LEARNING AN ONTOGENETIC SKILL: A CONSTRAINTS APPROACH

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A Thesis for the Degree
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TABLE OF CONTENTS

Chapter I

Chapter II

Chapter III

Chapter IV

Chapter V

CHAPTER ONE

Introduction

Historically, complex motor skills have been acquired by breaking down the task into simpler component parts. Traditionally, motor learning specialists have indicated that each part of the skill be taught separately before attempting the entire skill (Naylor & Briggs, 1993). Ontogenetic skills are examples of complex skills that are typically taught in parts before attempting the entire skill. In addition to instructing in parts, ontogenetic skills traditionally require extrinsic feedback specific to the performance in order for development to take place (Gallahue, Ozmun, & Goodway, 2012). Alternatively, phylogenetic skills can develop without augmented information and may not require reducing the task into component parts. Examples of phylogenetic skills would be fundamental skills such as reaching, grasping, throwing, and jumping. Examples of ontogenetic skills would be a tennis forehand, or a golf drive. Ontogenetic skills are influenced by one's culture or environment while phylogenetic skills develop regardless of the individual's culture or environment.

Traditional viewpoints regarding instruction fail to address how phylogenetic skills can develop without specific extrinsic feedback, modeling, or breaking the skill into component parts (Kelso, 1995). A more recent perspective (Dynamic Systems) regarding skill performance addresses the issue of skill development without extrinsic feedback and also questions whether there is a need for instructional differences for ontogenetic and phylogenetic skills. The Dynamic Systems perspective utilizes the Haken-Kelso-Bunz (HKB) model of motor pattern change to address the issue of skill development (Haken, Kelso, & Bunz, 1985). A dynamic system is any system that experiences change over time (Crutchfield, Farmer, Packard, & Shaw, 1987). According to the HKB model, change occurs when constraints reach a critical value that causes variability in the system allowing for a new behavior to emerge. A constraint can be defined as any variable that affects a dynamic system. Constraints are information to the system and also set boundaries for behaviors. Constraints both limit and enable motor patterns. The sources of constraints come from the individual, environment, and goal of the task (Newell, 1985). The critical value is the scale value at which a system must assume a form different from its original or stable pattern (Kugler, Kelso, & Turvey, 1982). When constraints reach a critical value they are called control parameters. Control parameters do not control anything, but rather, allow the motor pattern to change (Kugler, et al, 1982). All control parameters come from constraints but not all constraints will become control parameters. The identities of new patterns are determined by an order parameter. An order parameter is a mechanical principle related to the function of the movement. Stable patterns of movement are called attractor states. An attractor state is a pattern that the system falls into easily and returns to even when perturbed or interrupted (Kamm, Thelen, & Jensen, 1990).

A golf drive is an excellent example of what biomechanists and motor learning specialists would define as a complex motor skill (Dillman & Lang, 1994; Nesbit & McGinnis, 2009;). Although a golf swing involves the phylogenetic task of striking, the complexity of the skill makes it an ontogenetic skill. Consequently, from a learning standpoint, the popular opinion is that individuals cannot learn a proper golf drive without instruction (Lindsay, Versteegh, & Vandervoort, 2009). Dynamic systems proponents have a different point of view. Dynamic systems theorists do not draw a distinction between phylogenetic and ontogenetic skills. Ontogenetic skills can be learned without specific instruction if the proper constraints are applied during practice. From a dynamic systems perspective, scaling up on constraints, in the absence of specific instruction, could allow the performer to change motor pattern toward a more skillful performance.

The motion of a golf swing takes advantage of the same mechanical principle (order parameter) as other projection skills such as throwing or striking (Putnam, 1993). The open kinetic chain is the likely order parameter that allows for the transfer of angular momentum in a proximal to distal sequence down an open-linked system of segments represented in projection skills (Putnam, 1993). According to the HKB model of motor pattern change, scaling up on appropriate constraints should allow the system to take better advantage of the order parameter thereby increasing skill level.

In order for the golfer to take maximum advantage of the open kinetic chain (order parameter) the trunk should reach peak velocity first followed in order by the shoulder, elbow, and wrist joints. The club is the last link in the open kinetic chain. The system attempts to conserve angular momentum ($A.M. = I \times \omega$) generated by the angular velocity of the more proximal segments. When momentum is transferred from a proximal segment to its distal neighbor there is an increase in the distal joint velocity because the moment of inertia of the distal segment is less and the momentum generated by the more proximal segments is conserved (Myers, Lephart, Tsai, Sell, Smoliga, & Jolly, 2007). There are no studies that have examined whether the use of the order parameter for a golf drive can improve by focusing on constraints rather than receiving specific instruction regarding the motor pattern itself.

Purpose of the Study

The purpose of this study is to determine if goal constraints (velocity of swing and accuracy) are control parameters that change the motor pattern of a golf drive (ontogenetic skill) for inexperienced golfers.

Hypotheses

The hypotheses are that: 1) increasing speed of swing without instruction will improve swing pattern by increasing the number of joints experiencing distal lag; 2) focusing on accuracy will inhibit use of the open kinetic chain by decreasing the number of joints experiencing distal lag; and 3) increasing velocity of swing will result in an increase in the number of joints experiencing distal lag in a retention session following practice.

CHAPTER TWO

Literature Review

This literature review includes a discussion of dynamic systems and motor pattern change, instructional strategies in relation to a constraints approach, and the mechanics of a golf drive.

Dynamic Systems and Motor Pattern Change

Dynamic systems are self-organizing and do not require the storage of a program or schema to create or change a movement pattern. Patterns change when constraints reach a critical value and become control parameters that facilitate the formation of a new motor pattern (Haken, Kelso, & Bunz, 1985). Constraints may come from the environment, the individual, or a goal related to a given task. Environmental constraints come from the context in which an action takes place or the constraints resulting from a performance environment. For example, terrain and elevation changes to a running environment can affect an exerciser's gait pattern. Individual constraints originate within the performer. For example, increased leg strength can allow for the base of support to narrow when walking, allowing infants to use a more adult pattern (Adolph, Vereijken, & Shrout, 2003). Goal constraints are variables that occur as a result of movement specifications. If the goal of the movement is changed then the pattern could change as well. For example, a goal constraint could require a performer to complete a task with greater speed and or more accuracy (Thelen, 1985).

