VARIATIONS IN THE FIELD HOCKEY SWING EXPLAINED BY THE

KINEMATIC SEQUENCE

By

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Attempts to biomechanically analyze field hockey swings have been sparse. More so, the degree to which proximal-distal kinematic sequencing is expressed in field hockey swings is unknown. The aim of this study was to determine if kinematic sequencing is incorporated into field hockey swings, and to evaluate segmental contributions to stick speed across two swing types: classic grip and choke-grip drives. Kinematic data were collected on 10 high-level field hockey players (5 males and 5 females). Pelvis, thorax, arms and stick kinematics were quantified (3-axis rotations and translations), using a 12 sensor, 240 Hz, Polhemus-based AMM 3D Motion Analysis System (Phoenix, AZ). Subjects hit 10 to 15 shots of each swing type into a net, and provided feedback regarding the quality of their swings. Good and very good swings for each subject were analyzed. Of 37 classic grip swings analyzed, average stick head velocity was 72.4 +/- 11.6 mph, and 37.8% of the swings demonstrated the standard proximal to distal downswing sequence of pelvis, thorax, arm, and then the stick (expressed as rotational velocities). For 43 choke-grip swings analyzed, average stick head velocity was 69.5 +/- 10.9 mph, and 30.2% expressed the standard proximal to distal downswing sequence. For the classic and the choke-grip swings, most of the stick speed developed through the actions of the wrists (54.4% +/-5.0 and 58.1% +/- 5.5 contributions, respectively). Differences between males and females in stick speed were
significant; however, kinematic differences between the swing types were generally not.
The classic and choke-grip swings incorporated significantly more torso flexion at
address and ball impact than golf swings in professional golfers. The classic and choke-
grip swings clearly utilize proximal to distal segment sequencing, instrumental in
developing high stick velocity.
DEDICATION

This thesis is dedicated to my parents, Anthony and Patricia Davaro and my siblings, Lisa and Matthew Davaro. Without their continued support and faith, this work would not have been possible. Thank you for your unconditional love and your words of encouragement. This would not have been possible without you!
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CHAPTER I
INTRODUCTION

Field hockey is a popular sport that is played worldwide. Both Men’s and Women’s field hockey are Olympic sports. The world of field hockey is constantly growing, and thus research focused on various elements of field hockey swings is warranted.

Kinematics is the study of motion (positions, angles, velocities, and accelerations) without regard to the forces producing the motion (McGinnis, 2013). Kinematic analyses are foundational to golf swing analyses. In recent years, *kinematic sequence* and *kinematic sequencing* have emerged as descriptors of the efficient sequencing or ordering of motion expressed, during a skilled golf swing. This sequence describes a proximal-to-distal sequencing of movement, starting with the pelvis, to the thorax, to the arms, and concluding with the club. This order facilitates the build-up and transfer of energy from larger segments to the club head, much like a bull-whip relies on the transfer of energy from the heavier handle to the much lighter whip’s tip.

The kinematic sequence has numerous names, including proximal-to-distal sequencing (Sprigings & Neal, 2000), summation of speed principle (Bunn, 1972), and the kinetic chain (Kreightbaum & Barthels, 1985). All these terms describe a movement sequence in which accelerations and decelerations progress smoothly and sequentially, from large segments to small, culminating in very high-end point, smallest/distal segment velocity. Transitions from acceleration to deceleration for each segment (pelvis, torso, arms, for example) allows for the efficient transfer of energy from one segment to the next.
Qualitatively, the kinematic sequence can and has been used to study sequential synchronicity and the development of coordinated patterns. Quantitatively, the kinematic sequence can be used to describe angular velocity magnitudes for each segment, rotational speed gains across segments, peak velocity ordering (sequencing), and segment rotational accelerations and deceleration magnitudes. These detailed elements of the kinematic sequence have been used to study experienced (professional) versus inexperienced (amateur) golfers, male versus female professional golfers, and full versus partial golf shots (Cheetham, 2008; Myers et al., 2008; Horan et al., 2010; Tinmark et al., 2010). The kinematic sequence has even been described in several sports beyond golf, including baseball, tennis, and javelin.

Not unlike the golf swing, the field hockey swing can be broken down into three phases: the backswing, downswing, and follow-through (or finish). The backswing is composed of the movement of the stick away from the ground, with the stick being brought away from the target, back around the player’s body. The downswing involves stick motion in the opposite direction of the backswing, towards the target, composed of the area from the highest point of the stick head to the ball, at impact. The finish, or follow-through, is the time from impact until the end of the drive, which is described as the end of the movement when the stick reaches its highest point, just before the player relaxes (Brétigny et al. 2008).

The follow-through of the field hockey swing differs from the traditional golf swing, because the field hockey follow-through is abbreviated. In accordance with International Hockey Federation (2016) rules, use of the stick should not result in dangerous play, which includes lifting the stick over one’s head. With this rule in mind,
the height of the swung stick is limited to the height of the player’s pelvis; any higher results in a penalty.

Once hit, the field hockey ball must remain relatively close to the ground, to prevent player impact, with the exception being a direct shot on goal (International Hockey Federation, 2016). This aspect of field hockey swings differs greatly from the golf swing, in which the objective is to loft the ball to assist with its travel distance.

Minimal attempts have been made to biomechanically analyze the field hockey swing. The degree to which the kinematic sequence is expressed in field hockey swings, in particular, has not been reported. Questions addressed in this study include: “What does the kinematic sequence look like for the field hockey swing? Does a change in swing type influence the kinematic sequence? Does the grip style (classic versus short-hand grip) influence the swing?” A biomechanical evaluation of field hockey swings, with a specific look at kinematic sequencing, will provide scientists and coaches critical kinematic relationships expressed during these swings, to ideally guide coaches and athletes in the pursuit of more efficient and effective swings.

1.1. Purpose of the Study

The purpose of this study was to quantify the degree to which field hockey swings incorporate kinematic sequencing. This study evaluated segment rotational sequencing across two different swing types, the classic grip and the short hand grip. Our hypothesis was that the kinematic sequence would indeed be demonstrated in the field hockey swing, and characteristics of the sequence would change in response to alterations in grip/swing type. We further hypothesized that male and female field hockey players would differ in
their use of their pelvis, torso and wrist links in developing the kinematic sequence profile.

Parameters unique to the kinematic sequence describe segmental contributions to the stick head velocity (pelvis, torso and arms). Parameters analyzed included segment sequencing order, rotational velocity peaks for each segment, timing of these peaks, rotational speed gains between segments, and stick head speed at impact.

1.2. Outline of the Thesis

Chapter 2 (Literature Review) concentrates on existing publications and research on the kinematic sequence of the golf swing, and field hockey kinematics.

Chapter 3 (Study Design and Methods) provides a comprehensive explanation of the data collection and analysis processes.

Chapter 4 (Results/Discussion) presents the collected and processed kinematic data on the measured field hockey swings, provides relevant interpretation of the findings, and summarizes the major conclusions from the study.

