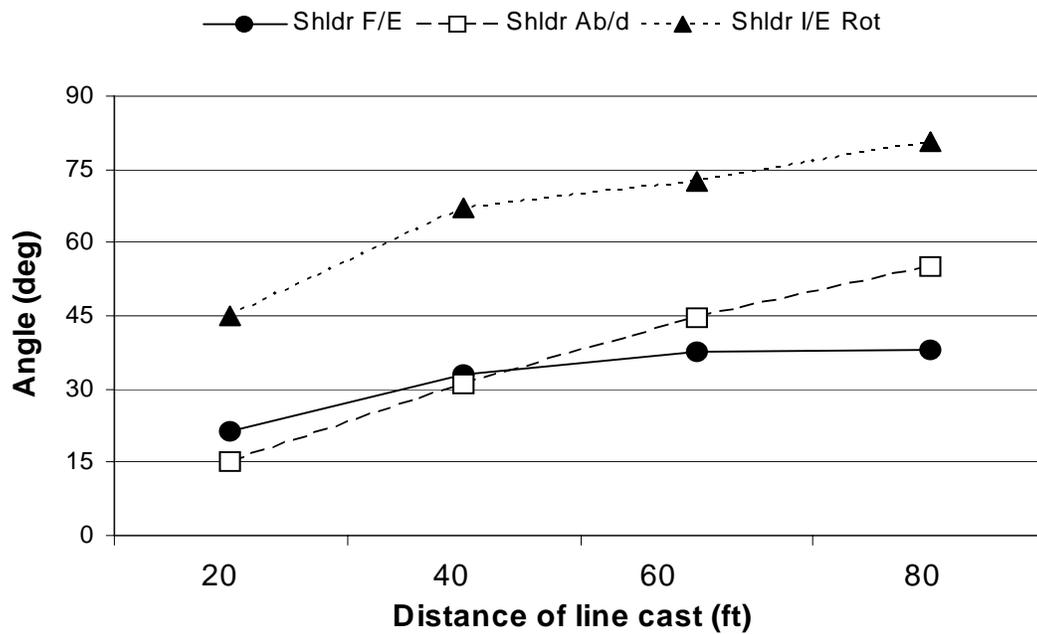


Figure 4.1: Total ROM for the shoulder, across conditions. The effect of line distance was significant ($p < 0.05$) for all DOF.

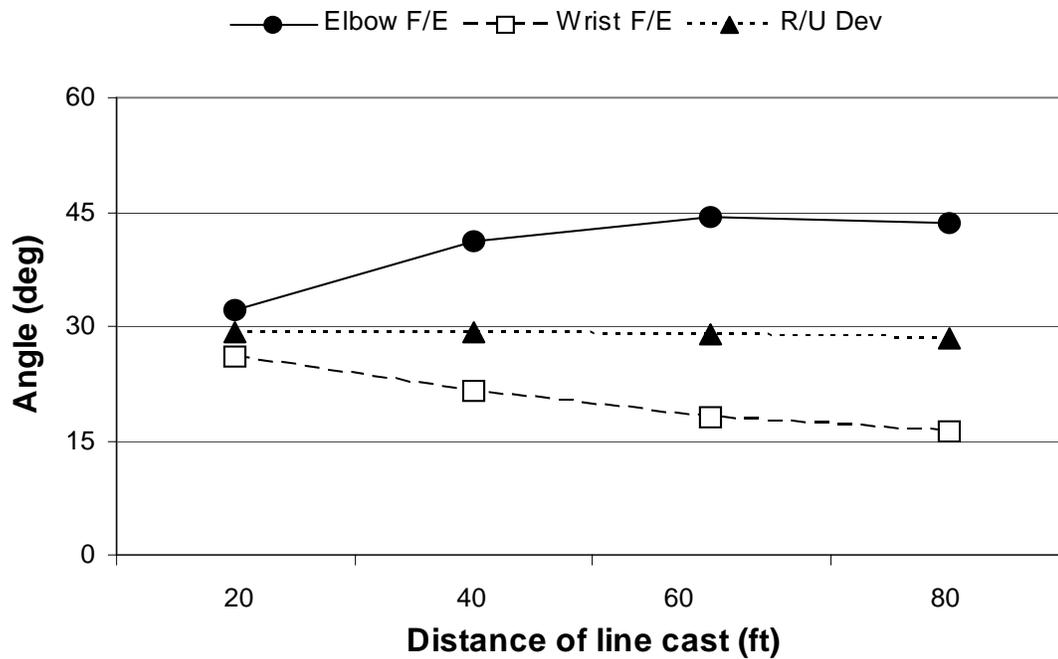


Figure 4.2: Total ROM for the elbow and wrist, across conditions. The effect of line distance was not significant.

Peak Angular Position

Phase 1

Peak angular position values during P1 are presented in Table 4.3. Significant increases in peak angular position recorded during P1 were for shoulder abduction and external rotation. Shoulder flexion also showed an increasing trend across conditions, although not significant (Figure 4.3). Post-hoc analysis revealed a significant condition effect on peak angular position during P1 for shoulder Abd and Ext rot between the 20 and 40 ft, and between the 40 and 60 ft conditions. Shoulder flex was also significantly different between the 40 and 60 ft conditions. Significant condition effects were noted for shoulder Abd and ER between 60 and 80 ft.

Elbow flexion and wrist ulnar deviation decreased significantly across conditions, with greater length of line cast. Conversely, peak angles for wrist extension significantly increased across conditions during P1. See Figure 4.4 for elbow and wrist peak angular position during P1. Post-hoc analysis revealed a significant condition effect on peak angular position during P1 for elbow flex, wrist flex, and wrist RD between the 20 and 40 ft, and between the 40 and 60 ft conditions. Significant condition effect was noted for elbow flex between 60 and 80 ft.

Table 4.3: Peak angular position (deg) during P1, across distance conditions; mean (SD).

Joint Action [†]	Distance Condition (ft)				p-value
	20	40	60	80	
Sh. Flex	3.3 (12.4)	1.4 (19.2) _b	9.1 (20.7) _b	11.2 (23.34)	0.095
Sh. Abd	22.8 (12.1) _a	36.8 (13.7) _{ab}	47.3 (12.9) _{bc}	52.2 (11.9) _c	< 0.001
Sh. ER	33.1 (35.9) _a	43.8 (22.9) _{ab}	64.5 (26.8) _{bc}	77.8 (23.9) _c	< 0.001
Elb. Flex	109.4 (14.2) _a	97.4 (20.2) _{ab}	85.3 (19.9) _{bc}	80.1 (18.7) _c	< 0.001
Wr. Ext	1.9 (25.9) _a	17.7 (23.1) _{ab}	24.4 (14.2) _b	27.3 (10.2)	0.001
Wr. RD	46.0 (16.2) _a	35.8 (16.0) _{ab}	28.9 (17.3) _b	26.4 (15.1)	0.002

[†] Flex = flexion, Abd = abduction, ER = external rotation, Ext = extension, RD = radial deviation. Sub-script notations of a, b, and c indicate significant post-hoc differences between paired conditions (Bonferroni adjusted alpha = 0.016).

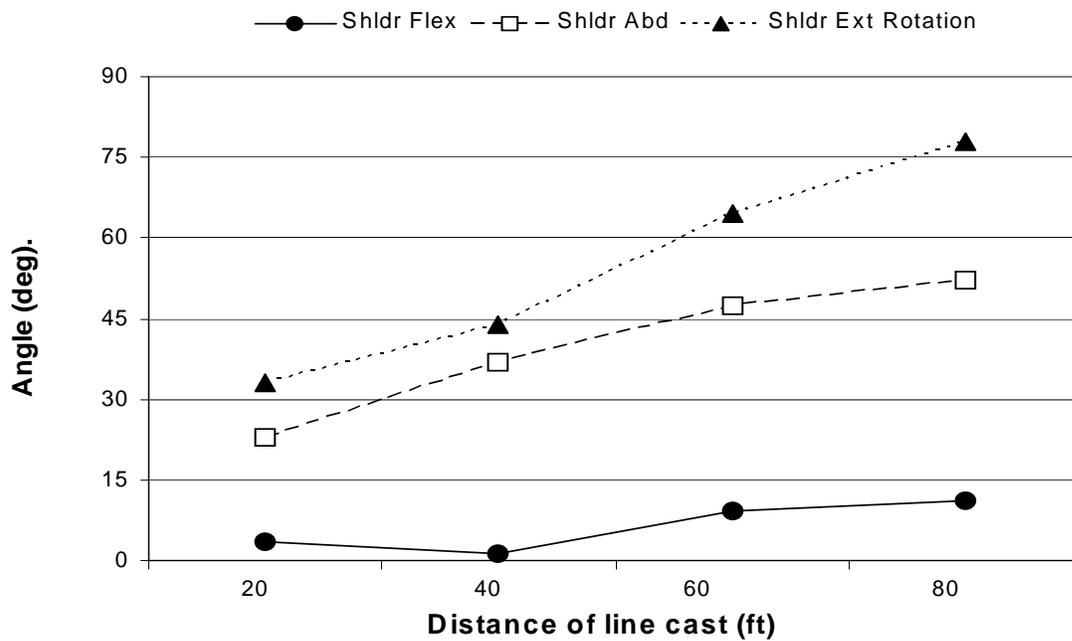


Figure 4.3: Peak angular position about the shoulder during P1. Shoulder flexion and abduction increased significantly with increased line length across conditions ($p < 0.001$).