Constraints. Constraints have been identified in studies where the manipulated variables affect the motor patterns of fundamental skills. Thelen (1986) demonstrated an individual constraint by placing 7-month-old infants in an upright supported position on a stationary and a moving treadmill. Infants were marked at critical joint locations with white tape. The markers were digitized to determine joint angular displacement. Infants were video-taped while walking by using high-speed photography over a 2-minute period. An uncharacteristic adult-like walking pattern emerged in the infants on the supported treadmill. Thelen (1986) concluded that the support was an example of increasing an individual constraint (balance), which allowed for a more mature walking pattern. Southard (1998) demonstrated how a goal constraint of velocity could affect the motor pattern of a throw. Twenty male volunteers were grouped depending on throwing proficiency. Throwing proficiency was defined by use of the open kinetic chain. Throwers were placed in four levels of proficiency based on the number of distal segments that lagged behind their proximal neighbors. Each participant threw a baseball size ball 10 times at four different velocities (25%, 50%, 75%, and 100%). Southard (1998) determined that lower level throwers increased their throwing proficiency (use of the open kinetic chain) when increasing throwing velocity. High-level throwers maintained their high-level of proficiency (complete use of the open kinetic chain) except when throwing at 100% effort. At 100% effort the high level throwers decreased in throwing proficiency. Southard (1998) explained this finding by indicating that velocity is a control parameter for throwing and that high level throwers cannot improve throwing pattern. Therefore, when reaching a critical value of 100% effort the throwing pattern of skilled throwers had no option but to reduce effectiveness. Southard (2011) also demonstrated that focusing on the constraint of velocity increased the level of throwing pattern better than instruction that focused on either internal or external variables important to performance. It is important to realize that neither Southard nor Thelen provided any extrinsic feedback to participants and scaled up on constraints to initiate a pattern change. The lack of extrinsic feedback accompanied by an increase in skill level supports the use of the HKB motel when describing motor pattern development.

Pattern Change. For most skills, change in pattern cannot occur without pattern variability (Schöner, 2008). Constraints that become control parameters create instability in patterns and allow for change to a new attractor state. New patterns are due to a change that instigates an initial period of instability that allows the system to reach a critical value and abandon an old motor pattern. Schöner and Kelso (1988) demonstrated how a change to a new movement pattern is preceded by an increase in variability. The researchers required participants to move their index fingers rhythmically in an anti-phase movement. That is, when one index finger is extended in the transverse plane the other index finger is flexed in the same plane. When participants scaled up on the constraint of velocity their fingers reached a critical value. At the critical value there was a period of instability where one finger oscillated in and out of in-phase and anti-phase. Following the period of instability both fingers shifted to an in-phase mode (both fingers flexed and extended at the same time). Beyond the critical value participants could not prevent their fingers from moving in an in-phase rhythmic pattern. The constraints placed on the system allowed for a reconfiguration of the motor pattern. This same approach has been used with a phylogenetic skill. Southard (2002) demonstrated increased variability in throwing pattern as participants reached a critical throwing velocity. Southard (2002) required 36 children ages 6 to 12, at varying skill levels, to complete five overhand throws at 10 relative velocities (10% to 100% in 10% increments). He determined that as throwing velocity increased a more efficient use of the order parameter (the open kinetic chain) was preceded by variability in throwing pattern. Variability was identified by a deviation from the original throwing pattern. He determined that critical values of velocity for throwing differ by joint and skill level.

Order Parameter. When a change occurs the new pattern attempts to take advantage of a mechanical principle known as an order parameter. For example, when throwers were asked to increase throwing velocity their pattern changed when velocity reached a critical value (Southard, 2002). The change in pattern allowed the thrower to take better advantage of the order parameter (open kinetic chain). When treadmill velocity was increased to a critical value, infants displayed a more mature walking pattern by taking advantage of the order parameter – pendular action of the legs (Thelen, 1985). Index fingers moving in an anti-phase rhythm underwent instability when frequency reached a critical value and the new pattern (in phase movement) adhered to the order parameter (Schöner & Kelso, 1988). Brown and Jensen (2006) determined that children could reach an adult cycling pattern when mass is added to the thigh and shank of the cyclist. Results indicated that the added mass altered the angle and magnitude of the muscle forces applied to the pedal. The angle of the muscle force vectors applied to the pedal shifted from between 210 and 270 degrees to 210 and 300 degrees. The added mass produced muscle pedal-force magnitudes that were closer to the pedal-force magnitudes collected for adults. In addition, added mass resulted in a shift from downward push to upward pull, which is characteristic of an adult pattern.

Recent Instructional Strategies and Constraints Approach

Recent evidence indicates that it is not just extrinsic feedback (information from a coach or instructor) that is important to learning ontogenetic skills – the learner's focus of attention can determine the efficacy of such information. Typically, extrinsic feedback is focused on the specifics of performance, which is called internal focus. Extrinsic feedback that focuses on the outcomes of the movement has been termed external focus. A consistent finding is that focusing on external factors such as the outcome of the movement results in more effective skill learning (Marchant, Clough, Crawshaw, & Levy, 2009; Wulf & Dufek, 2009; Wulf, McConnel, Gartner, & Schwarz, 2002; Wulf, Shea, & Park, 2001). The explanation by Wulf and colleagues concerning increased skill level by focusing on external components is the Constrained Action Hypothesis (CAH). Constrained Action Hypothesis indicates that external focus allows the motor system to focus on the outcome of the movement without disrupting the natural progression of skill development (Wulf, Shea, & Park, 2001). Internal focus forces the learner to concentrate on specific elements of the task, which are oftentimes out of the natural sequence of learning the skill. When instruction does not follow the natural sequence learning is impaired. In one experiment EMG readings show that not only is performance increased with external focus but there is an increase in motor unit recruitment related to the task (Zachry, Wulf, Mercer, & Bezodis, 2005). Fourteen university students were recruited to shoot 20 free throws from a distance of 15ft and a hoop height of 10ft. Subjects were asked to shoot 10 shots while focusing on the internal "snapping" motion of their wrist and 10 shots while concentrating externally on the center of the back of the basketball hoop. EMG recordings were collected by placing electrodes on the medial biceps brachii, the long head of the medial triceps brachii, the medial deltoid, and the medial flexor carpi radialis of each participant's shooting (preferred) arm. Movement was also captured with a video recorder and recorded with Vicon Motion Analysis system software. Their study not only confirmed that external focus resulted in greater task performance but external focus also resulted in more effective muscle recruitment.