Chapter 5 (Limitations and Future Improvements) outlines the various limitations of the present study, and provides suggestions for future research.
CHAPTER II
REVIEW OF THE LITERATURE

A rigorous literature search for the terms kinematic sequence and field hockey provided little insight into whether kinematic sequencing is used or has been studied in relation to field hockey swings. In fact, studies focused on the identification and characterization of kinematic sequencing in sport movements dominantly appear in the golf biomechanics literature. Not surprisingly, the term *kinematic sequencing* was first coined in golf biomechanics studies.

Kinematics is the study of motion without regards to the forces producing the motion (position, angle, velocities, and accelerations) (McGinnis, 2013). Research into the term kinematic sequencing populates numerous alternative names and phrases, such as proximal-to-distal sequencing, kinetic link or chain, and summation of speed principle.

2.1 Kinematic Sequences as Studied in Golf

Cochran and Stobbs (1968) stated that a powerful rotation of the arms and shoulders is achieved through a sequential buildup of speed. They added that a “tight” sequence is important to create this power, and unnecessary slack should be avoided. Cochran and Stobbs used a disk and spring model of the kinematic sequence to describe the sequence of motions of the golf downswing involving multiple segments. A visual representation of this model (Figure 2.1) is comprised of three separate disks rotating atop one another, on a common axis. The composition of the model starts with the largest disk at the bottom of a three-disk stack, with the disks becoming smaller until the last
disk, at the top of the stack, being the smallest. The smallest disk has a lever attached to it, representing a golf club.

Figure 2.1: Visual representation of the Cochran and Stobbs (1968) three-disk plus lever model. The angled black bands represent springs between the base and the lowest disk, between adjacent disks, and between the top disk and the lever. Adapted from the Cochran and Stobbs model (1968).

In the three-disk plus lever model. Springs are attached between a fixed base and the largest/bottom disk, and between successive disks and the lever at the top of the stack. The springs in this model represent tension in the muscles of a golfer. Rotation of the disk stack against the resistance of the springs represents the golfer’s backswing, and “coil” is the drive behind the entire system. Cochran and Stobbs used this model to explore and demonstrate how the order in which the springs are released influence final lever (club) velocity.

When the springs in the Cochran and Stobbs model are released naturally from their respective stretched states, maximal lever/club velocity is achieved. As much of the energy is imparted to the system by the first spring, the largest/bottom disk will slow down, causing the second disk to accelerate. This deceleration/acceleration relation
between adjacent disks happens again between the next two disks, and finally between the top disk and the lever. The lever at the top of the stacks achieves the greatest rotational speed of all the elements in the stack. This “tight” sequencing, as described by Cochran and Stobbs, allows the most transfer of energy from the base of the system to the top, compared to a “slack” sequence. This model was one of the first references to the sequencing actions of the major body segments in the golf swing (Cochran & Stobbs, 1968).

Bunn (1972) described a controlled golf swing in his book: Scientific Principles of Coaching, as a “rhythmic fashion.” To obtain optimum clubhead speed while still maintaining an efficient and effective swing, according to Bunn, the golfer must utilize proper swing sequencing. The ideal sequence involves a swing that begins slowly, rhythmically, and gradually. Bunn added that the sequencing of motion of the downswing of a golfer can be been described as a movement that starts with actions in the larger muscle groups and finishes with actions in the smallest muscle groups. This sequencing, according to Bunn, allows for the summation of all forces involved in the golf swing, and produces an effective stroke in which the club head speed increases as the stroke develops. Bunn referred to this sequencing in association with a “summation of speed principle,” and stated that the speed of each successive segment should be faster than its predecessor. In the human body, this means that the action will start with the activation of larger muscles, transferring through to the finish with the activation of the smallest muscle (Bunn, 1972).

Proximal-to-distal sequencing has also described as the kinetic-link principle (Kreightbaum & Barthels, 1985). A kinetic-link model here is composed of a series of
linked segments, with one end fixed and the other end open. The segments become smaller as the model’s link system progresses from the proximal or fixed end to the free end. The model demonstrates that the smaller, distal segment will travel extremely fast due to the sequential acceleration and deceleration of the previous segment.

A three-segment sequencing model of the golf swing was first described in detail by Sprigings and Neal (2000). These researchers hypothesized that the addition of an optimally timed wrist torque could increase clubhead speed at impact. They believed that this increase in clubhead speed could be made possible without jeopardizing the club position at impact. This model was also used to describe proximal-to-distal sequencing of joint torques, by looking at torso, shoulder, and wrist actions during the golf swing.

The Sprigings and Neal model was created as a system that is two-dimensional (2D) with three segments comprised of the torso, left arm and club, with the focus of the action being on the golfer’s downswing. Torque generators were modelled to act at the proximal end of each segment, with mathematical simulations exploring actions of the wrist joint torque generator (enabled versus disabled). This model demonstrated that at the start of the ideal swing, the torso begins its rotation immediately, followed by shoulder movements, finishing with movements of the wrists. The researchers also discovered that activation of the torque generators in a proximal-to-distal sequence resulted in maximum clubhead speed (Sprigings & Neal, 2000).

Dr. Phil Cheetham’s recent research into the biomechanics of the golf swing exposed how the kinematic sequence is expressed as an efficient method for the transfer of energy from the larger core segments to the smaller distal segments (Cheetham, 2008).
The graphical representations of his kinematic sequence, which have become a benchmark diagnostic tool for the study of golf swings, shows that there is an acceleration, then deceleration, during the downswing and before impact of a golf swing for the pelvis, thorax, arm, and club segments (see Figure 2.2).

In Cheetham’s kinematic sequence graphic, for a high-level golfer, energy is transferred from one segment to the next, with the addition of that segment’s own energy, resulting in an increase in speed from one segment to the next. The energy transmitted is managed and augmented by the muscles acting across each joint.

Figure 2.2: Kinematic sequence for a professional golfer, demonstrating accelerations and decelerations, in order, involving the pelvis, torso, arms and club. Vertical lines represent the address, top of swing, impact and finish positions of the golf swing.

Myers, Lephart, Tsai, Sell, Smoliga and Jolly (2008) analyzed the role of upper torso and pelvic rotations in relation to golfer’s swing performance. Myers and
colleagues (2008) wanted to determine how pelvis and torso rotations contribute to golf ball velocity after impact. The study was composed of 100 recreational golfers. Upper torso and pelvic rotations and velocities, as well as torso-pelvic separations and their velocities were measured and/or computed. Data were collected using the Peak Motus System v.8.2 three-dimensional (3D) motion analysis system with 8 optical cameras surrounding the golfer, capturing marker movements at a rate of 200 frames per second. Flight Scope Sim Sensor simulation software were used to measure ball flight. These researchers reported that a greater upper torso rotation velocity was achieved by increasing torso-pelvic separation. Greater ball velocity was achieved by increasing torso-pelvic separation velocity during the downswing. An increase in ball velocity was also associated with maximizing the separation between the upper torso and pelvis at the top of the backswing, and during the initiation of the downswing (Myers et al., 2008).