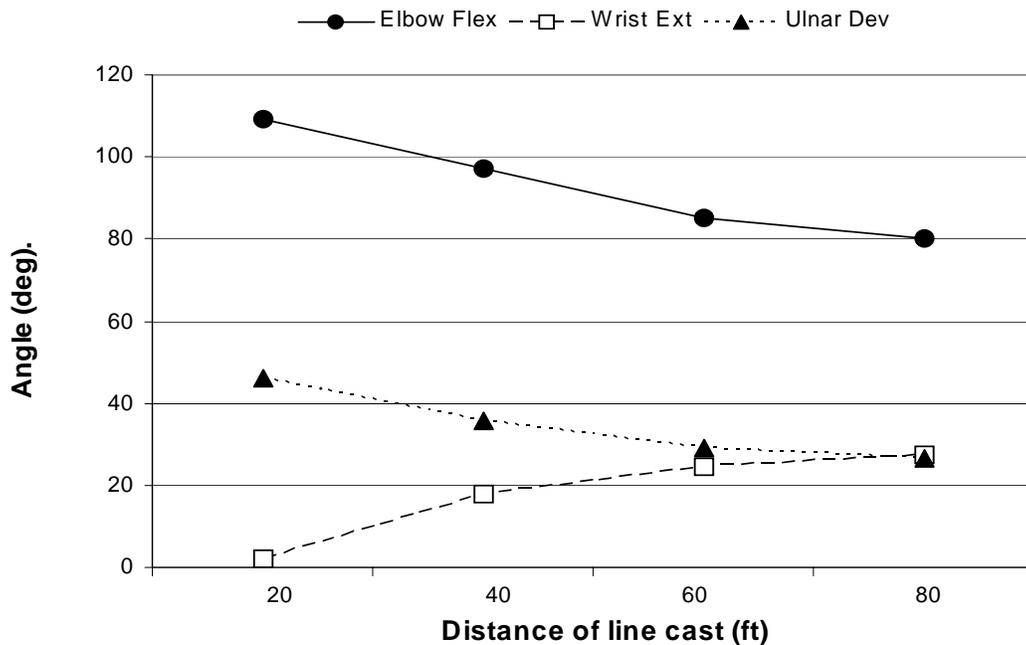


Figure 4.4: Peak angular position about the elbow and wrist during P1. There was significant effect of line length for each axis across conditions ($p \leq 0.002$).

Phase 2

Peak angular position values for the shoulder during P2 are presented in Table 4.4. Shoulder flexion values did not show significant change across conditions, while peak shoulder abduction and external rotation significantly increased with greater length of line cast during P2 (Figure 4.5). Post-hoc analysis revealed a significant condition effect on peak angular position during P2 for shoulder ER, between the 20 and 40 ft, and between the 40 and 60 ft conditions. Shoulder Abd was also significantly different between the 40 and 60 ft conditions. Significant condition effect was noted for shoulder Abd between 60 and 80 ft.

Elbow flexion angles during P2 followed the same trend as P1; significant peak angle decrease with increased line length. Wrist activity also followed the same trend as

P1. P2 wrist ulnar deviation peak angular position values significantly decreased with greater length of line cast. Conversely, peak angles for wrist extension significantly increased across conditions during P2 (Figure 4.6). Post-hoc analysis revealed a significant condition effect on peak angular position during P2 elbow flex, wrist flex, and wrist RD between the 20 and 40 ft, and between the 40 and 60 ft conditions. Significant condition effect was noted for elbow flex between 60 and 80 ft.

Table 4.4: Peak angular position (deg) during P2, across distance conditions; mean (SD).

Joint Action [†]	Distance Condition (ft)				p-value
	20	40	60	80	
Sh. Flex	24.2 (20.1)	26.3 (13.4)	26.8 (12.9)	26.3 (12.4)	0.958
Sh. Abd	33.2 (35.5)	48.9 (20.4) _b	66.9 (22.2) _{bc}	78.0 (18.5) _c	< 0.001
Sh. ER	28.9 (27.6) _a	55.1 (22.7) _{ab}	70.2 (19.6) _b	66.7 (44.0)	< 0.001
Elb. Flex	111.5 (17.2) _a	96.8 (24.4) _{ab}	78.3 (26.1) _{bc}	70.1 (22.3) _c	< 0.001
Wr. Ext	5.5 (29.3) _a	20.0 (27.3) _{ab}	26.8 (16.8) _b	29.5 (11.0)	0.010
Wr. RD	47.5 (15.9) _a	37.8 (16.5) _{ab}	31.8 (18.1) _b	29.3 (16.3)	0.009

[†] Flex = flexion, Abd = abduction, ER = external rotation, Ext = extension, RD = radial deviation. Sub-script notations of a, b, and c indicate significant post-hoc differences between paired conditions (Bonferroni adjusted alpha = 0.016).

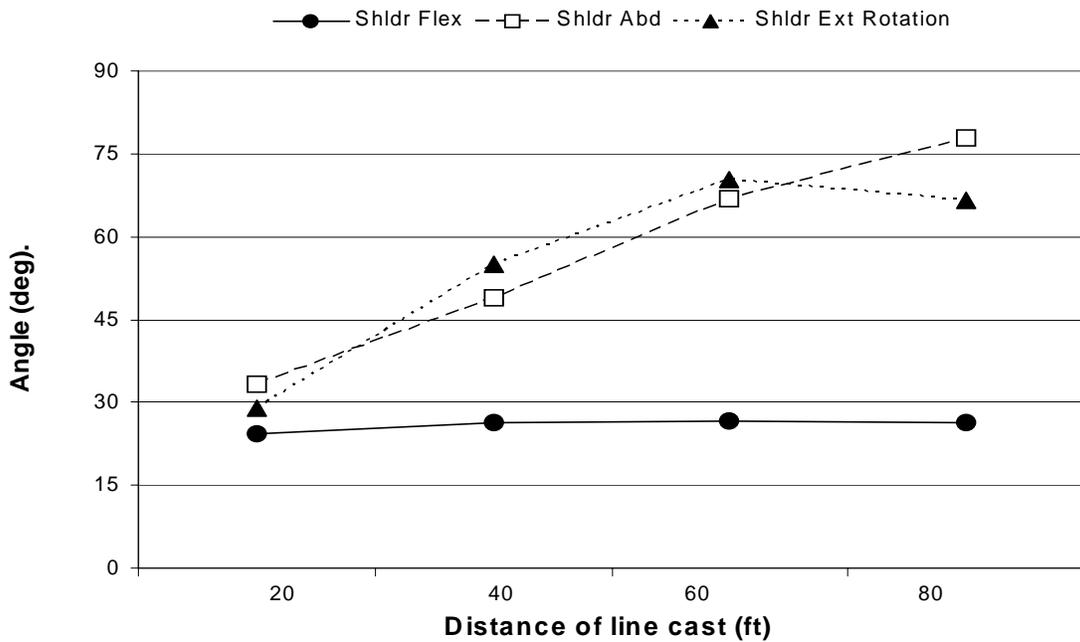


Figure 4.5: Peak angular position about the shoulder during P2. Shoulder abduction and external rotation increased significantly with line length across conditions ($p < 0.001$).

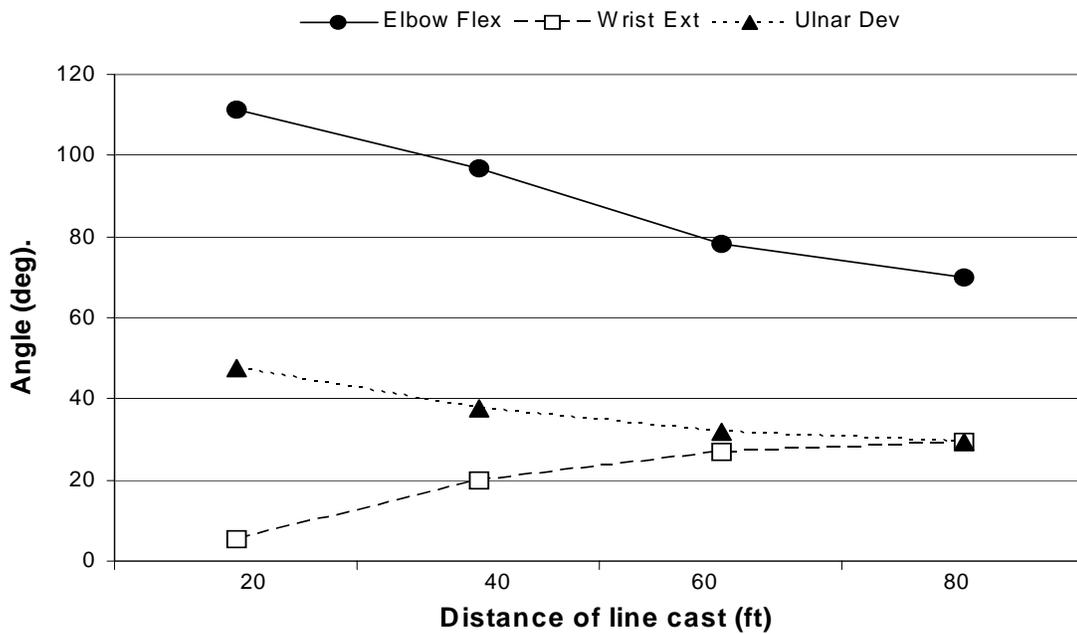


Figure 4.6: Elbow and wrist peak angular position during P2. There was a significant effect of line length for each axis across conditions ($p < 0.01$).

Phase 3

Peak angular position values during P3 are presented in Table 4.5. Peak Angular Position about the shoulder, elbow, and wrist during the forward cast (P3) followed a similar pattern to those presented for P1 and P2. Figure 4.7 displays peak shoulder angles for P3. All axes of rotation about the shoulder had significant increasing Peak angular positions with increased length of line cast. Post-hoc analysis revealed a significant condition effect on peak angular position during P3 for shoulder flex and ER between the 20 and 40 ft, and between the 40 and 60 ft conditions. Shoulder Abd was also significantly different between the 40 and 60 ft conditions. Significant condition effects were noted for shoulder ER and Abd between 60 and 80 ft.

Elbow and wrist peak angular position are presented in Figure 4.8. Peak angular position for elbow flexion significantly decreased with increased length of line cast. Peak angle values for wrist radial deviation significantly decreased across conditions. Wrist extension slightly increased with increased length of line cast, although not significantly.

Table 4.5: Peak angular position (deg) during P3, across distance conditions; mean (SD).

Joint Action [†]	Distance Condition (ft)				p-value
	20	40	60	80	
Sh. Flex	8.6 (15.6) _a	7.5 (23.2) _{ab}	23.0 (22.1) _b	27.7 (21.6)	< 0.001
Sh. Abd	34.0 (21.5)	47.5 (15.2) _b	54.6 (13.4) _{bc}	54.7 (10.0) _c	< 0.001
Sh. ER	36.8 (35.8) _a	59.0 (29.0) _{ab}	82.0 (29.1) _{bc}	95.6 (18.5) _c	< 0.001
Elb. Flex	111.2 (17.3) _a	97.6 (23.8) _{ab}	82.3 (24.4) _{bc}	75.9 (23.4) _c	< 0.001
Wr. Ext	2.7 (27.4) _a	13.2 (25.5) _{ab}	20.1 (18.3) _b	14.6 (40.6)	0.115
Wr. RD	20.5 (11.7) _a	41.2 (15.2) _{ab}	36.8 (15.9) _b	33.7 (15.6)	0.006

[†] Flex = flexion, Abd = abduction, ER = external rotation, Ext = extension, RD = radial deviation. Sub-script notations of a, b, and c indicate significant post-hoc differences between paired conditions (Bonferroni adjusted alpha = 0.016).