Wulf, et al (2001) completed two studies to determine if undergraduate women and undergraduate men preferred external focus or internal focus. In experiment one, subjects were exposed to both types of attentional focus while performing a balancing task on a balance board. Subjects were told to focus on their feet (internal) or to focus on a marker (external) located on the board. The same subjects were brought in a second day and prompted to select which form of focus they preferred. They were interviewed following the second day to determine which form they had used to balance. Results indicated that more people preferred an external rather than internal focus. In experiment two, subjects were allotted two days to test out both forms of internal and external focus. On the third day they were asked to select a preferred an focus method. Once again the majority of subjects preferred external focus. Performance results also indicated that subjects using an external focus performed at a higher level than those who selected internal focus.

Marchant, Clough, Crawshaw, & Levy (2009) completed a study with 72 novice dart throwers to determine instructional preference. Instruction was intended to give subjects an internal or external focus. On this first day subjects were given both sets of instructions. On the second day both sets of instructions were given but accuracy increased significantly in trials using external focusing instruction. Bell and Hardy (2009) determined that external focus is not only the preferred method of focus but also yields the best results over practice. The researchers placed 33 skilled male golfers in one of three conditions, one internal and two external. The internal condition required golfers to focus on wrist hinge during club swing. The two external conditions required golfers to focus either on the clubface through the swing keeping it square, or focus on ball flight post impact. All golfers performed 3 blocks of 10 chip shots towards a target 20 meters away. The ball flight focus group performed significantly better than the other two groups. The clubface external focus group performed significantly better than the internal focus group.

Dynamic systems takes the logic behind constrained action hypothesis to the extreme. That is, external focus reduces information specific to performance by focusing on the outcome of the movement. The external focus allows the motor system to progress naturally without interference from specific pattern information. However, oftentimes the external focus contains information concerning the pattern of movement. For example, Wulf et al (2002) required volleyball servers to focus on moving their serving limb like a whip. Whereas, the focus was on the outcome of the movement, the whip-like example still represented information concerning movement pattern. Consider that focusing on a constraint contains no information concerning movement pattern. Constraints are not related to the pattern of movement. Southard (2011) determined that focusing on the goal constraint of increasing throwing velocity resulted in significantly greater use of the order parameter than external focus following six throwing practice sessions. Thirty university students (ages 19 – 26 years, 13 males and 17 females) were placed in one of six conditions (Internal Focus Only, External Focus Only, Velocity Only, Control, Internal Focus Plus Velocity, and External Focus Plus Velocity). Subjects completed six practice sessions consisting of 15 throws with the non-dominant arm followed by a retention session (with no instruction) one week after the last practice session. Motor pattern data was collected with a Vicon Peak Motus Motion Analysis System. The control group began taking advantage of the order parameter and external focus at session four, internal focus at session five. The conditions that included focusing on the control parameter of velocity took advantage of the open kinetic chain for all six-practice sessions. Southard indicated that scaling up on a constraint provides compatibility between the task demands and the intrinsic dynamics of the performer.

Mechanics of Golf Drive

The striking motion of a golf swing can be compared with other projection motions such as throwing or kicking (Putnam, 1993). The order parameter for projection skills is likely the open kinetic chain. The open kinetic chain allows for the transfer of angular momentum down an open-linked system of segments, which end in a free moving distal segment (Putnam, 1993). This transfer results in an increase in the velocity of the most distal segment in the link of segments. Southard (2002) described the nature of such segmental interaction for throwing. Angular momentum is conserved as distal segment mass decreases causing an increase in velocity in the more distal segments. The increase in velocity as angular momentum is transferred distally is a result of the more distal segments lagging behind their proximal neighbors.

Neal and Wilson (1985) provide evidence regarding the use of an open kinetic chain during a golf drive. They collected three-dimensional kinematic data on four professional golfers and two low-handicap amateur golfers. Golfers were asked to hit the ball for both distance and accuracy. Markers were used to create a 3D representation of segments (Abdel-Aziz & Karara, 1971). Results indicated that the less massive, distal segments, such as the arm, reached peak acceleration after the more massive proximal segments, such as the trunk. Their three-dimensional analysis of a golf swing demonstrated proximal to distal lag and proximal to distal increases in velocity.

The relationship between torso-pelvis separation and ball velocity has been demonstrated (Myers, Lephart, Tsai, Sell, Smolia, & Jolly, 2008). The stretch between torso and pelvis is referred to as the “x-factor” and is an example of an initial link in the open kinetic chain. One hundred experienced golfers were fitted with markers and instructed to swing at a golf ball a total of 10 shots off an artificial turf tee into a projected practice range. Swing biomechanics were recorded with the Peak Motus System and ball flight was assessed with the Flight Scope Sim Sensor integrated with About Golf simulation software. The researchers found that an increase in upper torso and pelvis rotation increased club and ball speed. The “x-factor” was measured at four points during the swing; the top of the swing, lead arm parallel during the downswing, the point at the last 40 ms before impact, and impact. A greater “stretch” between torso and pelvis was found to effect ball velocity positively and increase torso-pelvic rotation during the downswing. An increase in angular velocity from segment to segment results in an overall increase in the velocity of the most distal segment (the club). Increasing torso-pelvic separation maximizes the opportunity for generating more energy via the transfer of angular momentum through the open kinetic chain and an increased performance of the golf drive.