Horan, Evans, Morris and Kavanagh (2010) investigated 3D kinematic profiles of the thorax and pelvic, and specifically differences in these motions between male and female golfers. The study was composed of 19 males and 19 females. Horan et al., hypothesized that female golfers would achieve a greater rotation of the thorax and pelvis at the top of the backswing, and at ball contact, than males. The results of the study concluded that male and female skilled golfers demonstrate different kinematics of the thorax and the pelvis. Compared to females, males expressed a greater range of lateral tilt for the pelvis, and a higher pelvic lateral tilt velocity at the top of the backswing and at ball contact. Males also demonstrated a greater range of thorax anterior tilt. This greater range corresponds to the generation of higher thorax anterior tilt in males. From the top of the backswing to ball contact, males had a greater range of anterior-posterior tilt for
the pelvis and compared to females as well, and a higher pelvic anterior-posterior tilt velocity (Horan et al., 2010).

Tinmark, Hellstrom, Halvorsen, and Thorstensson (2010) studied the kinematic sequence of full-swing and partial swing shots in elite golfers. The aim of the study was to determine if both partial and full-swing golf shots utilized proximal-to-distal sequencing and speed summation principles, to achieve an effective and efficient shot. The study compared golfers of different skill level and gender. The study was comprised of 11 male tournament professionals, 21 male elite amateurs, and 13 female elite amateurs. Data collection utilized a 3D electromagnetic tracking system that recorded the pelvic, upper torso, and hand movements at 240 Hz. The system allowed for the measurement of the magnitude of the resultant angular velocity vector of the segments (Tinmark et al., 2010). The conclusion of the study was that proximal-to-distal sequencing is utilized in each shot condition. The study also found that there is a successive increase in the maximum segment angular speed across both genders and skill level (Tinmark et al., 2010).

2.2 Kinematics of Field Hockey Swings: Is There a Kinematic Sequence?

The field hockey swing has similarities and differences from the golf swing. Like the golf swing, the field hockey swing is composed of a backswing and a follow through. In field hockey, the space in which the backswing is performed is the player’s space. Any intrusion into this space, by another player, takes place at the opponent’s own risk.

Unlike the golf swing, the field hockey swing has an abbreviated follow-through. This is because the execution of the shot must not put an opposing player at risk.
means that upon the follow-through of a shot, the stick must not come higher than the pelvis. This is considered dangerous play and results in an offense (International Hockey Federation, 2016). The field hockey hit is utilized for shots on goal and long-distance passes. This shot generates high ball velocity and is produced through the use of a two-handed swing model (Lerner & Wilmoth, 2007).

Brétigny, Seifert, Leroy, and Chollet (2008) researched upper-limb kinematics between the short grip and classic grip drives in field hockey with the aim of comparing the upper-limb kinematics and the coordination of the two swing types. The protocol involved 10 female elite national level field hockey players. Ball velocity after impact was collected via radar speed detection, and kinematics were captured using a VICON optoelectronic system. Subjects had 5 cameras collecting images at 50 frames per second. Each player completed 5 classic drive and 5 short grip drives. These researchers based their kinematic analysis on the displacement of the right wrist in the frontal plane during the entire stroke.

Brétigny et al., (2008) reported that ball velocity was not affected by the way the stick was held. The short grip drive took less time to perform; however, the differences in relative swing duration were not significant. In particular, the study showed that the backswing of the short grip shot had a shorter relative duration compared to the classic drive, but the finish of the short grip shot had a longer relative duration when compared to the classic drive. Brétigny et al. posed that this observation is caused by the conditions in which the short grip drive is performed. A short grip drive is typically used for rapid actions, often needed during an offense/defense challenge. Such a challenge involves
reduced preparation time, and the time saved can be utilized during the finish to adjust the direction and accuracy of the shot (Brétigny et al., 2008).

A study on the planarity of stick-face motion during the downswing in field hockey shots was conducted by Willmott and Dapena (2012). Their study assessed the sustainability of a planar pendulum model for simulating a field hockey hit. The study subject group was composed of 13 experienced female field hockey players who were either an NCAA Division I varsity player or coach. Testing utilized the most basic field hockey swing that still incorporated the forward step; a single approach step to a stationary ball. The single step hit is what distinguished the field hockey hit from motions such as the golf swing.

To measure stick motions, Willmott A. & Dapena placed one marker on the stick toe, one on the distal shaft, and the final marker on the proximal shaft, distal to the hands. Two motion-picture cameras collected data at 200 frames per second. Stick motion analysis focused on the last frame captured before the player’s left foot lost contact with the ground and at the beginning of the forward step. The measurement of the planarity of the stick-face motion involved curve-fitting to the motion data, using a least-squares regression technique, applied over several time-based intervals during the downswing. Swing shapes were classified as “straight” and “looped” after analysis. The study found that on average, 83 ± 12% of the downswing path of the stick face was planar, with the planar section length ranging from 1.85m to 2.70m. (Willmott A. & Dapena J, 2012).

In 2006, Kerr and Ness researched the kinematics of the penalty corner push-in in field hockey. The aim of this study was to determine what variables significantly
influence the push-in execution of a penalty corner. The study subjects were composed of 8 experienced male push-in performers, and 9 inexperienced male push-in performers. The push-in executions were recorded using 250Hz video cameras that recorded transverse and longitudinal views. Variables collected were ball speed, stance width, drag distance, time of the drag, drag speed, center of mass displacement, and segment and stick displacement and velocities (Kerr & Ness, 2006).

Kerr & Ness reported that there was a significantly greater stance width and distance between the ball and the front foot at the beginning of the push-in involving the experienced subjects. Experienced subjects also had a significantly faster ball speed when compared to the inexperienced subjects. A positive correlation was noted between playing experience and ball speed. Experienced players also utilized a combination of simultaneous and sequential segmental rotation. Sequential segmental rotations were positively correlated to faster ball speeds and improved accuracy (Kerr & Ness, 2006).

Finally, De Subijana, Gomez, Martin-Casado and Navarro (2010) conducted a study in which the purpose was to analyze the kinematic sequence of the penalty-corner drag-flick. The study was composed of one skilled male player, specializing in performing drag-flick shots on goal, 6 elite male players and 6 elite female players. Data collection involved an optoelectronic motion analysis system and utilized six 250 Hz cameras. Force platforms were used to collect ground reaction force (GRF) parameters, and the GRFs were used to identify the last support instant of the front foot. Each subject completed 20 drag-flick trials.
De Subijana et al., reported that there was a significantly lower ball velocity at release in both player groups when compared to the skilled drag-flicker. The study also showed that both player groups showed a significantly smaller peak angular velocity of the pelvis when compared to the skilled drag-flicker. The skilled drag-flicker had a larger normalized ground reaction force than the gender group players. Finally, the study reported that a wide stance, with a whipping action of the stick followed by sequential movements of the pelvis, thorax and stick in an explosive manner, was utilized by the skilled level drag-flicker (De Subijana et al., 2010).
CHAPTER III
METHODS

3.1. Participants

Participants were recruited through a competitive field hockey club in Colorado. Of the 10 subjects, 5 were male and 5 were female. Complete participant demographics are provided in Table 3.1. All subjects were right-hand dominant and used 36.5” sticks, with the exception of one 35.5” stick. Stick manufactures included Dita, Osaka, Adidas, and Harrow. All subjects were free of injury at time of testing. Institutional Review Board (IRB) approval was obtained prior to data collection. These subjects are described as highly skilled field hockey players. All participants provided informed consent as required by the University of Colorado, Colorado Springs IRB.