Post-hoc analysis revealed a significant condition effect on peak angular position for elbow flex, wrist flex, and wrist RD between the 20 and 40 ft, and 40 and 60 ft conditions. Significant condition effect was noted for elbow flex between 60 and 80 ft.

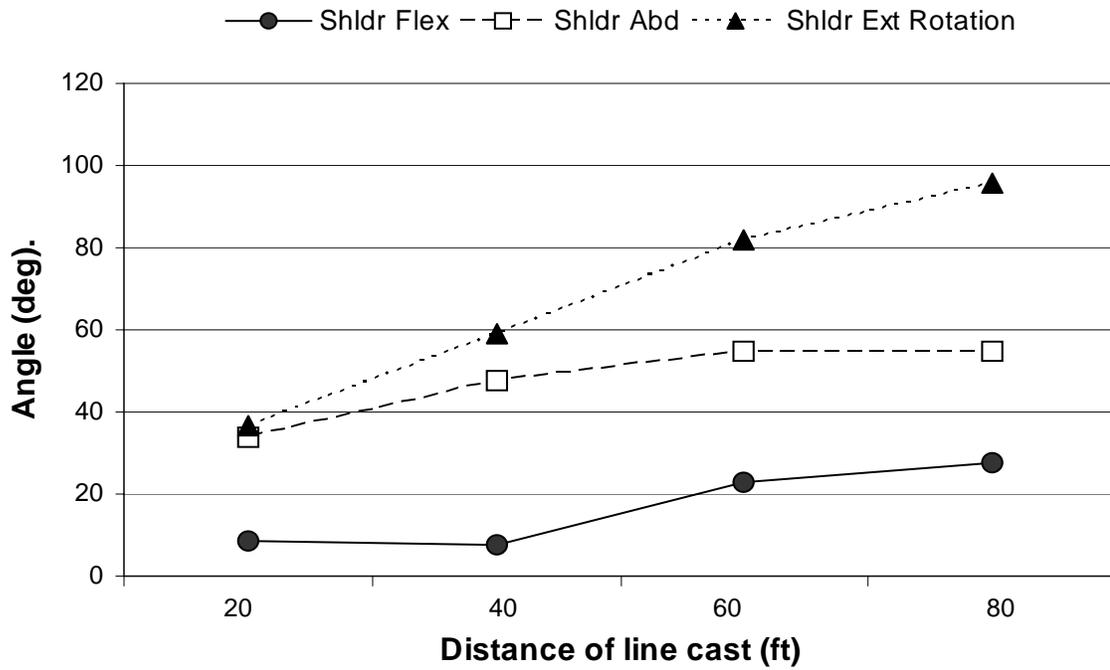


Figure 4.7: Peak angular position about the shoulder during P3. There was a significant effect of line length for each axis across conditions ($p < 0.001$).

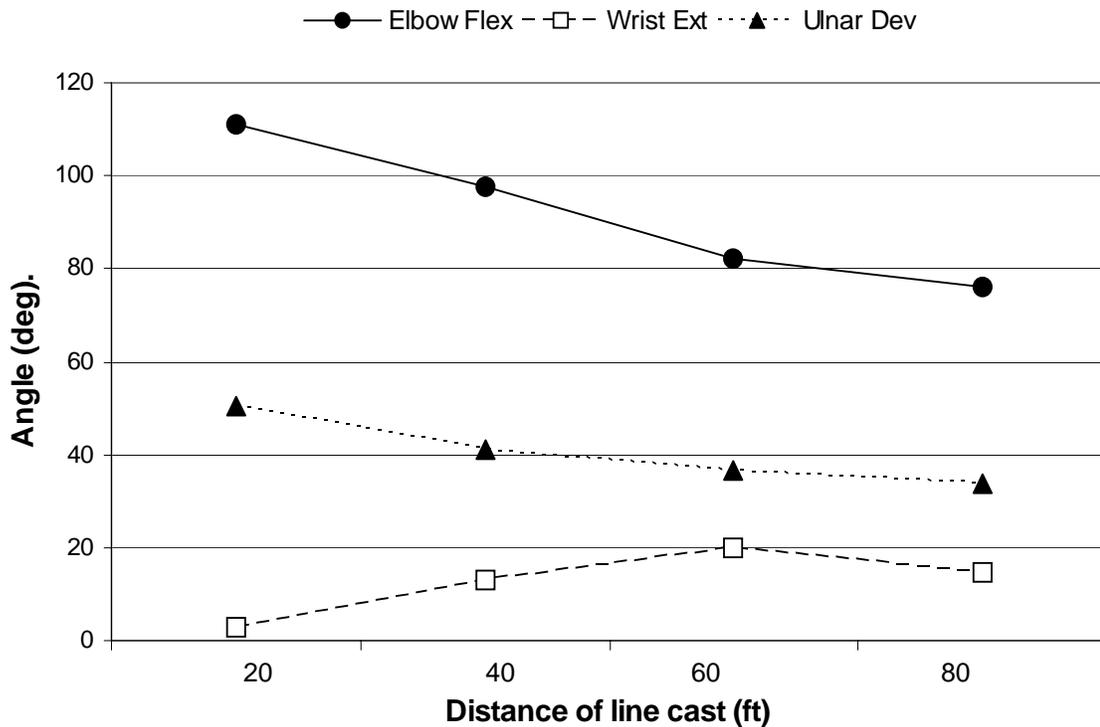


Figure 4.8: Peak angular position about the elbow and wrist during P3. Elbow flexion and wrist ulnar deviation decreased significantly with an increase in line length across conditions ($p \leq 0.006$).

Joint Coordination

Peak velocity values for shoulder internal rotation were greater than shoulder adduction and flexion velocities. For the wrist, peak ulnar deviation velocity was greater than that of wrist flexion. Thus, primary DOF utilized were shoulder I/E rotation, elbow F/E, and wrist R/U deviation.

Magnitude of peak angular velocity during P3 increased significantly with increased line length for all rotation axes about the shoulder (Table 4.6). Post-hoc analysis revealed a significant condition effect on peak velocity during P3 for shoulder

ext and IR between the 20 and 40 ft conditions. Shoulder flex and Add were significantly different between the 40 and 60 ft conditions. Angular velocity data for the shoulder are presented in Figure 4.9.

Peak elbow extension velocity increased across conditions, although not significantly. Angular velocities about the wrist axes (F/E and R/U) showed little change across conditions. Post-hoc analysis revealed a significant condition effect on peak elbow ext velocity during P3 between the 20 and 40 ft conditions. See Figure 4.10 for peak angular velocities about the elbow and wrist.

Table 4.6: Peak velocity values (deg/s) during P3 for the shoulder, elbow, and wrist; mean (SD).

Joint Action [†]	Distance Condition (ft)				p-value
	20	40	60	80	
Shldr Ext.	28.5 (33.2) _a	63.6 (37.4) _{ab}	89.5 (43.9) _b	87.3 (36.5)	< 0.001
Shldr Add	15.7 (17.5) _a	49.0 (63.9) _{ab}	86.3 (76.1) _b	116.5 (103.2)	0.001
Shldr IR [‡]	107.2 (54.9) _a	148.4 (48.3) _a	158.1 (56.4)	161.8 (70.2)	0.028
Elbow Ext [‡]	82.7 (32.4) _a	104.7 (48.3) _a	118.3 (70.2)	121.4 (79.4)	0.216
Wrist Flex	23.5 (20.4)	28.2 (23.8)	26.4 (16.7)	23.1 (19.5)	0.856
Wrist UD [‡]	57.1 (25.7)	57.3 (32.6)	55.0 (34.8)	55.6 (44.1)	0.996

[†] Ext = extension, Add = adduction, IR = internal rotation, Flex = flexion, UD = ulnar deviation.

[‡] = primary DOF. Sub-script notations of a, b, and c indicate significant post-hoc differences between paired conditions (Bonferroni adjusted alpha = 0.016).

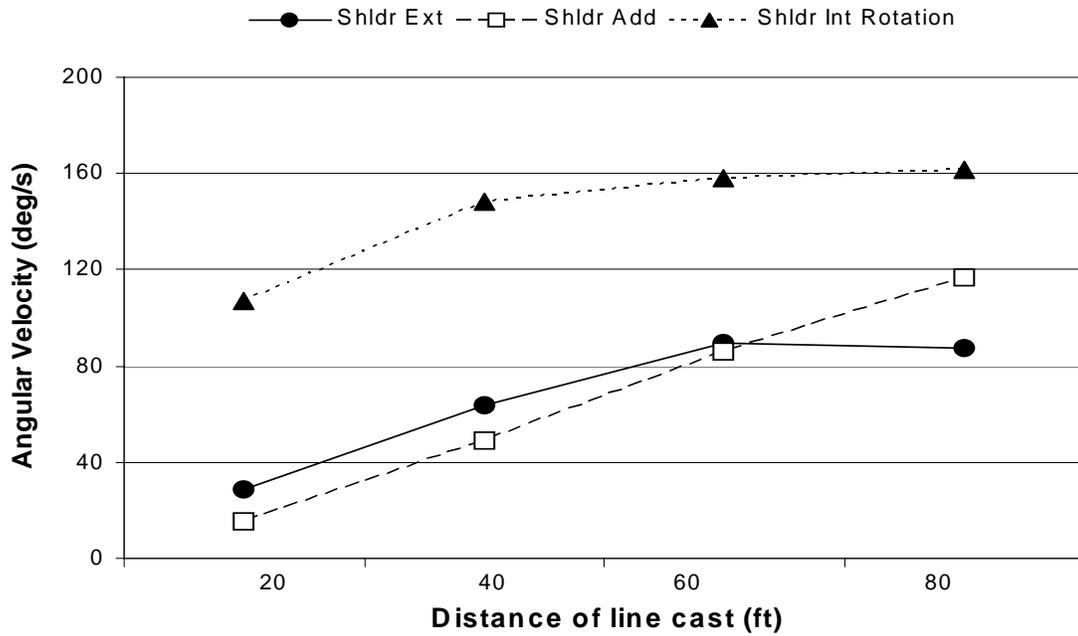


Figure 4.9: Peak angular velocities about the shoulder during P3. There was significant effect of line length for each axis across conditions ($p \leq 0.028$).