Chu, Sell, and Lephart (2010) examined the swing kinetics and corresponding ball velocities of 308 golfers. Golfers were outfitted with light reflective markers and recorded with cameras controlled by The Peak Motion System. After a warm up, golfers hit 10 shots off an artificial turf tee into a projected practice range image. They searched for similarities across golfer that might contribute to driving ball velocity. Increasing the pelvic-torso separation delayed the initiation of movement in more distal segments, which contributed to a maximized use of the open kinetic chain used in a golf drive. The "x-factor", or the pelvic-torso separation, was found to be a significant contributor to ball velocity.

The following overview of a golf swing emphasizes the complexity of the task and why more traditional learning specialists insist that specific instruction is required to learn the skill. A golf drive is typically broken down into four main components; the set-up, backswing, downswing and follow-through. According to Geisler (2001), for the set up the body should be slightly flexed forward at the knees and waist while weight should be focused on the back foot. A forward bend in the waist will increase acceleration of the swing (Chu, et al., 2010). The backswing stretches the body and contributes to the generation of potential energy prior to the downswing. It is during this setup that the golfer takes advantage of the "x-factor" (Hume, Keogh, & Reid, 2005). Next, the downswing allows the golfer to make contact with the ball while reaching peak acceleration at contact (Nesbit & McGinnis, 2009). The accelerating portion of the downswing is initiated by the uncoiling, or reversal, of the pelvis, torso, arms, hands and club (Meister, Ladd, Butler, Zhao, Rogers, Ray, & Rose, 2011). The hip alignment at impact should feature the leading hip slightly elevated in comparison to the lagging hip (DeNunzio, 2007). At impact an upward movement of the whole body could increase ball velocity Miura (2001). The follow-through takes place post impact. For right handed golfers as the trunk and hips continue to rotate to the left, the left shoulder and arm externally rotate while the right shoulder and arm internally rotate. The follow-through allows for the club head to decelerate (Hume, et al, 2005).

Constraints Approach to Learning

Patterns self-organize in a way that reflects the constraints acting on that system (Clark, 1997). A change in motor pattern is the result of the manipulation of constraints that cause control parameters to reach critical values and take full advantage of an order parameter. An example of how constraints guide systems to new patterns is Thelen's (1986) explanation concerning the development of walking. Thelen (1986) identified eight potential constraints (there may be more) that dictated an infant's ability to walk. Proposed constraints were tonus control, articular differentiation, extensor strength, postural control, body constraints, visual flow sensitivity, and motivation. Each constraint must reach a critical value before the infant will take his/her first step. For example an infant might have the ideal muscle tone and strength to walk but if the motivation constraint has not reached a critical value the infant will not walk. On the other hand a highly motivated infant might lack the muscular strength to support him/herself and have to choose a form of locomotion other than walking. As one aspect of the system changes it causes the rest of the system to adapt accordingly. To regain a state of homeostasis (stable pattern of movement) all constraints adjust in such a way that allows for a new state of stability to emerge. Southard (2002) provided an additional example of this process by demonstrating that when immature throwers reached a critical value of velocity their limb segments experienced a period of instability. The instability was followed by an adjustment to a new throwing pattern.

Constraints may lead to adjustments that do not require changing motor pattern. Chow, Davids, Button, and Koh (2006) selected five skilled kickers (age: 18 to 22 years) to participate in a study examining how constraints can change motor patterns. Participants were asked to chip a soccer ball over a barrier to a skilled receiver. The only instruction given was the goal of the task. Players kicked a ball from a kicking area (2X2) to one of four targets (10m to 14m perpendicular to the kicking position). The height barrier was created with an adjustable horizontal bar that was manipulated between 1.5m and 1.7m. After five warm up kicks all players performed 10 kicks over a 1.6m barrier to a target 12m away. Players then performed five kicks over a 1.5m barrier to a target 10m away, five kicks over a 1.6m barrier 14m away, and five kicks over a 1.7m barrier 14m away. The 15 kicks were used to assess a player's ability to vary foot velocity to meet the demand of the height and accuracy constraints. Performance outcome was assessed by accuracy of the kick to the receiver. Kinematic data for the duration of segment movement in the kicking leg based on the center of mass (COM) was collected with the Visual 3D software. Researchers found that players were able to effectively alter foot velocity while only making subtle changes to original coordination patterns for kicking. Key findings suggest that as the constraints of the task changed, skilled kickers made the appropriate changes in foot velocity to achieve the goal of the kicking task without sacrificing their global pattern of kicking. Since subjects already demonstrated the global motor pattern for kicking, a change in motor pattern would be a more likely outcome with less skilled performers.

Ilmane and LaRue (2011) forced a pattern change by changing a temporal constraint. Three conditions were used to compare the coordination pattern of raising a weighted arm. Ten male participants were placed in three conditions, a quick response to a stimuli, a synchronized movement with mobile stimulus, and a self-initiated movement with no stimulus. To respond to a stimulus subjects raised their dominant arm from a horizontal to a vertical position. A force platform was used to record ground reaction forces and any movement in the sagittal, frontal, or vertical planes. An accelerometer was attached to the wrist of each participant. EEG activity was recorded with four electrodes placed on the arm and postural muscles. Motor action of the arm was recorded with a custom made circuit that was completed when the subjects hand contacted it. The arm-raising task was performed 20 times in each condition. Significant variations in motor patterns were identified through activation of muscles and initiation of forces. Pattern fluctuations were due to the velocity and the anticipated rate at which a participant was instructed to perform the task. Coordination patterns differed depending on the temporal constraint of the condition.