Table 3.1: Subject demographics

<table>
<thead>
<tr>
<th>Demographics</th>
<th>Weight (lbs.)</th>
<th>Height (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>186.4 ± 34.3</td>
<td>70.2 ± 2.4</td>
</tr>
<tr>
<td>Females</td>
<td>138.0 ± 11.5</td>
<td>63.1 ± 1.7</td>
</tr>
</tbody>
</table>

3.2. Instrumentation

Kinematic data of the field hockey player’s swings were collected using a 240 Hz, Polhemus-based, AMM 3D Motion Analysis System and Software (Phoenix, AZ). This system utilizes twelve electromagnetic sensors placed on the head, thorax, pelvis, upper arms, hands, shins, feet and field hockey stick. An emitter fixed to a tripod transmits a harmless electromagnetic signal that allows the software to pick up the location of the twelve sensors.
Sensor wires are secured to the subject’s body using Velcro bands to minimize interference with movements. A sensor is firmly attached to the stick, just below the grip, using electrical tape. Body landmarks are digitized before data collection to locate body segments and specific anatomical locations (for example, joint centers) relative to the sensor positions. This digitizing process requires one sensor to be used in a plastic stylus and placed on anatomical landmarks, in sequence, as data from the sensors are collected. Once digitization is completed, the system has a digital representation of the subject’s body.

3.3. Procedures

Each participant attended one test session, lasting roughly an hour. Participants were fitted with the twelve electromagnetic sensors centered on the forehead, on the bilateral posterior brachium above the olecranon, on the posterior hands, on the upper thorax, on the sacrum, on the anterior tibial shafts below the tibial tuberosities, on the top of the feet, and on shaft of the stick. A subject fitted with the sensors is shown in Figure 3.1.
Each participant was instructed to warm up before data collection at their own discretion. Each participant took practice swings to familiarize themselves to the sensor system and become comfortable with the sensors and wires. Data collection consisted of participants hitting the field hockey ball with their own stick in a classic grip drive and a short-gripped drive. Participants hit 10 to 15 shots of each swing off an artificial turf matt into a net/target, while kinematics of the field hockey swings were collected. Subjects were asked to rate their swings: very good, good, okay, bad. Subjects provided feedback regarding their poorer swings; hit turf first, toed it, topped it, etc.

3.4. Data Analysis

The AMM 3D Motion Analysis Software generated reports describing multiple variables characterizing the swing movements. The focus of this study was on the movement sequencing of the pelvis, thorax, arms and stick – throughout the swing.
The downswing of the field hockey swing, where stick speed is generated, was analyzed in detail to assess (a) peak rotational velocities of each segment, (b) the timing of each segment’s peak speed in the downswing, used to establish segment peak speed ordering, (c) rotational speed gains between segments (thus across the links joining adjacent segments), and (d) percent contributions of each segment to total stick speed.

Early in the data collection and analysis we noticed that in virtually every swing, peak stick rotational velocity (and thus stick head speed) occurred well before the moment the stick head struck the ball. This finding contrasts with what is seen in golfing, where peak club velocity (for good golfers) occurs nearly simultaneous with ball impact. As such, we analyzed this pre-impact stick speed peak, calculating time (in msec) before ball impact where peak stick rotational speed occurred, across the swing styles.

Although the focus of this study was on the sequencing of the body segments during field hockey swings, select positional variables were analyzed to explore elements of the sequences. Peak pelvis, thorax, and spine rotation angles during the backswings for both the classic and choke grip swings, described for the total group and separately for males and females, were quantified.

Finally, because the transition from the backswing to the downswing has been identified as a dynamic and critical phase in the development of swing speed in golf, the transition phases of the field hockey swings captured in this study were analyzed. Specifically, the time before the top of the backswing (in msec) at which point the pelvis segment transitioned from rotating backwards, away from the target, to rotating towards the target, was quantified - for each swing type.
Sequence ordering during the downswings were expressed as counts and percentages, for each swing type and across genders. Mean values (± 1 SDEV) were calculated for all other parameters. Statistically significant differences were evaluated using independent t-tests (two-tailed, alpha = 0.05), assessed between swing types, between genders, and between field hockey swings and those of professional (PGA and LPGA) golfers.
CHAPTER IV  
RESULTS AND DISCUSSION  

4.1 Results

Across the 10 subjects, a total of 63 classic grip swings were collected. Of these, 37 were rated good or very good by the participants and were subsequently analyzed. A total of 57 choke-grip swings were recorded, and 43 of these were rated good or very good by the participants, and subsequently analyzed.

Average peak stick head velocity (± 1 SD) of the 37 classic grip swings, across the ten subjects, was 72.4 ± 11.6 mph. Average peak stick head velocity for the 43 choke-grip swings, across the subjects was 69.5 ± 10.9 mph. Differences in stick head velocity between the classic grip and choke-grip drives were not statistically significant. When broken down by gender, females demonstrated an average peak stick head velocity for the classic and choke grips of 66.5 ± 4.3 mph and 63.9 ± 4.8 mph, respectively. For males, average peak stick head velocities for classic drive and choke grip swings were 78.4 ± 14.0 and 75.2 ± 12.9 mph, respectively. The differences were not statistically significant when compared between genders (t (8) = 1.82; p = 0.106 for classic and t (8) = 1.83; p = 0.105 for choke-grip).

Specific to kinematic sequencing, 37.8% of the 37 classic drives demonstrated the standard, four segment, proximal to distal sequence of pelvis (1), thorax (2), arm (3), and then stick (4) during the downswing (expressed as rotational velocities). This standard ordering will be referred to as a 1-2-3-4 sequence. Exemplar graphics displaying such standard sequencing for a classic swing, and a non-standard downswing for a classic
swing, are provided in Figures 4.1 and 4.2, respectively. With good and very good swings averaged for each subject, 31.6% of males and 44.4% of females demonstrated the standard, four segment proximal to distal sequence.

Figure 4.1: Exemplar Kinematic Sequence for a classic grip field hockey swing, demonstrating downswing accelerations and decelerations, in order, involving the pelvis, torso, arms and stick. Vertical lines represent the address, top of swing, impact and finish positions of the swing.
Figure 4.2: Exemplar Kinematic Sequence for a classic grip field hockey swing, demonstrating a non-1-2-3-4 sequence. Figure represents a 1-4-2-3 downswing sequence, in which peak stick speed in the downswing occurred before peak thorax and arm speed.

The distribution of downswing sequences observed across all the classic grip swings analyzed is provided in Figure 4.3. As indicated, most of the swings (57%) were either the standard 1-2-3-4 sequence, a 1-3-2-3 sequence, or a 2-3-1-4 sequence. A 1-3-2-3 sequence essentially describes a swing in which the peak downswing speed of the segments occurs in the following order: pelvis (1), arms (3), thorax (2), and then stick (4), although the stick and arms peak speeds occur at the same time (hence the second “3” designation). The remaining 43% of the swings involved highly varied swing sequences and were thus classified as “other.”
Figure 4.3: Sequencing distribution of the downswing in classic drives. The 1-2-3-4 sequence represents the standard pelvis (1), thorax (2), arms (3) and stick (4) sequence.