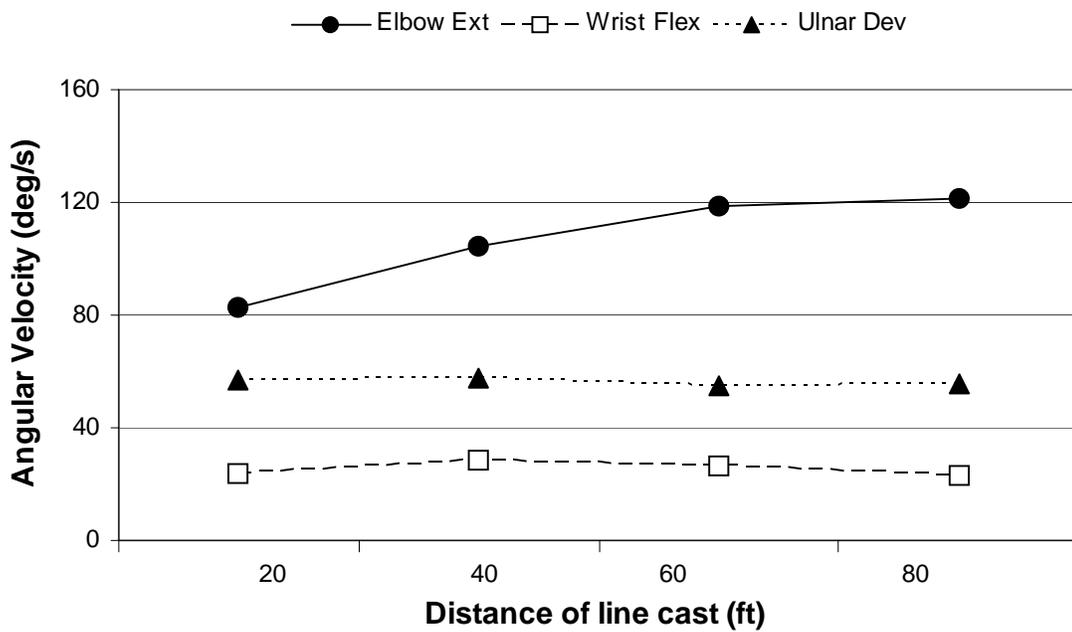


Figure 4.10: Angular velocities about the elbow and wrist during P3. Effect of line length was not significant across conditions.

Timing of peak angular velocity exhibited a proximal to distal trend for all four distance conditions. During P3, peak internal rotation velocity about the shoulder occurred first, followed by elbow extension velocity, and ulnar deviation velocity. See Table 4.7 for peak angular velocity timing. The effect of line length was significant for timing of shoulder internal rotation peak and elbow extension peak, as they both drifted toward the end of P3. Post-hoc analysis indicated no significant differences between distance conditions.

Table 4.7: Peak angular velocity timing (% of P3); mean (SD).

Joint Action [†]	Distance Condition (ft)				p-value
	20	40	60	80	
Shoulder IR	38 (10)	46 (9)	48 (11)	49 (13)	0.009
Elbow Ext	47 (10)	57 (9)	67 (9)	69 (8)	< 0.001
Wrist UD	76 (24)	80 (20)	82 (17)	81 (15)	0.780

[†] IR = internal rotation, Ext = extension, UD = ulnar deviation. No post-hoc differences between paired conditions were noted (Bonferroni adjusted alpha = 0.016).

Shoulder IR, elbow extension, and wrist UD were analyzed for joint velocity timing. Time between P3 peak angular velocities was analyzed for: Total peak timing (time between peak shoulder IR velocity and wrist UD velocity), shoulder-to-elbow timing (time between peak shoulder internal rotation velocity and peak elbow extension velocity), and elbow-to-wrist timing (time between peak elbow extension velocity and peak wrist UD velocity).

Time-to-peak angular velocity differences are presented in Table 4.8. As length of casted line increased, the timing of peak angular velocities between the shoulder, elbow, and wrist decreased slightly. The distal linkage showed a slight decrease in elbow-to-wrist velocity, although not significantly. Conversely, the shoulder-to-elbow

timing increased significantly. Figure 4.11 displays joint velocity timing information across conditions. Post-hoc analysis indicated a significant difference for time between shoulder and elbow peaks between the 40 and 60 ft conditions.

Table 4.8: Time-to-peak angular velocity differences across conditions (% of P3); mean (SD).

Timing	Distance Condition (ft)				p-value
	20	40	60	80	
Total (Shoulder-to-wrist)	38 (26)	35 (22)	35 (19)	32 (19)	0.914
Shoulder-to-Elbow	9 (10)	12 (11) _b	19 (11) _b	19 (15)	0.037
Elbow-to-Wrist	29 (27)	23 (20)	15 (21)	12 (16)	0.175

Sub-script notations of a, b, and c indicate significant post-hoc differences between paired conditions (Bonferroni adjusted alpha = 0.016).

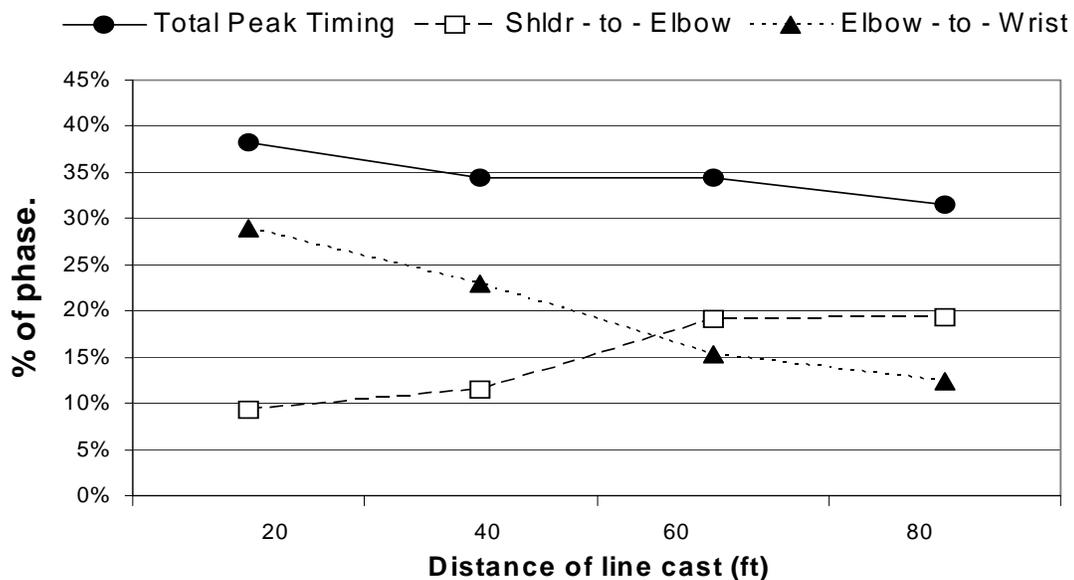


Figure 4.11: Joint velocity timing for P3. Total peak timing is the difference (expressed in % of P3) between peak shoulder angular velocity and peak wrist angular velocity. Shoulder-to-elbow is the difference between peak shoulder angular velocity and peak elbow angular velocity. Elbow-to-wrist is the difference between peak elbow angular velocity and peak wrist angular velocity. Increasing line length significantly increased the time between shoulder and elbow peaks across conditions ($p = 0.037$).

CHAPTER FIVE

DISCUSSION

Introduction

The overall goal of this project was to document kinematic patterns common to fly-casting. With respect to that goal, the purpose of this study was to determine the kinematic and joint coordination changes necessary to cast lines of different length.

Two major hypotheses were tested. First, it was hypothesized that kinematic parameters of casting (peak and total range of motion, timing of peak joint angular velocity, and magnitude of peak joint angular velocity) would increase in order to cast lines of different length. Second, it was hypothesized that when greater length of line is cast, the time between peak angular velocities would decrease.

Data have been presented to support the first major hypothesis, such that kinematic parameters of casting will increase in order to cast lines of different length. The second major hypothesis was not supported by the data in this study. Time between angular velocity peaks for the shoulder, elbow, and wrist, did not significantly decrease with greater length of line cast.

Total ROM

Total ROM about all shoulder axes increased significantly ($p < 0.001$) with greater length of line cast. Greater line length increased demands upon all DOF for the shoulder resulting in longer and greater arm movement.

Total ROM for axes about the elbow and wrist showed no significant increases across conditions for elbow flexion. Total ROM for the elbow F/E axis had an increasing trend between conditions 1 to 2, and 2 to 3. Little change was noted in total elbow flexion ROM between conditions 3 and 4. This could be due to the fact that subjects may have been close to their maximum casting capacity at the 60 ft distance. Therefore, at the 80 ft distance, casters may have utilized a similar ROM with slightly greater force.

Line length had no significant effect on wrist extension and ulnar deviation. Movement about the wrist R/U axis showed little change in total ROM across conditions. Conversely, wrist F/E decreased slightly, although not significantly, in total ROM with increased line length conditions. F/E movement about the wrist may have greater importance at the shorter distances, utilizing a relatively greater ROM to allow for a higher degree of accuracy. Decrease in wrist F/E across distance conditions may also be due to the need to hold the rod grip much steadier at longer distances. This allows the distal end of the fly rod to perform its designed function and propel the line forward at a higher velocity for longer distances.

Peak Angular Position

Shoulder

Dillman et al. (1993) showed that, in most throwing activities, the upper arm is positioned in an abducted position about the shoulder. It may then be inferred that the 90-110° abducted position is a very strong, dynamic position for the arm and shoulder during throwing. In this study, the shoulder was abducted from a minimum of 34° during P1 of the 20 ft cast, to a maximum of 78° during P2 of the 80 ft cast; a smaller degree

than reported by Dillman. The nature of fly-casting may be the cause of this difference. The baseball pitch is a very ballistic and dynamic activity, whereas the motion of fly-casting as a whole is more deliberate and rhythmic in nature. Dillman et al. (1993) also reported that external and internal rotation about the shoulder can be one of the most dynamic movements in the human body, noting that external rotation can reach peak angles of 178° during baseball pitching. Similarly, Escamilla et al. (2002) reported maximum shoulder external rotation of $181^\circ \pm 8$ during the arm-cocking phase of baseball pitching. The current study found that the shoulder externally rotated to a maximum of $96^\circ \pm 19$ during P3 of the 80 ft cast. Greater magnitude of external rotation during baseball pitching could be due to the more explosive nature of the pitching motion in comparison to fly-casting, which will be discussed at the end of the joint coordination section.