Mazyn, Montagne, Savelsbergh, and Lenoir (2006) applied temporal constraints to a catching task. Nine subjects caught balls, starting from a natural position, with their dominant hand at seven different speeds ranging from 8.5 m/s to 19.7 m/s. The ball was a mid-pressure tennis ball projected by a Singly Promatch ball projection machine at a distance of 8.4m towards the subject. Catching was recorded with a 240Hz 3D motion capturing system and reflective markers attached to the processus caracoideus of the scapula, processus coronoideus of the humerus, processus styloideus of radius and ulna, caput metacarpal and external face of the distal phalanx of thumb, index, and little finger or the catching arm. While there was an inverse relationship between performance and the speed of the ball, there was also evidence of pattern adaptation. Cross-correlation of transport of the ball and manipulation of the ball increased as speed increased, and the cross-correlation between elbow movement and hand movement increased as speed increased. The constraint of speed forced catchers into a new motor pattern that changed coordination between the transport and manipulation phase of the ball as well as between joint movements.

CHAPTER THREE

Method

This method section includes information about participants, apparatus, procedure, and design and analysis for both quantitative and qualitative data.

Participants

Sixteen females (ages 18-22 years) participated in this study. Participants had no prior golf experience. No prior golf experience is defined as having never hit a golf ball with a driver. Participants with prior golf experience were excluded from data collection. All participants signed a university approved consent form prior to participation.

Apparatus

The PEAK motion analysis system was used to collect and digitize data. Two digital cameras captured participants' motion during the golf swing. One camera was placed 5 meters from the participant and perpendicular to the principle axis of motion (X-axis). The second camera was placed 5 meters behind the participant, in line with the principle axis of motion (X-axis). The Y-axis was in the vertical direction and the Z- axis was toward and away from camera one. The cameras were placed on a tripod 1.8 meters from the floor. The system was calibrated with a 16-point calibration frame. A field rate of 60hz and a shutter speed of 1/1000 provided a clear view of the club and limb segments during the movement. Light reflective markers were placed in the following anatomical locations: Right and left lateral and medial gleno-humeral axis, right and left lateral and medial epicondyle, right and left styloid process, right and left knuckle of the index finger, right and left greater trochanter, right and left iliac crest. A marker was also placed on the head of the club. Floodlights were used to illuminate and identify the data points during digitization. A hollow practice golf ball was hit to a 3m x 5m mat located 5 meters directly in front of the participant. When accuracy was a requirement, the target was a solid orange line (8cm wide) positioned vertically down the center of the mat. The ball was placed on a rubber golf tee that was positioned on a 1m X 1m piece of artificial turf located in line with the target. A JUGS radar gun provided instant information concerning the velocity of the golf ball at release from the golf tee.

Procedure

Participants were randomly assigned to one of four conditions (control, speed, accuracy, and speed & accuracy). Participants were divided equally among conditions. Each condition required that participants hit a golf ball toward the padded mat 12 times for each of six practice sessions. Participants in each condition were told that the goal of the golf drive was to hit the ball as far and as straight as possible. In the control condition, participants received no instruction. The goal of the movement was to simply hit the golf ball into the mat without regard for accuracy or increasing ball velocity. For the accuracy condition, participants were told the goal of the movement but were instructed to focus on hitting the centerline target. The velocity of the ball was dictated only by the goal of the task. For the speed condition, participants were told the goal of the movement and instructed to focus on hitting the golf ball with as much velocity as possible. Accuracy was dictated only by the goal of the task and the target was removed for the velocity condition. For the speed and accuracy condition, participants were told the goal of the task and instructed to hit the ball as accurately as possible and with as much velocity as possible. The target was placed on the mat for the speed and accuracy condition. Participants in the accuracy, speed, and speed and accuracy conditions were reminded of their conditions/goal constraints (speed, accuracy, or speed and accuracy) after trials 3, 6, and trial 9. Velocity feedback (velocity of ball at release) and accuracy feedback (position of ball to center line target) was provided to participants in respective velocity, accuracy, or speed and accuracy conditions after trials 3, 6, 9, and 12.

Participants reported to the Motor Behavior Lab for six practice sessions. Each session required the completion of 12 trials. A trial consisted of one swing with a golf driver club. Ball contact was required for a trial to be completed. There were three practice sessions per week for 2 weeks. Each session was on a different day. A retention session was scheduled one week after the final practice session. There were no accuracy and or speed requirements and no extrinsic feedback provided during the retention session. Participants were reminded of the goal of the task and the focus specific to their condition prior to the beginning of each session.

Design and Analysis

Quantitative Analysis. Four separate 4 X 7 MANOVA's were used to examine the effects of goal constraints (speed and accuracy) on swing pattern. The independent variables were the four practice conditions with a repeated measure for the six sessions of practice along with the retention session. The dependent variables for two of the MANOVA's were temporal lag between a distal joint and its proximal neighbor (elbow lag and wrist lag) for the lead and back joints. The dependent variables for the remaining two MANOVA's were the peak velocity differences between distal joints and their proximal neighbors (elbow velocity difference and wrist velocity difference) for lead and back joints. Motor pattern was determined by the relative use of the order parameter. That is, the distal lag of each joint in relation to its proximal neighbor indicated possible use of the order parameter. Distal lag was determined by subtracting the time to peak velocity of a distal joint from the time to peak velocity of its proximal neighbor. Distal joint lag was determined for the lead elbow, lead wrist, back elbow and back wrist. In order to confirm that there was a transfer of velocity that accompanied distal lag the joint peak velocity of the proximal joint was subtracted from the joint peak velocity of its distal neighbor. If the 4X7 MANOVA indicated significance in a dependent measure then a follow-up univariate two-way (4X7) ANOVA determined the dependent measures responsible for significance. Means responsible for significant follow-up ANOVA were determined using Scheffé Post Hoc analysis. Partial eta square designated effect size and a Huyhn-Feldt adjustment was made for a sphericity violation. Two separate 4X7 univariate ANOVA's were used to determine angular segmental lag and angular segmental velocity differences between the pelvis and trunk. Distal segment lag between the pelvis and trunk along with positive velocity difference indicated use of the x-factor, which is characteristic of an experienced golfer. Positive lag values along with positive velocity differences indicated use of the open kinetic chain. A negative lag value and or a negative velocity difference indicated decreased use of the open kinetic chain.