Analysis of the choke-grip swings showed that the proximal to distal downswing sequence of pelvis, thorax, arm, and then stick was expressed in 30.2% of all the swings analyzed. By gender, 33.3% of males and 27.3% of females demonstrated the standard, four segment proximal to distal sequence for choke grip swings. An exemplar graphic displaying such a sequence for a choke grip swing is provided in Figure 4.4.
Figure 4.4: Kinematic Sequence for the choke-grip field hockey swing, demonstrating accelerations and decelerations, in order, involving the pelvis, torso, arms and stick. Vertical lines represent the address, top of swing, impact and finish positions of the swings.

The distribution of sequences observed across all the choke grip swings analyzed is provided in Figure 4.5. As indicated, most of the swings (49%) were either the standard 1-2-3-4 sequence, a 1-3-2-4 sequence, or a 2-3-1-4 sequence. Approximately 30% of the swings involved highly varied swing sequences, and were thus classified as “other.”
Figure 4.5: Sequencing distribution of the downswing in classic drives. The 1-2-3-4 sequence represents the standard pelvis (1), thorax (2), arms (3) and stick (4) sequence.

Peak rotation speeds (deg/sec) during the downswing for the major body segments are provided in Table 4.1. The data show that there is an increase in the peak segment rotational speed as the swing transitions from the most proximal to the most distal segments. There was no significant difference in peak rotation speeds across the segments between swing types. Differences between males and females were not statistically significant, except for peak rotation speed of the stick in the choke grip swing (males 2060.8 ± 296.6 deg/sec; females 1692.7 ± 89.2 deg/sec; t (8) = -2.65, p = 0.029.
Table 4.1: Average peak rotation speed during the downswing (deg/sec) across the main body segments (pelvis, thorax, arm, stick), or each swing type and gender type.

<table>
<thead>
<tr>
<th></th>
<th>Pelvis₁</th>
<th>Pelvis₂</th>
<th>Thorax₁</th>
<th>Thorax₂</th>
<th>Arm₁</th>
<th>Arm₂</th>
<th>Stick₁</th>
<th>Stick₂</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total</strong></td>
<td>382.4 ± 116.9</td>
<td>385.1 ± 92.1</td>
<td>615.5 ± 86.8</td>
<td>649.1 ± 57.5</td>
<td>765.8 ± 81.9</td>
<td>778.0 ± 91.2</td>
<td>1729.6 ± 156.7</td>
<td>1876.7 ± 283.3</td>
</tr>
<tr>
<td><strong>Males</strong></td>
<td>349.9 ± 154.7</td>
<td>355.9 ± 95.6</td>
<td>577.4 ± 60.2</td>
<td>620.5 ± 60.2</td>
<td>758.6 ± 89.0</td>
<td>779.3 ± 114.4</td>
<td>1812.1 ± 296.6</td>
<td>2060.8 ± 296.6</td>
</tr>
<tr>
<td><strong>Females</strong></td>
<td>414.9 ± 64.5</td>
<td>414.4 ± 49.2</td>
<td>653.7 ± 64.6</td>
<td>677.6 ± 42.0</td>
<td>773.0 ± 83.9</td>
<td>776.6 ± 75.1</td>
<td>1647.0 ± 140.4</td>
<td>1692.7 ± 89.2</td>
</tr>
</tbody>
</table>

1 Classic Swing
2 Choke-grip Swing

Rotational speed gains (deg/sec) derived from the pelvis to thorax, thorax to arms, and arms to stick interactions during the downswing are provided in Table 4.2. The data show that the largest angular speed gain, in both the classic drive and the choke-grip drive, occurs between the arm and the stick (at the wrists). The angular speed gains from the arms to the stick for the classic drives were 1067.0 ± 43.3 deg/sec and 874.0 ± 128.7 deg/sec for males and females, respectively. Males had a larger wrist-based speed gain for classic drives when compared to females.

Similarly, males performing a choke-grip swing demonstrated an angular speed gain across the wrists of 1293.5 ± 217.8 deg/sec. Females performing a choke-grip drive exhibited an angular speed gain across the wrists of 916.0 ± 102.1 deg/sec. These differences show that females had a smaller speed gain across the wrists when compared to males. The smallest angular speed gain, in both swings, occurred between the thorax and the arms, across the shoulders.
Table 4.2: Average angular speed gains (deg/sec) between the segments of the body during the swings analyzed, across swing types and genders

<table>
<thead>
<tr>
<th>Angular Speed Gains</th>
<th>Plv-Thx₁</th>
<th>Plv-Thx₂</th>
<th>Thx-Arm₁</th>
<th>Thx-Arm₂</th>
<th>Arm-Clb₁</th>
<th>Arm-Clb₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>233.1 ± 86.9</td>
<td>264.0 ± 58.1</td>
<td>150.2 ± 60.3</td>
<td>128.9 ± 71.3</td>
<td>970.5 ± 136.2</td>
<td>1104.8 ± 255.6</td>
</tr>
<tr>
<td>Males</td>
<td>227.6 ± 113.2</td>
<td>264.7 ± 69.6</td>
<td>180.9 ± 63.0</td>
<td>158.8 ± 67.0</td>
<td>1067.0 ± 43.3</td>
<td>1293.5 ± 217.8</td>
</tr>
<tr>
<td>Females</td>
<td>246.0 ± 71.3</td>
<td>263.2 ± 52.3</td>
<td>119.4 ± 43.0</td>
<td>98.9 ± 68.7</td>
<td>874.0 ± 128.7</td>
<td>916.0 ± 102.1</td>
</tr>
</tbody>
</table>

1 Classic Swing
2 Choke-grip Swing

The percentage contributions the legs, core, shoulders, and wrists make to generating stick velocity (speed of the swing) are provided in Table 4.3. These contributions are derived from the speed gains between the segments. For example, the core contribution represents the speed gain between the pelvis and thorax; the shoulders contribution represents the speed gain between the thorax and arms, and so on. The legs’ contribution represents the speed developed by the pelvis here, without breaking down this speed into contributions from the segments of the legs themselves.

As noted in Table 4.3, more than half of the stick speed is generated by actions at the wrists, in both the classic and choke-grip swing types (54.4% ± 5.0 and 58.1% ± 5.5, respectively), and this dominance in wrist action contribution is seen in both males and females. Males had a larger percent contribution of the wrists in the choke-grip drive when compared to females. When looking at the differences in percent contribution of the legs in the choke-grip swing, females had the larger contribution when compared to the males.
Table 4.3: The percent contributions to stick speed derived from the links between segments (legs, core, shoulder, wrists).