Elbow

Escamilla et al. (2002) reported a maximum elbow flexion angle of 104° during the arm-cocking phase of baseball pitching, which would be similar to P2 of the current study. For the current study, maximum elbow flexion angle of $111^\circ \pm 17$ occurred during P2 of the 20 ft cast. Elbow flexion values and the subsequent timing of these values are similar for baseball pitching and fly-casting. This is possible due to the arm-cocking phase of pitching preceding the forward pitching motion, similar to P2, which precedes the forward motion of the fly-cast.

Fleisig et al. (1996) reported maximum elbow flexion of $100^\circ \pm 13$ for baseball and $113^\circ \pm 10$ for football. For this study, peak elbow flexion was $76^\circ \pm 23$ during P3 of

the 80 ft cast. Dissimilar to the forward (arm acceleration) phase of baseball pitching, a lesser magnitude of elbow flexion was seen during P3 of the fly-cast. The magnitude of peak elbow flexion decreased across conditions, indicating an increasingly straighter elbow with increases in line length (Figures 4.4, 4.6, 4.8).

Wrist

Fly-casting may differ from other common throwing motions, in that primary wrist activity occurs about the R/U deviation axis during the casting motion. Mean total ROM for wrist F/E during casting was 20°. Mean total ROM for R/U deviation during casting was 29°. Greater total R/U deviation ROM indicates greater utilization of that specific DOF during fly-casting. This could be due to the way in which the fly rod is gripped. Most fly fishers utilize a “thumb on top” style of gripping the fly rod, with the palm aligned in the sagittal plane.

A baseball (fastball) pitch is usually released in a position of forearm pronation, with the palm facing toward the ground. This orientation dictates greater wrist flexion at release of the baseball pitch. Debicki et al. (2004) reported peak wrist flexion of approximately 50°, occurring early in the throwing motion (arm-cocking phase). There was no indication of wrist flexion in the current study. Instead, peak wrist extension angles ranged from 2° during P1 of the 20 ft cast, to 30° during P2 of the 80 ft cast. Peak wrist extension during the pausing phase further facilitates loading of the fly rod by the line; this would therefore be exaggerated at longer distances, such as the 80 ft cast.

Throwing vs Casting

Fly-casting is similar to common throwing motions in that there is a movement from anterior to posterior (P1 of the fly-cast, arm-cocking of baseball), in preparation for an anterior movement to project an object forward. P2 of the fly-cast is different than other throwing motions, because the caster has to wait for the line to load the rod, preceding the forward cast. P3 of the fly-cast is somewhat similar as a whole, but not nearly as ballistic or aggressive as a baseball pitch.

The primary goal of a baseball pitch (fastball) is high end point velocity of the hand as the ball is released, whereas during fly-casting the rod is not released and thereby acts as the last segment in the chain. The “extension” of the arm/hand that the rod provides serves to limit the need for excessive shoulder motion (compared to baseball pitching) and affects an extension and radial deviation of the hand segment. Thus, during fly-casting, large upper extremity ROM is not needed to facilitate maximum angular velocities.

Joint Coordination

The second major hypothesis of this study was that when greater length of line is cast, the time between peak angular velocities will decrease in response to the greater amount of mass of line. The study’s findings do not support that hypothesis (Table 4.8). A trend of decreased peak angular velocity timing was noted between elbow and wrist peaks, but did not show significance ($p = 0.175$). The only significant difference for timing patterns was the time between peak shoulder and peak elbow angular velocities (p

= 0.037). Peak shoulder internal rotation velocity and peak elbow extension velocity actually occurred further apart as distance of line cast was increased, rather than closer together. This may be due to the tendency of the caster to lean the trunk anteriorly, immediately preceding the forward cast. This would force the shoulder to be most active, with respect to the elbow, at an earlier point in P3 (Table 4.8).

Studies of baseball pitching (Barrantine et al. 1998; Dillman et al., 1993; Feltner and Dapena, 1986; Fleisig et al., 1996), javelin throwing (Best et al. 1993), and American football (Fleisig et al., 1996; Rash and Shapiro, 1995) have reported proximal-to-distal sequencing for high velocity throwing actions. Similar to those studies, joint timing patterns during fly-casting had been reported in a previous pilot study to be proximal-to-distal (O'Keefe et al., 2005). Data from the current study supports those findings. The proximal-to-distal trend held across all distance conditions (Table 4.7). The distance conditions had significant effect on timing of shoulder internal rotation peak velocity ($p = 0.009$) and elbow extension peak velocity ($p < 0.001$). Both the shoulder and elbow peaks drifted toward the end of P3 as distance of line cast was increased. Timing of ulnar deviation peak angular velocities also drifted toward the end of P3, although not significantly.

Future Research Considerations

Interesting sub-groupings were noted and will be discussed in the following, although they were not part of the original hypotheses. The differences between sub-groups could be a potential direction of future research.

Of the 18 subjects that were part of this study, 10 reported more than 100 days/year, in fact averaging $150 \text{ days} \pm 47$ per year. The majority of said respondents were professional guides and will be further referred to as “guides” ($n = 10$). The other 8 subjects all reported fishing less than 100 days/year ($35 \text{ days} \pm 27$) and will be referred to as “non-guides” ($n = 8$).

For the guides, shoulder internal rotation velocity was the major motion during casting, and increased in magnitude with increased casting distance. Shoulder adduction and shoulder extension angular velocity appear to be secondary to shoulder internal rotation (Figure 5.1)

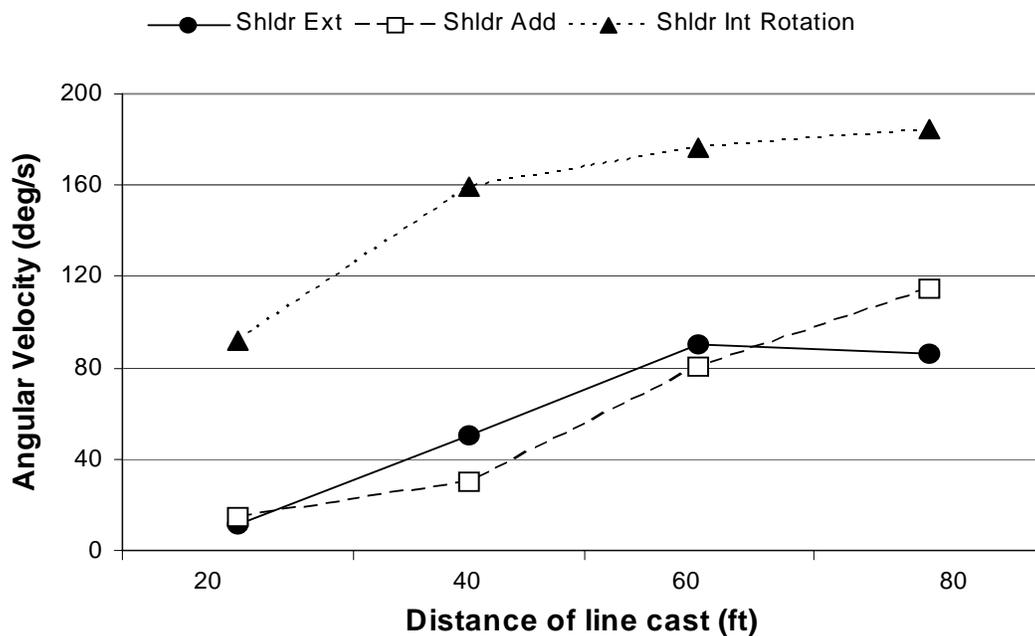


Figure 5.1: Peak angular velocities about the shoulder during P3 for guides.

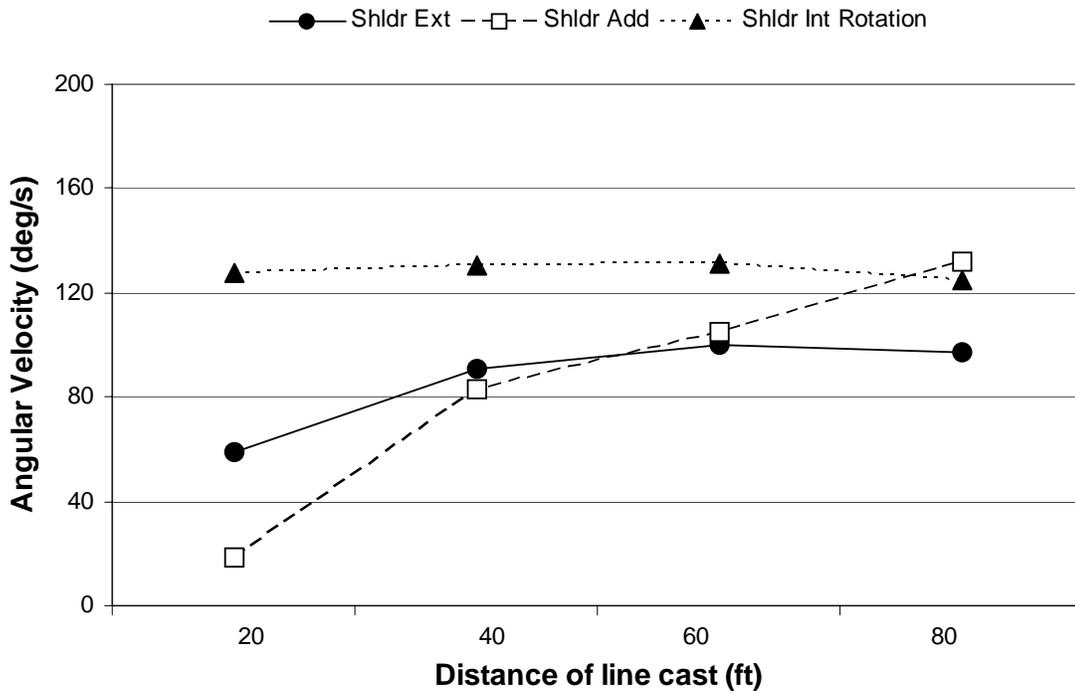


Figure 5.2: Peak angular velocities about the shoulder during P3 for non-guides.