Club velocity and accuracy (absolute constant error and variable error) was analyzed using three univariate two-way (4X7) ANOVAs. Scheffē post hoc procedure was used to determine mean values responsible for significance. An omega square was used to determine effect size. Club peak velocity was digitized from a trajectory graph (PEAK Analysis Systems). Accuracy was recorded in the X-axis only since the horizontal displacement of ball is uniform. Y-axis accuracy is related to horizontal displacement therefor accuracy was recorded in the x-axis. The dependent measures for accuracy were absolute constant error and variable error.

The difference in time between when the club reached peak velocity and when the club made ball contact was analyzed with a two-way ANOVA. Independent factors were condition and sessions with repeated measure by session. The dependent measure was the time difference between peak velocity and contact with the ball. The closer the club reaches peak velocity relative to ball contact – the more effective would be the golf drive. Scheffē post hoc analysis determined the means responsible for significant main effects and interaction. Omega square was used to designate effect size.

Qualitative Analysis. Phase planes of the velocity and displacement of the golf club for Sessions 1, 6, and 7 for each condition represented changes in club kinematics with practice. The shape of the phase plane was used to determine the consistency of patterns. There was no attempt to quantify shape through statistical analysis.

CHAPTER FOUR

Results

The pattern change results are presented by lead and back joint. The lag data for each joint is followed by the velocity difference data for the corresponding joint. The results are organized by lag and velocity difference data to better represent changes in the order parameter. That is, it is necessary to have both positive lag and positive velocity difference in order to take advantage of the open kinetic chain. Figures representing lag data are located above velocity difference data so that a comparison of positive and negative values can more easily be determined.

Pattern Change: Quantitative Analysis

Trunk Lag and Velocity Differences. Results of the 4X7 ANOVA for temporal lag of the trunk segment indicated a significant main effect by Condition (F (3, 1296) = 71.85, $p<.05$), $\omega^2 = .18$). Post hoc analyses of main effect by Condition indicated that the negative lag values for Conditions 1 and 2 were significantly less than the positive values for Conditions 3 and 4. In addition Condition 3 (velocity) was significantly greater than Condition 4. See Figure 1 for graphic representation of trunk lag by Condition and Session.

Results of the 4X7 ANOVA for peak velocity difference between the trunk and pelvis indicated a significant main effect by Condition (F (3, 1296) = 168.02, $p<.05$); Session (F (6, 1296) = 9.23, $p<.05$, $\omega^2 = .22$); and a Condition X Session Interaction (F (18, 1296) = 3.56, $p<.05$, $\omega^2 = .08$). Post hoc analyses indicated that Condition 3 was significantly greater than remaining conditions while Condition 1 had a significantly lower velocity difference than the remaining conditions. There were no negative velocity differences by condition. Post hoc analyses of main effect by Session indicated that Sessions 4, 5, 6, and 7 were positive with greater velocity differences than Sessions 1, 2, and 3, which were also positive. Condition 3 was the only condition that displayed positive joint lag and velocity differences across sessions indicating that participants in the velocity condition were taking advantage of the open kinetic chain throughout sessions. Condition 4 displayed positive joint lag for Sessions 2, 3, 4, and 7 with Condition 1 positive for Sessions 2 and 3.

Post hoc analysis of Condition X Session Interaction indicated that for Conditions 1, 3 and 4 there was generally an increase in trunk velocity over Sessions 1-6 with the exception of Sessions 2 and 6 in Condition 1 and Sessions 3 and 5 in Condition 3. Session 7 displayed a decrease relative to the last practice session in all conditions but 1 where it was the highest velocity value over sessions. Condition 2 was the only condition to have its highest velocity values in the first 2 sessions followed by lower values in the remaining sessions. See Figure 2 for graphic representation of velocity differences by Condition and Session.

Lead Joint Lag and Velocity Differences. Results of the 4X7 MANOVA for temporal lag of lead joints indicated a significant main effect for lead joint lag by Condition (Wilks' Lambda = .829, F (3, 2534) = 41.379, $p<.05$, $\eta^2= .089$); Session (Wilks' Lambda = .959, F (6, 2534) = 4.509, $\eta^2= .021$); and a Condition X Session Interaction (Wilks' Lambda = .938, F (18, 2534) = 2.689, $p<.05$, $\eta^2= .037$). Follow-up ANOVA indicated that lead elbow lag (F (3, 1296) = 20.787, $p<.05$) and lead wrist lag (F (3, 1296) = 41.538, $p<.05$) were responsible for the significant main effect by Condition. Lead wrist lag (F (6, 1286) = 4.087, $p<.05$) was responsible for the significant main effect by Session. Lead elbow lag (F (18, 1296) = 2.737, $p<.05$) and lead wrist lag (F (18, 1296) = 2.846, $p<.05$) were responsible for the Condition X Session Interaction. Huyhn-Feldt adjustment did not affect significance.

Results of the 4X7 MANOVA for the dependent measures of peak velocity differences of lead joints indicated significant main effects by Condition (Wilks' Lambda = .779, F (3, 2534) = 56.275, p<.05, $\eta2 = .118$); and Session (Wilks' Lambda = .977, F (6, 2534) = 2.463, p<.05, $\eta2 = .012$). Follow-up ANOVA procedures indicated that lead elbow velocity difference (F (3, 1296) = 58.698, $p<.05$) and lead wrist velocity difference (F (3, 1296) = 28.152, $p<.05$) were responsible for the significant main effect by Condition and lead elbow velocity difference (F (6, 1296) = 3.661, $p<.05$) was responsible for the main effect by Session. Huyhn-Feldt adjustment did not affect significance.