<table>
<thead>
<tr>
<th>Contribution</th>
<th>Legs1</th>
<th>Legs2</th>
<th>Core1</th>
<th>Core2</th>
<th>Shldr1</th>
<th>Shldr2</th>
<th>Wrist1</th>
<th>Wrist2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>20.8 ± 7.3</td>
<td>20.9 ± 5.6</td>
<td>12.4 ± 7.6</td>
<td>14.4 ± 4.1</td>
<td>11.8 ± 12.6</td>
<td>6.6 ± 3.2</td>
<td>54.4 ± 5.0</td>
<td>58.1 ± 5.5</td>
</tr>
<tr>
<td>Males</td>
<td>17.7 ± 8.6</td>
<td>17.3 ± 5.6</td>
<td>10.1 ± 9.9</td>
<td>13.1 ± 4.5</td>
<td>16.3 ± 17.2</td>
<td>7.4 ± 2.3</td>
<td>56.0 ± 4.6</td>
<td>62.2 ± 2.4</td>
</tr>
<tr>
<td>Females</td>
<td>24.1 ± 4.5</td>
<td>24.5 ± 2.5</td>
<td>14.7 ± 4.9</td>
<td>15.6 ± 3.8</td>
<td>7.3 ± 2.5</td>
<td>5.7 ± 4.0</td>
<td>52.8 ± 5.4</td>
<td>54.0 ± 4.5</td>
</tr>
</tbody>
</table>

1 Classic Swing
2 Choke-grip Swing

Analysis of the kinematic data showed that both the classic drive and the choke grip drives resulted in the peak rotational speed of the stick occurring *before impact*. Examples of swings in which peak stick speed occurred prior to ball impact are apparent in the kinematic sequence graphics provided as Figures 4.1, 4.2 and 4.3.

Data describing the time at which stick rotation speed peaked before impact are provided in Table 4.4. In the classic drive, the time at which stick speed peaked before impact averaged 29.3 ± 13.8ms. For the choke grip drive, the time at which stick speed peaked before impact averaged 22.8 ±14.9ms. There were no significant differences in pre-impact peak stick speed timing between swings and between genders.

Table 4.4: Time (ms) the stick reached its peak rotational speed, pre-impact.

<table>
<thead>
<tr>
<th>Peak, Pre-Impact</th>
<th>Classic</th>
<th>Choke-Grip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>29.3 ± 13.8</td>
<td>22.8 ± 14.9</td>
</tr>
<tr>
<td>Males</td>
<td>26.4 ± 15.9</td>
<td>21.0 ± 13.5</td>
</tr>
<tr>
<td>Females</td>
<td>32.2 ± 12.5</td>
<td>24.6 ± 17.5</td>
</tr>
</tbody>
</table>
Although the focus of this study was on the sequencing of the body segment actions during field hockey swings, select positional variables were analyzed to explore elements of these sequences. Average pelvis, thorax, and spine (pelvis-thorax link) rotation angles for both the classic and choke grip swings are described for the total group, and separately for males and females, in Table 4.5. As shown, pelvis, thorax and spine rotations between the classic and choke grip swings were remarkably similar. Females demonstrated greater average pelvis rotations in the backswing than males, in both swing types, but the differences were not statistically significant.

Table 4.5: Peak rotations for the pelvis, thorax, and spine for a classic swing and a choke-grip swing.

| Rotations (deg) | Pelvis  
|:---------------|:---
| Total          | 69.2 ± 19.5 | 68.3 ± 23.2 | 96.2 ± 19.1 | 95.4 ± 19.4 | 35.3 ± 12.2 | 38.4 ± 13.9
| Males          | 62.6 ± 23.3 | 63.7 ± 24.6 | 97.0 ± 22.5 | 98.2 ± 25.1 | 41.7 ± 7.8  | 44.4 ± 10.8
| Females        | 75.8 ± 14.4 | 72.9 ± 24.6 | 95.3 ± 17.6 | 92.6 ± 14.0 | 28.8 ± 13.1 | 32.4 ± 15.2

1 Classic Swing  
2 Choke-grip Swing

Transition timing involving the segments in the captured field hockey swings was quantified. Transition timing describes the time (in msec) between adjacent segment reversals of motion occurring about the top of the backswing. The presence of a transition time delay between adjacent segments generally represents augmented coil in the backswing to downswing “transition,” theorized to be a powerful move in the overall sequence. Transition timing is provided in Table 4.6.

As indicated in Table 4.6, the largest transition time (msec) for both swing types occurred between the pelvis and the thorax, while the shortest transition time occurred
between the arms and the club. The same can be said when comparing the transition
times of each swing between genders. Transition times were not statistically significant
between swing types, and between genders.

Table 4.6: Transition times (msec) across the segments.

<table>
<thead>
<tr>
<th>Transition Times</th>
<th>Plv-Thx&lt;sub&gt;1&lt;/sub&gt;</th>
<th>Plv-Thx&lt;sub&gt;2&lt;/sub&gt;</th>
<th>Thx&lt;sub&gt;1&lt;/sub&gt;-Arm&lt;sub&gt;1&lt;/sub&gt;</th>
<th>Thx&lt;sub&gt;2&lt;/sub&gt;-Arm&lt;sub&gt;2&lt;/sub&gt;</th>
<th>Arm&lt;sub&gt;1&lt;/sub&gt;-Clb&lt;sub&gt;1&lt;/sub&gt;</th>
<th>Arm&lt;sub&gt;2&lt;/sub&gt;-Clb&lt;sub&gt;2&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>47.4 ± 48.5</td>
<td>62.7 ± 70.5</td>
<td>23.6 ± 19.2</td>
<td>30.6 ± 38.3</td>
<td>5.6 ± 14.7</td>
<td>3.8 ± 14.2</td>
</tr>
<tr>
<td>Males</td>
<td>42.3 ± 61.0</td>
<td>54.3 ± 41.8</td>
<td>32.9 ± 23.3</td>
<td>42.1 ± 51.3</td>
<td>0.4 ± 18.4</td>
<td>0.4 ± 17.5</td>
</tr>
<tr>
<td>Females</td>
<td>52.4 ± 38.9</td>
<td>71.0 ± 96.2</td>
<td>14.3 ± 8.5</td>
<td>19.0 ± 18.2</td>
<td>11.0 ± 11.0</td>
<td>7.2 ± 10.7</td>
</tr>
</tbody>
</table>

1 Classic Swing
2 Choke-grip Swing

Because field hockey players are noticeably in a more flexed posture at address
and at impact compared to golfers, torso flexion at both address and impact in our
subjects was quantified, and compared to golfers. On average, total group torso flexion at
address was 47.8 ± 12.0 degrees in the classic drives, and 48.5 ± 10.1 degrees in the
choke grip drives. When separated between males and females for the classic drive, torso
flexion at address was 48.0 ± 17.2 degrees and 47.7 ± 5.4 degrees, respectively. When
separated between males and females for the choke grip drives, torso flexion at address
was 48.1 ± 13.1 degrees and 48.9 ± 7.6 degrees, respectively. There was no difference in
torso flexion at address, assessed between the drive types and between males and
females.

At impact, total group torso flexion in the classic and choke grip drives were 47.7
± 10.3 degrees, and 50.2 ± 9.9 degrees, respectively. Males demonstrated a torso flexion
at impact of 45.1 ± 13.7 degrees in the classic drive and 47.8 ± 12.1 degrees in the choke
grip swing. In females, torso flexion at impact for the classic drive averaged 50.3 ± 5.9
degrees, and 52.6 ± 7.9 degrees in the choke grip swing. There was no significant difference calculated across the swing types and between males and females.