For the non-guides, shoulder internal rotation velocity was the major contributor at the 20 ft casting distance. But, as distance increased, the non-guides utilized more shoulder adduction velocity to compensate for the demands of casting greater lengths of line. Based on qualitative observation during data collection, the non-guides started to appear uncomfortable casting at distances past 40 ft. In these conditions (60 and 80 ft), their form deteriorated and they began to utilize inefficient movement patterns to accomplish the task (Figure 5.2).

The same trend was found for elbow extension velocity when comparing guides to non-guides. Elbow extension velocity appeared to increase linearly across distance conditions for the group of guides (Figure 5.3). For non-guides, elbow extension velocity

appeared to increase until the 40 ft distance, after which a plateau effect was seen (Figure 5.4).

Wrist activity for the guides appeared to be steady across conditions (Figure 5.3). Wrist activity for the non-guides appeared to decrease slightly with increased line length (Figure 5.4). The main difference in wrist activity for guides and non-guides was found in the magnitude of peak ulnar deviation velocities. Guides showed greater ulnar deviation velocities, which seemed to increase across conditions. Ulnar deviation velocities for the non-guide group were greatest at the 20 ft distance, and slightly decreased as line length increased. The non-guides were not as proficient at using ulnar deviation velocity as a means of casting greater lengths of line.

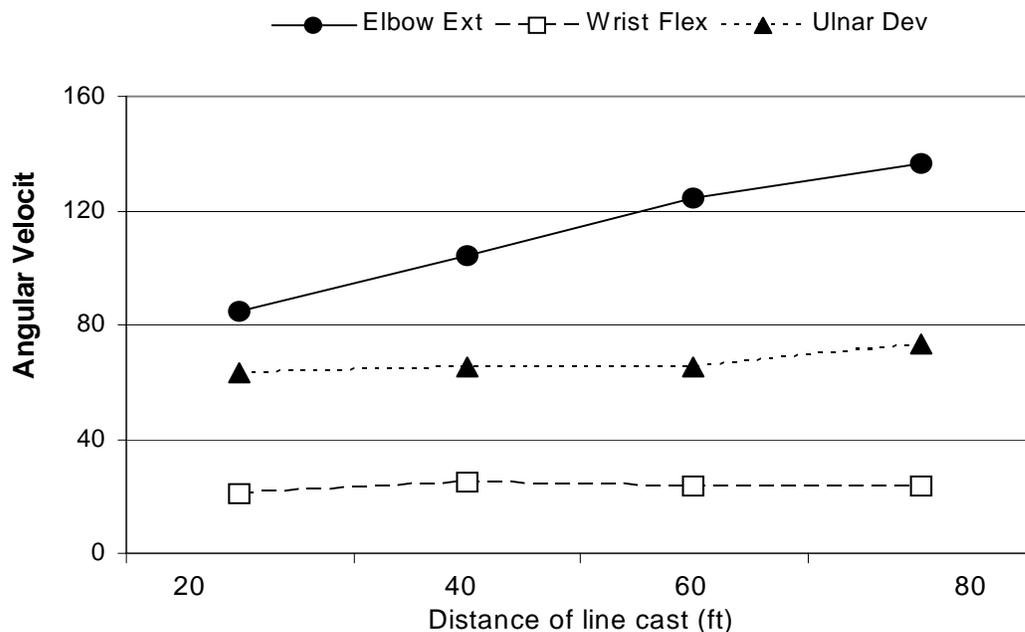


Figure 5.3: Peak angular velocities about the elbow and wrist during P3 for guides.

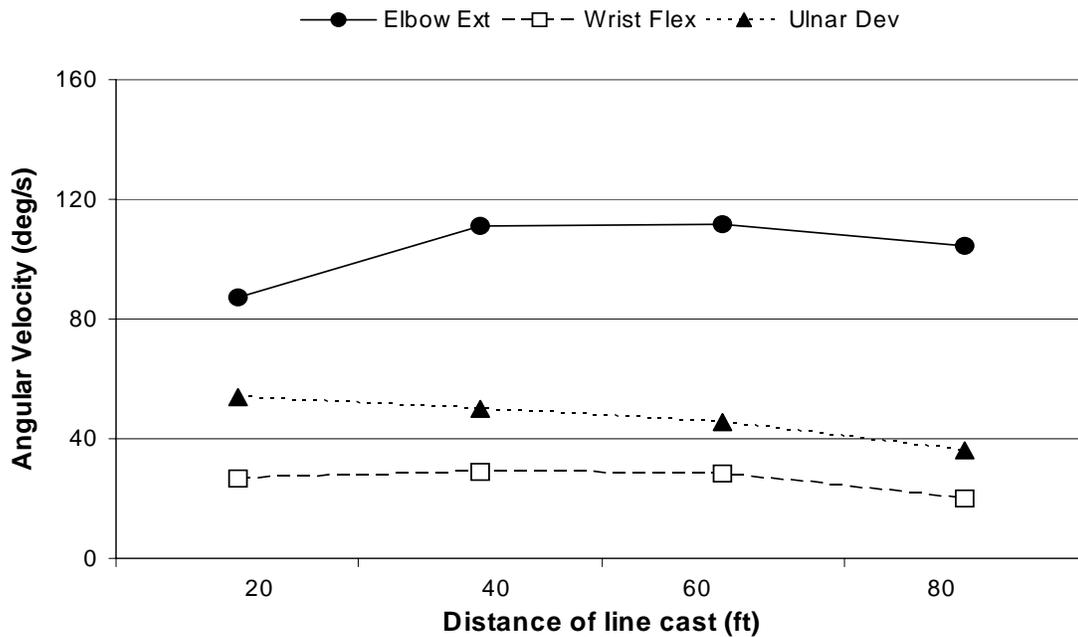


Figure 5.4: Peak angular velocities about the elbow and wrist during P3 for non-guides.

It has been shown that throwers with higher skill levels (especially baseball pitchers) possess the ability to move their arm segments through a greater ROM and at a higher velocity than less skilled throwers (Escamilla et al., 2002). From the present study's findings, it may be inferred that a similar trend is true for fly-casters. As skill level and experience increase, fly-casters have a greater capacity of utilizing ROM and velocity about the primary rotation axes (shoulder IR/ER, elbow F/E, and wrist R/U deviation).

The differences noted between guides and non-guides indicate a skill component in fly-casting that undoubtedly is a product of experience. It seems as if skilled casters (the "guide" group) may have the capacity to move through a greater ROM at a higher velocity (Figures 5.1 – 5.4) than less-skilled casters ("non-guides"). Therefore, results from this study indicate that casters with high experience and skill levels may possess the

ability to utilize higher velocities produced about the velocity about the primary rotation axes (shoulder IR/ER, elbow F/E, and wrist R/U deviation). Principal utilization of ROM and velocity about primary rotation axes (as opposed to using greater ROM and velocity about multiple axes) was shown to be a characteristic of the subjects in this study.

CHAPTER SIX

CONCLUSIONS

The purpose of this study was to determine the kinematic and joint coordination changes necessary to cast lines of different length. Two major hypotheses were tested. First, it was hypothesized that kinematic parameters of casting would increase in order to cast lines of different length. Second, it was hypothesized that when greater length of line is cast, the time between peak angular velocities would decrease.

Findings from this study indicate that significant changes in total ROM were needed to accommodate the demands of casting greater lengths of line. Overall, total ROM increased with increased length of line cast, supporting the first hypothesis. However, wrist R/U deviation total ROM changed little across all distances, and wrist F/E total ROM decreased with increased line length.

Primary DOF utilized to produce velocity during for forward motion of fly-casting (P3) were shoulder internal rotation, elbow extension, and wrist ulnar deviation. Similar to other throwing motions (Cook and Strike, 2000), timing of peak angular velocity exhibited a proximal-to-distal trend for all four distance conditions. During P3, peak shoulder internal rotation velocity occurred first, followed by elbow extension velocity, then wrist ulnar deviation velocity.

Data from this study did not support the second hypothesis. Time between peak joint velocities of the primary DOF did not decrease with increased line length. In fact, the only significant difference was actually an increase in the time between peak shoulder and elbow angular velocities ($p = 0.037$) as line length increased. This may be due to the

tendency of the caster to lean the trunk forward immediately preceding the forward cast, forcing the shoulder to generate velocity earlier, with respect to the elbow, in P3 (see Table 4.8).

Two distinct groups within the sample were noted. Ten of the 18 subjects reported fly-fishing more than 100 days/year (“guides”), while the other 8 subjects reported fishing less than 100 days/year (“non-guides”). The data indicated some interesting differences between groups. As skill level and experience increase, the data indicates that fly-casters may have a greater capacity of utilizing ROM and velocity about the primary rotation axes (shoulder IR/ER, elbow F/E, and wrist R/U deviation). That being said, principal utilization of ROM and velocity about primary rotation axes (as opposed to using greater ROM and velocity about multiple axes) may be directly associated with pain and/or injury, and possibly fly-casting performance. The origin of pain and/or injury could then be differentiated between casting movement patterns and/or overuse symptoms. Results from this study may contribute to an explanation of the incidence of pain noted in McCue’s article (2004) about pain and fly-casting instructors.

As with most sporting activities, inclusion of professional instruction will develop a better casting stroke. One area of further research would be the quantification of professional instruction on total ROM and peak angular velocity timing during fly-casting. Furthermore, it seems likely that a learned element of “accuracy vs power” is a necessary component of fly-casting. The differences noted between guides and non-guides indicate a skill component in fly-casting that is a product of experience. An accuracy variable and/or power variable would be a natural addition to the methods used in the current study, and would be an excellent direction to take this research. Future

research could then quantify the effect of experience on ROM and joint coordination patterns, as well as accuracy and power.

In conclusion, the results from this study provide a foundation for further explanation of the UE pain associated with the repetitive nature of fly-casting (McCue et al., 2004). Specifically, total ROM and joint coordination patterns presented in this study establish the initial link between casting styles and UE pain or injury.