Post hoc analyses of main effect by Condition indicated that lead elbow lag for Condition 3 was significantly greater than remaining conditions with Condition 4 greater than 1 and 2. Condition 2 was significantly less than Condition 1. All conditions exhibited positive elbow lag. Post hoc analysis of the Condition X Session Interaction indicated that elbow lag values generally increased through Session 5 for Conditions 2, 3, and 4. Conditions 1 and 3 were the only conditions that increased in lag values for Session 6. Elbow lag values increased in the retention session for those conditions not focusing on velocity. All lag values by session were positive. See Figure 3 for graphic representation of lead elbow lag by Condition and Session.

Post hoc analysis of main effect by Condition for lead elbow velocity difference indicated that Condition 1 had a significantly lower (negative) mean velocity difference than the remaining conditions, which were positive and not significantly different from one another. Post hoc analysis indicated that Session 7 had a significantly lower velocity difference than Session 2. All sessions indicated a positive velocity difference for the lead elbow. See Figure 4 for graphic representation of mean lead elbow velocity difference by Condition and Session.

Post hoc analyses of main effect by Condition for lead wrist lag indicated that Condition 3 was significantly greater than remaining conditions. Conditions 1 and 2 were significantly less than Condition 4. Conditions 1 and 2 displayed negative values and Conditions 3 and 4 displayed positive values. Post hoc analyses of main effect by Session indicated that Session 7 was significantly lower (negative) than remaining sessions. Sessions 2, 3, 4, and 5 were significantly higher than remaining sessions. Post hoc analysis of Condition X Session Interaction indicated that Condition 3 was the only condition that was positive for all sessions with Condition 4 positive for Sessions 1 through 6. Condition 1 was negative for the last three sessions and Condition 2 was negative for 4 out of the 7 sessions. See Figure 5 for graphic representation of the Condition X Session Interaction for lead wrist lag.

Post hoc analysis of main effect for lead wrist velocity difference by Condition indicated that Conditions 1 and 3 had a significantly higher mean velocity difference than Conditions 2 and 4 which were not significantly different from each other. Lead wrist velocity difference was positive for Conditions 1, 3, and 4. Positive lag and velocity differences for the wrist joint indicated that Condition 3 was the only condition to consistently take advantage of the open kinetic chain. See Figure 6 for graphic representation of mean lead wrist velocity difference by Condition and Session.

Back Joint Lag and Velocity Differences. Results of the 4X7 MANOVA for temporal lag of back joints indicated a significant main effect for back joint lag by Condition (Wilks' Lambda = .932, F (3, 2534) = 15.108, p<.05, η^2 = .089); and a Condition X Session Interaction (Wilks' Lambda = .952, F (7, 2534) = 1.759, p<.05 , η^2 = .021). Follow-up ANOVA procedures indicated that back elbow lag (F (3, 1296) = 15.078, *p*<.05) and back wrist lag (F (3, 1296) = 12.635, *p*<.05) were responsible for the significant main effect by Condition. Back wrist lag (F (18, 1296) = 1.843, *p*<.05) was responsible for Condition X Session Interaction.

Results of the 4X7 MANOVA for dependent measures of peak velocity differences of back joints indicated significant main effects by Condition (Wilks' Lambda = .880, F (2534) = 27.998, *p*<.05, η2 = .062); Session (Wilks' Lambda = .953, F (2534) = 5.200, *p*<.05, η2 = .024); and Condition X Session Interaction (Wilks' Lambda = .957, F (2534) = 1.566, *p*<.05, η2 = .022). Follow-up ANOVA procedures indicated that back elbow velocity difference (F (3) = 50.330), *p*<.05) and back wrist velocity difference (F (3) = 12.813, p<.05) were responsible for the significant main effect by Condition. Back elbow velocity difference (F (6) = 4.410, *p*<.05) was responsible for the main effect by Session; and back elbow velocity difference (F (18) = 1.660, *p*<.05) was responsible for the Condition X Session Interaction. Huyhn-Feldt adjustment did not affect significance.

Post hoc analyses of main effect by Condition indicated that back elbow lag for Condition 4 was significantly less (greater negative value) than remaining conditions. Conditions 2 and 3 were the only conditions with positive lag values for the back elbow joint. See Figure 7 for graphic representation of back elbow lag by Condition and Session.

Post hoc analysis of main effect of back elbow velocity difference by Condition indicated that Condition 3 was greater than remaining conditions with Condition 2 significantly less than Conditions 1 and 4. Back Elbow Velocity Differences were positive across conditions.

Post hoc analysis of back elbow velocity difference for main effect by Session indicated that Session 6 was significantly greater than the remaining sessions. Sessions 2 and 3 were significantly less than sessions 1, 4, 5, and 7. All sessions displayed positive velocity difference values.

Post hoc analysis of the Condition X Session Interaction for back elbow velocity difference indicated that Sessions 3, 4, 5, and 6 steadily increased for Conditions 1, 3, and 4 with the exception of a decrease in the mean back elbow velocity difference between Session 5 and 6 for Condition 1. Condition 2 was the least consistent condition and experienced increases and subsequent decreases in velocity difference by sessions. See Figure 8 for graphic representation of the Condition X Session Interaction.

Post hoc analyses of main effect for back wrist lag by Condition indicated that Condition 3 was significantly greater than remaining conditions that were not significantly different from one another. Condition 3 was the only condition with consistent positive back wrist lag.

Post hoc analysis of the Condition X Session Interaction for back wrist lag indicated that Condition 3 displayed positive wrist lag across sessions with the exception of Session 1. Remaining conditions were consistently negative across conditions with the exception of Session 3 for Condition 1 and Sessions 6 and 7 for Condition 4. See Figure 9 for graphic representation of back wrist lag by Condition and Session.