Again, torso flexion at address for these field hockey swings was compared to torso flexion at address in professional golfers (developed from a PGA and LPGA database built into the AMM 3D software package). Flexion at address in golf swings for male professional golfer’s averages 20.5 ± 7.5 degrees (N=10). When compared to the male values for the classic grip field hockey swings, the differences were statistically significant (t (13) = 3.42; p = 0.0046). Compared to the male choke-grip swing, the differences were also statistically significant (t (13) = 4.35; p = 0.00078).

Flexion at address for female professional golfer’s average 20.7 ± 6.9 degrees (N=6). When compared to the values for the classic grip field hockey swing, the differences were statistically significant (t (9) = 7.27; p < 0.0001). When compared to the females using a choke-grip swing, the differences were also statistically significant (t (9) = 6.39; p = 0.00013). Male and female field hockey players flex forward at the torso at address, using either the classic or choke grip swing techniques, much more than professional golfers.

At impact, torso flexion of male professional golfers averages 31 +/- 7 degrees (N=10). Compared to the male values for the classic grip field hockey swings, male professional golfers have less torso flexion. This decreased torso flexion in male golfers was also seen when compared to the choke-grip field hockey swing.

Torso flexion at impact for female professional golfers averaged 34.8 ± 9.3 degrees (N=6). When compared to the classic field hockey drive, female field hockey
players had an average torso flexion that was larger than the LPGA golfers. This increase in torso flexion was also noted in the choke-grip field hockey swing when compared to female professional golfers. Male and female field hockey players flex forward at the torso at impact, using either the classic or choke grip swing techniques, much more than professional golfers.

4.2 Discussion

In field hockey, the purpose of classic grip and choke-grip drives is to send the ball either across the pitch, or at high speed toward the goal. To have a shot that has both power and accuracy, it is important to have energy transferred effectively from the largest body segments (legs and pelvis) through the torso, shoulders and arms to the field hockey stick. Therefore, an ordered kinematic sequence, extensively researched and expressed in good players in golf swings, would be logically beneficial in field hockey swings.

Observation and analyses of both the classic and choke-grip drives in our study show that while kinematic sequencing of the field hockey swings involves some variability in segment speed ordering, a large proportion of field hockey players performing both the classic grip and choke-grip drive use standard proximal to distal sequencing (1-2-3-4). Peak segment rotational speeds during both the classic and choke-grip drives, occurring dominantly in proximal to distal order, and are a perfect representation of Bunn’s Summation of Speed Principle (Bunn, 1972).

As the downswing progresses from the top of the swing to impact, there is a successive increase in rotational peak speed of each segment. This transfer of energy from the larger segments to the smaller segments allows for the highest speed achievable
at the free endpoint in the linked system; at the stick. This transfer of energy reflects the kinetic-link principle described by Kreightbaum and Barthels (1985). Like golf, rotation speed gains (increases observed between adjacent segments) build from proximal to distal, with the greatest speed gains occurring across the wrists. The field hockey swing does indeed involve sequential actions of the body segment, much like golf, baseball batting, throwing.

Some of the field hockey downswing sequences observed in our study deviated from the classic pelvis (1), thorax (2), arms (3), stick (4) order. Notably, however, downswing sequences not involving a 1-2-3-4 sequence have also been reported in golfers, even professionals. Cheetham and Broker (2016) reported that only 25% of PGA and 39% of LPGA players demonstrate a classic proximal-to-distal sequencing. They also reported pelvis-arms-torso-club and pelvis/arms-torso-club sequencing in 41% of PGA players and 19% of LPGA players. Often this non-standard sequencing emerges because segment peak velocities often occur just milliseconds apart, and thus slight timing differences can alter the peak ordering (especially in the 1-2-3-4 versus the 1-3-2-4 sequences).

Further on this point, our data show that in the majority of swings tested, peak stick rotational speed (and thus stick head velocity) was measured prior to ball impact. This contrasts with observations in golf, where in good players, peak club rotational speed and thus clubhead speed occur virtually coincident with ball impact.

When peak stick velocity occurs some time prior to ball impact, the chance that a peak segment speed involving a proximal segment or segments, such as the arms and
thorax, occur after peak stick speed naturally increases. Such an effect of early peak stick speed on sequencing is seen in Figure 4.2. Due to the early occurrence of peak stick speed, the sequence represented in Figure 4.2 became 1-4-3-2; or pelvis-stick-thorax-arms.

Why field hockey players might decelerate their sticks prior to ball impact is certainly of interest. One logical and reasonable explanation for such deceleration involves how the game is played. In field hockey, the follow-through of the swing is limited to the height of the player’s pelvis. Any swing finishing higher than the player’s pelvis is considered dangerous play and results in a turnover to the opposing team (International Hockey Federation, 2016). When thinking about our data and comparing our observations to live play, it became clear that peak stick head velocity occurring prior to impact could be due to the player restricting their follow-through to prevent their stick from rising higher than their pelvis. Abbreviated follow-throughs could also explain the dominance in the wrists’ contribution to stick rotational speed, also observed in our study. In the attempt to control the follow-through, but still maintain accuracy, the wrists may assume an increasingly important role. Further investigation of our data will address this finding, including a check on stick sensor accuracy in low (near the ground plane) stick positions.

Cheetham and Broker (2016) reported that during the downswing, PGA golfers exhibited a higher segmental contribution to clubhead speed (speed gains) from dynamic wrist actions when compared to their counterparts in the LPGA, who demonstrated a larger contribution coming from the pelvis. The dynamic wrist actions allowed the PGA
golfers to increase the angular velocity of their club swing, resulting in a significant increase in club head speed.

When comparing the PGA data to our data collected from the two field hockey swing types, we see similarities in the main contributor of the swing coming from the wrists. The reported PGA observations are similar to the findings of our study. The wrists were determined to be the largest contributor to the swing in both the classic grip and choke-grip drive. When we separated the swings out by style, however, statistically significant contributions of the wrist emerged only in the choke-grip swing.

In relation to an actual game scenario, it makes sense to have the dominant wrist swing contribution coming in the choke-grip drive. This is due to the use of this swing during an offense/defense challenge, when the player must get a shot off quickly with little time for swing preparation (Brétigny et al., 2008). As Brétigny and colleague described, the choke-grip swing can be adjusted for direction and accuracy at the finish, which is where the wrists logically come into play. Our study also confirmed the shorter backswing and the longer finish durations seen in the choke-grip drive, as described by Brétigny et al. (2008).

Comparison of torso flexion angles between the field hockey swings and the golf swings proved to be informative. Field hockey players adopt a more flexed torso position at address than golfers, and they maintain this more flexed posture through impact. This is understandable, since the golf swing at address and impact involves a more upright stance – commensurate with longer clubs. In field hockey, the player’s center of gravity is closer to the ground, accomplished using significant flexion in the torso and the knees.
The lower position of play for the field hockey player allows for more control of the ball, adaptive to the many type of shots/passes/redirections employed.