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APPENDICES

APPENDIX A

Subject Consent Form

SUBJECT CONSENT FORM
FOR PARTICIPATION IN HUMAN RESEARCH
MONTANA STATE UNIVERSITY

PROJECT TITLE: KINEMATIC ANALYSIS OF THE UPPER EXTREMITY
DURING FLY-CASTING

PROJECT DIRECTOR: Joshua R. Allen, Graduate Student, Biomechanics
Dept. of Health and Human Development
Movement Science / Human Performance Laboratory
Montana State University, Bozeman, MT 59717-3540
Phone: (406) 994-6325; FAX: (406) 994-6314;
E-mail: jrallen@montana.edu

FUNDING: This project is not currently funded.

PURPOSE OF THE STUDY:

The purpose of this study is to document the kinematic patterns and determine joint timing patterns common to fly-casting. Involvement in this project includes a *single* visit to either the Movement Science / Human Performance Laboratory (basement of Romney Building, MSU campus), or a gymnasium in the Hosaeus PE complex. Time commitment will be less than one hour. The laboratory experiments will consist of the following:

- Brief questionnaire to assess injury history and level of fly-casting expertise.
- Analysis of movement while casting for different distances, using various techniques.

STUDY PROCEDURES:

After reading and signing the Informed Consent Document, you will be asked to change into a tank top shirt, to allow placement of reflective markers onto the surface of your skin. You will then have your body weight and body height determined using a standard physician's beam-scale.

Movement analysis will follow, requiring the placement of reflective markers onto the surface of your skin, over several bony landmarks from your head to waist. These markers will be placed using double-sided tape. During the movement analysis, you will be asked to perform a variety of fly-casting techniques. An estimated total of 40 casting trials will be performed. The entire testing session will take less than one hour to complete.

POTENTIAL RISKS:

It is possible that you may experience some discomfort in removing adhesive tape (used for marker placement) from your skin at the end of the experiment. Throughout the testing session, if you feel uncomfortable with any procedure, you may feel free to stop the test at any time.

BENEFITS:

In addition to receiving feedback to enhance fly-casting performance and suggestions for prevention of joint injury, the results of this study may contribute to more effective musculoskeletal therapies leading to improved rehabilitation programs being designed and implemented in the medical fields of sports medicine, orthopedics and physical medicine. All participants will receive informal feedback regarding their patterns of joint motion. This information may be useful to individuals interested in the mechanics of their sporting activities. Additionally, study participants may request a summary of the study findings by contacting the Project Director, Joshua R. Allen, by phone (406-994-6325) or by E-mail (jrallen@montana.edu).

CONFIDENTIALITY:

The personal information, and all recorded data will be regarded as privileged and confidential materials. Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. Subject identities will be kept confidential by coding the data using subject pseudonyms. The code list will be kept separate and secure from the actual data files.

FREEDOM OF CONSENT:

Participation in this project is completely voluntary.

You may withdraw consent for participation in writing, by telephone, or in person without prejudice or loss of benefits (as described above). Please contact the Project Director, Joshua R. Allen, by phone (406-994-6325) or by E-mail (jrallen@montana.edu) to discontinue participation.

In the UNLIKELY event that your participation in the project results in physical injury to you, the Project Director will advise and assist you in receiving medical treatment. Montana State University can not be held responsible for injury, accidents, or expenses that may occur as a result of your participation in this project. Additionally, Montana State University can not be held responsible for injury, accidents, or expenses that may occur as a result of traveling to and from your appointments at the Movement Science / Human Performance Laboratory. *Further information regarding medical treatment may be obtained by calling the Project Director, Joshua R. Allen, at 406-994-6325.* You are encouraged to express any questions, doubts or concerns regarding this project. The Project Director will attempt to answer all questions to the best of their ability prior to any testing. The Project Director fully intends to conduct the study with your best interest, safety and comfort in mind. *Additional questions about the rights of human subjects can be answered by the Chairman of the Human Subjects Committee, Mark Quinn, at 406-994-5721.*

PROJECT TITLE:

KINEMATIC ANALYSIS OF THE UPPER EXTREMITY DURING
FLY-CASTING

STATEMENT OF AUTHORIZATION

I, *the participant*, have read the Informed Consent Document and understand the discomforts, inconvenience, risks, and benefits of this project. I, _____
(*print your name*), agree to participate in the project described in the preceding pages. I understand that I may later refuse to participate, and that I may withdraw from the study at any time. I have received a copy of this consent form for my own records.

Signed: _____ Age _____
Date _____

Subject's Signature

APPENDIX B

Subject Questionnaire

Fly-Casting Data Collection
Montana State University

Subject Code _____

1. Name _____
2. Age _____
3. Height _____
4. Weight _____
5. Date of Birth _____

Fly-casting background

6. Which arm is your primary (main) casting arm? (*circle one*)
 Right Left
7. Which arm is your primary (main) reeling arm? (*circle one*)
 Right Left
8. What is your default (standard) casting style?
 Overhead (*i.e. classic*) / Sidearm / Elliptical
9. How long have you been fly-fishing (*years*)? _____
10. Which level of “expertise” would you consider yourself? (*circle one*)
 Beginner / Novice / Intermediate / Advanced / Professional
11. On average, how many days have you fly-fished per year? (*past 5 years*)

12. What types of fly rods do you typically use? (*list your three most-used rods*)
 Length / Weight? Action? (*circle*) Years used? Days/yr?
 A. ____ / ____ Fast / Med / Slow _____ _____

B. _____ / _____ Fast / Med / Slow _____

C. _____ / _____ Fast / Med / Slow _____

13. Do you often use a “hauling” technique when casting? (*circle*) Yes No
 ***If “No,” skip to question #16. If “Yes,” continue to question #14.
14. Do you Single haul when using a single handed rod? (*circle*) Yes No
 If “Yes,” what percentage of the time? _____%
15. Do you Double haul when using a single handed rod? (*circle*) Yes No
 If “Yes,” what percentage of the time? _____%
16. What are your typical casting distance(s) used? (*circle all that apply*)
 10-30 ft / 30-50 ft / 50-70 ft / 70-90 ft / 90+ ft
17. Can you routinely cast over 80 ft (*including leader*) with a single handed rod?
 (*circle*)
 Yes No N/A

Symptom Self-evaluation

18. Do you have any previous upper extremity injury history? (*circle*)
 Yes No N/A
19. If “Yes” to #18, please explain:
 Injury _____
 Date of injury _____
 Cause _____
 Intervention (*surgery, rehab, rest, etc.*) _____
19. Do you have pain or tenderness from casting? (*circle*)
 Yes No N/A
 If “Yes,” how often? (*circle*)

APPENDIX C

Matlab Codes

Matlab Custom Processing Code for Peak Angles and Angular Velocities

```

clear
close all

cond_name=input('What is your subject/condition code: ','s')
[fname,fpath]=uigetfile('*.*xls','pick trial','Multiselect','on')
cd(fpath);
numtr=length(fname);
for i=1:numtr;
    close all
    trial_data=xlsread(fname{i});

    %%%%%%%%% Enter frame #'s indicating time events %%%%%%%%%
    first_mvmt=input('Enter 1st_mvmt frame#: ');
    Bck_stop=input('Enter Bck_stp frame#: ');
    Fwd_mvmt=input('Enter Fwd_mvmt frame#: ');
    End=input('Enter End frame#: ');

    t1=1;
    t2=minus(Bck_stop,first_mvmt);
    t3=minus(Fwd_mvmt,first_mvmt);
    t4=minus(End,first_mvmt);

    %%%%%%%%% CORRECTION FACTOR(S) %%%%%%%%%
    for k = [2,3,5,6,7];

        if min(trial_data(:,k)) <= -50 & min(trial_data(:,k)) >= -230;
            trial_data(:,k) = trial_data(:,k) + 180;

        elseif min(trial_data(:,k) < -230);
            trial_data(:,k) = trial_data(:,k) + 360;

        end;

    end;

    for g = 4;
        if min(trial_data(:,g)) <= -120 & min(trial_data(:,g)) >= -360;
            trial_data(:,g) = trial_data(:,g) + 180;

        elseif min(trial_data(:,g)) < -360;
            trial_data(:,g) = trial_data(:,g) + 360;
        end;
    end;
end;

```

end;

end

```
%%%%%%%%%%
%%%%%%%%%%
```

```
%%%%%%%%% Designate phases for each trial %%%%%%%%%
```

```
phat_1=trial_data(t1:t2,1:7);%[phase 1 -- time,shldx,shldy,shldz,elbx,wrx,wry]%
```

```
phat_2=trial_data(t2:t3,1:7);%[phase 2 -- time,shldx,shldy,shldz,elbx,wrx,wry]%
```

```
phat_3=trial_data(t3:t4,1:7);%[phase 3 -- time,shldx,shldy,shldz,elbx,wrx,wry]%
```

```
%% Tells the length of each phase...per trial %%
```

```
num_ph1(i)=length(phat_1);
```

```
num_ph2(i)=length(phat_2);
```

```
num_ph3(i)=length(phat_3);
```

```
%%%%%%%%%% Angles
```

```
info.%%%%%%%%%
```

```
[ph1_pkshldrA_x,A_p1sx]=max(phat_1(:,2));
```

```
TTpkA_p1sx=A_p1sx/length(phat_1(:,1));
```

```
[ph1_pkshldrA_y,A_p1sy]=max(phat_1(:,3));
```

```
TTpkA_p1sy=A_p1sy/length(phat_1(:,1));
```

```
[ph1_pkshldrA_z,A_p1sz]=max(phat_1(:,4));
```

```
TTpkA_p1sz=A_p1sz/length(phat_1(:,1));
```

```
[ph1_pkelbowA_x,A_p1ex]=max(phat_1(:,5));
```

```
TTpkA_p1ex=A_p1ex/length(phat_1(:,1));
```

```
[ph1_pkwristA_x,A_p1wx]=max(phat_1(:,6));
```

```
TTpkA_p1wx=A_p1wx/length(phat_1(:,1));
```

```
[ph1_pkwristA_y,A_p1wy]=max(phat_1(:,7));
```

```
TTpkA_p1wy=A_p1wy/length(phat_1(:,1));
```

```
[ph2_pkshldrA_x,A_p2sx]=max(phat_2(:,2));
```

```
TTpkA_p2sx=A_p2sx/length(phat_2(:,1));
```

```
[ph2_pkshldrA_y,A_p2sy]=max(phat_2(:,3));
```

```
TTpkA_p2sy=A_p2sy/length(phat_2(:,1));
```

```
[ph2_pkshldrA_z,A_p2sz]=max(phat_2(:,4));
```

```
TTpkA_p2sz=A_p2sz/length(phat_2(:,1));
```

```
[ph2_pkelbowA_x,A_p2ex]=max(phat_2(:,5));
```

```
TTpkA_p2ex=A_p2ex/length(phat_2(:,1));
```

```
[ph2_pkwristA_x,A_p2wx]=max(phat_2(:,6));
```

```
TTpkA_p2wx=A_p2wx/length(phat_2(:,1));
```

```
[ph2_pkwristA_y,A_p2wy]=max(phat_2(:,7));
```

```
TTpkA_p2wy=A_p2wy/length(phat_2(:,1));
```

```
[ph3_pkshldrA_x,A_p3sx]=max(phat_3(:,2));
```

```
TTpkA_p3sx=A_p3sx/length(phat_3(:,1));
```

```
[ph3_pkshldrA_y,A_p3sy]=max(phat_3(:,3));
TTpkA_p3sy=A_p3sy/length(phat_3(:,1));
[ph3_pkshldrA_z,A_p3sz]=max(phat_3(:,4));
TTpkA_p3sz=A_p3sz/length(phat_3(:,1));
[ph3_pkelbowA_x,A_p3ex]=max(phat_3(:,5));
TTpkA_p3ex=A_p3ex/length(phat_3(:,1));
[ph3_pkwristA_x,A_p3wx]=max(phat_3(:,6));
TTpkA_p3wx=A_p3wx/length(phat_3(:,1));
[ph3_pkwristA_y,A_p3wy]=max(phat_3(:,7));
TTpkA_p3wy=A_p3wy/length(phat_3(:,1));
```

```
%%% Average time spent (s) in each phase %%%
```

```
avgtime_ph1=mean(num_ph1)/200;
avgtime_ph2=mean(num_ph2)/200;
avgtime_ph3=mean(num_ph3)/200;
cond_avgtime=[avgtime_ph1 avgtime_ph2 avgtime_ph3];
```

```
%%% Peak ANGLE means for each condition & phase#... + mean length of phase (S)
%%%
```

```
cond_data_ph1A(i,:)=[ph1_pkshldrA_x,TTpkA_p1sx,ph1_pkshldrA_y,TTpkA_p1sy,ph1
_pkshldrA_z,TTpkA_p1sz,ph1_pkelbowA_x,TTpkA_p1ex,ph1_pkwristA_x,TTpkA_p1
wx,ph1_pkwristA_y,TTpkA_p1wy];
cond_data_ph2A(i,:)=[ph2_pkshldrA_x,TTpkA_p2sx,ph2_pkshldrA_y,TTpkA_p2sy,ph2
_pkshldrA_z,TTpkA_p2sz,ph2_pkelbowA_x,TTpkA_p2ex,ph2_pkwristA_x,TTpkA_p2
wx,ph2_pkwristA_y,TTpkA_p2wy];
cond_data_ph3A(i,:)=[ph3_pkshldrA_x,TTpkA_p3sx,ph3_pkshldrA_y,TTpkA_p3sy,ph3
_pkshldrA_z,TTpkA_p3sz,ph3_pkelbowA_x,TTpkA_p3ex,ph3_pkwristA_x,TTpkA_p3
wx,ph3_pkwristA_y,TTpkA_p3wy];
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Velocity info. %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
for j=2:7;
```

```
    pva_pt1=dif_filt(200, 2, trial_data(t1:t4,j));
    vel=pva_pt1(:,2);
```

```
    phat_3V(:,j)=vel(t3:t4);%[phase 3 -- Velocities for...shldx,shldy,shldz,elbx,wrx,wry]%
end %for j=
```

```
[ph3_pkshldrV_x,V_p3sx]=max(phat_3V(:,2));
TTpkV_p3sx=V_p3sx/length(phat_3(:,1));
[ph3_pkshldrV_y,V_p3sy]=max(phat_3V(:,3));
TTpkV_p3sy=V_p3sy/length(phat_3(:,1));
```

```

[ph3_pkshldrV_z,V_p3sz]=max(phat_3V(:,4));
TTpkV_p3sz=V_p3sz/length(phat_3(:,1));
[ph3_pkelbowV_x,V_p3ex]=min(phat_3V(:,5));
TTpkV_p3ex=V_p3ex/length(phat_3(:,1));
[ph3_pkwristV_x,V_p3wx]=max(phat_3V(:,6));
TTpkV_p3wx=V_p3wx/length(phat_3(:,1));
[ph3_pkwristV_y,V_p3wy]=min(phat_3V(:,7));
TTpkV_p3wy=V_p3wy/length(phat_3(:,1));

```

```

%%%% Peak VELOCITY means for phase 3 %%%
%cond_data_ph1V(i,:)= [ph1_pkshldrV_x,TTpkV_p1sx,ph1_pkshldrV_y,TTpkV_p1sy,ph1_pkshldrV_z,TTpkV_p1sz,ph1_pkelbowV_x,TTpkV_p1ex,ph1_pkwristV_x,TTpkV_p1wx,ph1_pkwristV_y,TTpkV_p1wy];
%cond_data_ph2V(i,:)= [ph2_pkshldrV_x,TTpkV_p2sx,ph2_pkshldrV_y,TTpkV_p2sy,ph2_pkshldrV_z,TTpkV_p2sz,ph2_pkelbowV_x,TTpkV_p2ex,ph2_pkwristV_x,TTpkV_p2wx,ph2_pkwristV_y,TTpkV_p2wy];
cond_data_ph3V(i,:)= [ph3_pkshldrV_x,TTpkV_p3sx,ph3_pkshldrV_y,TTpkV_p3sy,ph3_pkshldrV_z,TTpkV_p3sz,ph3_pkelbowV_x,TTpkV_p3ex,ph3_pkwristV_x,TTpkV_p3wx,ph3_pkwristV_y,TTpkV_p3wy];

```

```

clear phat_*
pause
end % for i=

```

```

%%%%%%%%%% %Condition specific average ANGLE peaks for each phase %%%%%%%%%%

```

```

cond_data_ph1A(4,:)=mean(cond_data_ph1A(1:numtr,:));
cond_data_ph2A(4,:)=mean(cond_data_ph2A(1:numtr,:));
cond_data_ph3A(4,:)=mean(cond_data_ph3A(1:numtr,:));

```

```

%%%%%%%%%% %Condition specific stdev's for each ANGLE peak...per phase %%%%%%%%%%

```

```

cond_data_ph1A(5,:)=std(cond_data_ph1A(1:numtr,:));
cond_data_ph2A(5,:)=std(cond_data_ph2A(1:numtr,:));
cond_data_ph3A(5,:)=std(cond_data_ph3A(1:numtr,:));

```

```

%%%%%%%%%% %Condition specific average VELOCITY peaks for each phase %%%%%%%%%%

```

```

%cond_data_ph1V(4,:)=mean(cond_data_ph1V(1:numtr,:));
%cond_data_ph2V(4,:)=mean(cond_data_ph2V(1:numtr,:));
cond_data_ph3V(4,:)=mean(cond_data_ph3V(1:numtr,:));

```

```

%%%%%%%%%% %Condition specific stdev's for each VELOCITY peak...per phase %%%%%%%%%%

```

```

%cond_data_ph1V(5,:)=std(cond_data_ph1V(1:numtr,:));
%cond_data_ph2V(5,:)=std(cond_data_ph2V(1:numtr,:));
cond_data_ph3V(5,:)=std(cond_data_ph3V(1:numtr,:));

```

```

A_cond_out=[cond_data_ph1A, cond_data_ph2A, cond_data_ph3A];
V_cond_out=[cond_data_ph3V];
Phat_time_out=[cond_avgtime];

```

```

%%%%%%%%%% Write out ANGLE condition/trial data %%%%%%%%%%%
out_file=[cond_name, '.ang'];
H=[cond_name, ' ', ' '];
mmsave_ads(A_cond_out, H, out_file);

```

```

%%%%%%%%%% Write out VELOCITY condition/trial data %%%%%%%%%%%
out_file=[cond_name, '.vel'];
H=[cond_name, ' ', ' '];
mmsave_ads(V_cond_out, H, out_file);

```

```

%%%%%%%%%% Write out ANGLE condition/trial data %%%%%%%%%%%
out_file=[cond_name, '.phat'];
H=[cond_name, ' ', ' '];
mmsave_ads(Phat_time_out, H, out_file);

```

```

%%%%%%%%%%

```

Matlab Custom Code for Total ROM

```

clear
close all

```

```

cond_name=input('What is your subject/condition code: ','s')
[fname,fpath]=uigetfile('*.*xls','pick trial','Multiselect','on')
cd(fpath);
numtr=length(fname);
for i=1:numtr;
    close all
    trial_data=xlsread(fname{i});

```

```

%%%%%%%%%% CORRECTION FACTOR(S) %%%%%%%%%%%
for k = [2,3,5,6,7];

```

```

    if min(trial_data(:,k)) <= -50 & min(trial_data(:,k)) >= -230;

```

```

    trial_data(:,k) = trial_data(:,k) + 180;

elseif min(trial_data(:,k) < -230);
    trial_data(:,k) = trial_data(:,k) + 360;

end;

end;

for g = 4;
if min(trial_data(:,g)) <= -120 & min(trial_data(:,g)) >= -360;
    trial_data(:,g) = trial_data(:,g) + 180;

elseif min(trial_data(:,g)) < -360;
    trial_data(:,g) = trial_data(:,g) + 360;
end;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%Total ROM Code%%

    shldr_x_ROM = max(trial_data(:,2)) - min(trial_data(:,2));
    shldr_y_ROM = max(trial_data(:,3)) - min(trial_data(:,3));
    shldr_z_ROM = max(trial_data(:,4)) - min(trial_data(:,4));
    elbow_x_ROM = max(trial_data(:,5)) - min(trial_data(:,5));
    wrist_x_ROM = max(trial_data(:,6)) - min(trial_data(:,6));
    wrist_y_ROM = max(trial_data(:,7)) - min(trial_data(:,7));

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

cond_data_ROM(i,:)=[shldr_x_ROM,shldr_y_ROM,shldr_z_ROM,elbow_x_ROM,wrist
_x_ROM,wrist_y_ROM];

end

cond_data_ROM(4,:)=mean(cond_data_ROM(1:numtr,:));
cond_data_ROM(5,:)=std(cond_data_ROM(1:numtr,:));

ROM_out=[cond_data_ROM];

%%%% Write out ROM condition/trial data %%%

```