The lower position of field hockey players also prevents lofting of the ball (an undesired shot outcome). In fact, prematurely rising, or “popping up” out of a field hockey swing is a common swing fault, which tends to cause excessive lifting of the ball. Excessive lift of the ball is not permitted (the ball must remain lower than the knees), unless it is a direct shot on goal or a long pass executed into open field space, without opponents in the immediate vicinity of the shot. Such a shot is termed an aerial.

As developed in golf swing research, intersegmental transitions before impact appears to be crucial for the build-up of energy in the multi-link system. Much like the spring and disk model described by Cochran and Stobbs in 1968, the muscle groups need time to be “loaded,” to produce the most power and transfer energy efficiently. The large transition times between the pelvis and the thorax observed in our study sets up the stretch-shorten cycle (torso coil and recoil) believed to be so powerful in golf swings. This allows the more proximal muscle groups the opportunity to transfer as much energy into the system as possible. As the swing progresses, the more distal segments transition faster, or closer together in time, logically due to the decrease in the mass of the moving segments. This allows for the final segment (the field hockey stick) to have the highest club velocity possible for the swing.

In conclusion, our hypothesis regarding the classic proximal to distal sequencing in field hockey was supported. The field hockey classic and choke grip drive swings are not that dissimilar to golf swings, with respect to the smooth, coordinated
accelerations/decelerations of segments, dominantly occurring in a proximal to distal sequence during the downswing. Deviations from the classic proximal to distal sequence occurred in our study, quantitatively and logically in response to an abbreviated follow-through in field hockey swings.
CHAPTER V
LIMITATIONS AND FUTURE IMPROVEMENTS

This study confirmed the existence of proximal to distal segment sequencing in classic and choke grip drives in experienced field hockey players. Slight differences between field hockey swings and golf swings, connected both with sequencing (based on peak stick speed timing) and posture were exposed as well. As is often the case with sport performance analyses, several limitations to the study exist.

First, the subject population was small. Only ten total subjects were tested and analyzed; five males and five females. Although trends in the data were apparent regarding male and female differences, variations between swing types, and differences between field hockey swings and golf swings, many comparisons lacked the statistical power to expose suspected effects. More subjects from both genders would strengthen the study of field hockey swings.

Second, we only tested high level players from a single club team in Colorado Springs. While this team is nationally competitive, all the subjects train under the same coach, and thus may have developed similar swing techniques. The analysis of more players from different teams involving a wider range of ability levels would permit a wider exploration of the kinematic issues studied, facilitating a more comprehensive generalization of the findings to a broader field hockey player population.

Third, the AMM 3D sensor system used in the study limits the examination of field hockey swings to relatively stationary swing types. The similarities between golf swings and field hockey swings are not surprising, given the type of field hockey swings
studied. Full running and pivoting swings, common in the sport, were not analyzed in this study, and could not be due to limitations in the electromagnetic (Polhemus) motion capture system. Use of a motion capture system capable of capturing player in 3D movements in running and pivoting situations would broaden the analysis of field hockey biomechanics to a wider variety of swing types.

The AMM 3D sensor system used in this study also required a start position for each swing with the stickhead immediately behind the ball, to determine the ball’s location in space and to identify where impact occurs. Use of a motion capture system capable of capturing swings not starting at the ball (some players start a penalty stroke with their stick poised in the air) would broaden the depth of the biomechanical study.

Fourth, we assumed that the swings performed by the subjects in the study were “typical” field hockey, classic and choke grip drives, representative of what these players would use in a game situation. Performing drives in a swing laboratory, outside of game conditions, has the potential to influence player swing techniques. Extrapolation of our data directly to game type situations should be done with our test conditions and possible effects in mind.

Finally, an area of future study, suggested by our findings and presently lacking in the field hockey scientific literature, involves wrist kinematics. Little is known about the 3D actions of the wrists in field hockey drives. Wrist kinematic parameters of interest include flexion/extension, radial/ulnar deviation, and pronation/supination, expressed throughout both the backswing and downswing. The AMM Polhemus system we
employed to study field hockey swing sequencing has the capability to study these wrist motions, and thus wrist kinematic analyses may be a near term research direction.
REFERENCES


APPENDICES

A. ADDITIONAL GRAPHS

Figure A.1: Sequencing distribution of the downswing in classic drives in males. The 1-2-3-4 sequence represents the standard pelvis (1), thorax (2), arms (3) and stick (4) sequence.

Figure A.2: Sequencing distribution of the downswing in classic drives in females. The 1-2-3-4 sequence represents the standard pelvis (1), thorax (2), arms (3) and stick (4) sequence.
Figure A.3: Sequencing distribution of the downswing in choke-grip drives in males. The 1-2-3-4 sequence represents the standard pelvis (1), thorax (2), arms (3) and stick (4) sequence.

Figure A.4: Sequencing distribution of the downswing in choke-grip drives in females. The 1-2-3-4 sequence represents the standard pelvis (1), thorax (2), arms (3) and stick (4) sequence.
B. INSTITUTIONAL REVIEW BOARD APPROVAL

University of Colorado
Colorado Springs

Institutional Review Board (IRB) for the Protection of Human Subjects

Date: 11/1/2017

IRB PROTOCOL NO.: 18-031
Protocol Title: Variation in the field hockey swing explained by the kinematic sequence
Principal Investigator: Andrea Davaro
Faculty Advisor if Applicable: Jeff Brooker
Application: New Application
Type of Review: Expedited 7
Risk Level: No more than Minimal Risk
Reduction of Risk Level: (If changed from original approval) if Applicable: N/A No Change
This Protocol involves a Vulnerable Population: N/A (No Vulnerable Population)
Expires: 31 October 2018
*Note, if exempt: If there are no major changes in the research, protocol does not require review on a continuing basis by the IRB. In addition, the protocol may match more than one review category not listed.
Externally funded: ☐ No ☐ Yes
OSF #: Sponsor:

Thank you for submitting your Request for IRB Review. The protocol identified above has been reviewed according to the policies of this institution and the provisions of applicable federal regulations. The review category is noted above, along with the expiration date, if applicable.

Once human participant research has been approved, it is the Principal Investigator’s (PI) responsibility to report any changes in research activity related to the project:
- The PI must submit all protocol, recruitment, advertising, and consent form amendments/revisions to the IRB for approval.
- The IRB must approve these changes prior to implementation.
- If you are a student, please note that it is required to include the IRB approval letter to the library when you submit the dissertation/thesis.
- The PI must promptly inform the IRB of all unanticipated serious adverse (within 24 hours). All unanticipated adverse events must be reported to the IRB within 1 week (see 45 CFR 46.103(b)(5)). Failure to comply with these federally mandated responsibilities may result in suspension or termination of the project.
- Renew study with the IRB at least 10 business days prior to expiration.
- Notify the IRB when the study is complete.

If you have any questions, please contact Research Integrity Specialist in the Office of Sponsored Programs and Research Integrity at 719-255-3903 or irb@uccs.edu

Thank you for your concern about human subject protection issues, and good luck with your research.

Sincerely yours,

Michele Okun, Ph.D.
IRB Reviewer

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