Post hoc analysis of main effect by Condition for back wrist velocity difference indicated that Condition 2 was significantly less negative than remaining conditions. Velocity differences were negative across all conditions and sessions. The consistent negative velocity differences across sessions indicated that none of the conditions was taking advantage of the open kinetic chain relative to back wrist activity. See Figure 10 for graphic representation of back wrist velocity differences.

Club Velocity. Results of the 4X7 ANOVA indicated a significant main effect by Condition (F (3, 1296) = 28.361, $p<.05$, $\omega^2 = .14$) for peak club velocity. Post hoc analysis of the main effect by Condition indicated that Conditions 3 and 4 were significantly greater than Conditions 1 and 2 with Condition 2 significantly lower than Condition 1. The results confirm that participants in the velocity conditions were focusing on increasing club velocity. See Figure 11 for graphic representation of mean club velocity by Condition and Session.

Time to Peak Club Velocity and Time to Contact. Results of the 4X7 ANOVA indicated a significant main effect by Condition (F (3, 1296) = 11.515, $p<.05$, $\omega^2 = .31$) for difference in time between peak club velocity and time to ball contact. Post hoc analysis of the main effect by Condition indicated that Conditions 3 and 4 had significantly less negative values than Conditions 1 and 2. Condition 2 displayed significantly greater negative value than remaining conditions. Results indicate that each condition reached peak velocity before ball contact but Conditions 3 and 4 were closer to ball contact than 1 and 2. See Figure 12 for graphic representation of timing differences between peak club velocity and velocity at contact by Condition and Session.

Pattern Change: Qualitative Analysis

Phase Planes. Phase planes representing conditions and sessions indicate changes in displacement and velocity of the club head during the swing. An overlapping phase plane would represent relative consistency of swing by condition for Sessions 1, 6, and 7. See Figure 13 for graphic representation of phase planes for Conditions 1, 2, 3, and 4 and by Sessions 1, 6, and 7. Notice the increase in velocity and club displacement over session for Conditions 3 and 4. There is little change in velocity or displacement for the control group and neither the control group nor the accuracy group develop a back swing during practice. A back swing is represented by negative velocity on the phase plane.

Accuracy

Constant Error. Results of the 4X7 ANOVA indicated a significant main effect by Condition (F (3, 1296) = 3.328, $p<.05$, $\omega^2 = .19$); with a significant Condition X Session Interaction (F (18, 1296) = 1.820, $p<.05$, $\omega^2 = .10$). Post hoc analysis of the main effect by Condition indicated that Condition 3 had the greatest constant error with Conditions 1 and 2 significantly less than Condition 4. Results indicate that conditions focusing on velocity were less accurate than remaining conditions. Interestingly the Accuracy Condition was not significantly more accurate than the Control Condition. Analysis of the Condition X Session Interaction indicated that Sessions 2 and 3 had the greatest error for Conditions 3 and 4. Session 7 had the greatest error for Conditions 1 and 2. The only negative constant error (error to the left of the target) was displayed by Condition 2 for Session 5 and Condition 4 for Session 7. See Figure 14 for graphic representation of constant error by Condition and Session.

Variable Error. Results of the 4X7 ANOVA indicated no significant main effects or interaction. See Figure 15 for graphic representation of variable error by Condition and Session.

CHAPTER FIVE

Discussion

The purpose of this discussion is to answer the hypotheses presented in the introduction and discuss practical implications as well as future research.

The hypothesis that increasing speed of swing without instruction will improve swing pattern by increasing the number of joints experiencing distal lag is accepted. The conditions (velocity, velocity and accuracy) where participants focused on increasing velocity of swing exhibited a greater number of joints with both positive lag and positive velocity differences. Data from this study are in agreement with other studies where the order parameter was the open kinetic chain (Putnam, 1993; Southard 1998; Southard, 2002; Southard, 2011). That is, velocity is a control parameter that allows for change in the pattern of swing. Further evidence that increasing velocity improves swing performance is provided with the analysis of time to peak velocity of the club in comparison with time of ball contact. Increasing velocity resulted in less time between ball contact and peak velocity of the club. Ideally, if the performer is taking maximum advantage of the open kinetic chain to increase club velocity, then peak club velocity should occur at the point of impact with the ball. The positive lag and velocity differences between the trunk and hips commonly referred to as the X factor (Myers et al, 2008) is further indication that increasing velocity of swing improves performance. The use of the X factor is recognized as an aspect of the golf swing utilized primarily by experienced performers.

The hypothesis that focusing on accuracy will inhibit use of the open kinetic chain by decreasing the number of joints experiencing distal lag was accepted. Requiring participants to focus on accuracy was a detriment to taking advantage of the order parameter in comparison with the velocity conditions. However, it should be noted that there were not substantial differences in the Control Condition compared with the Accuracy Condition. Apparently, focusing on accuracy is not a detriment to distal lag relative to simply practicing without focusing on accuracy or velocity of swing. This finding supports the importance of scaling up on a constraint that is a control parameter during skill development (Clark, 1997).

Back segments typically did not take advantage of the transfer of velocity as often as the lead segments. The exception was the velocity condition, which was the only condition displaying positive lag and velocity differences for all back segments. The lack of data concerning back segments during the golf swing makes it difficult to compare the back segment results of this study with past research concerning the golf swing. However, taking in consideration that maximizing the transfer of angular momentum aids the golfer in accomplishing maximum horizontal displacement - it can be concluded that positive lag and velocity differences of the back segments would be a desired aspect of the swing.

The hypothesis that increasing velocity of swing will result in a greater number of joints experiencing distal lag in the retention session was accepted. The Velocity condition was the only condition that displayed consistent positive lag and velocity differences for trunk and lead segments one week following no practice. There were no conditions that displayed consistent positive lag and velocity differences for back joints at the retention session. Apparently, when velocity is not a goal constraint the back segments serve primarily to help guide the club but do little to add to club velocity.

Interestingly, there were no differences in accuracy for the speed only and speed and accuracy conditions. Considering that there was not a target present for the speed condition, the data indicates that increasing speed is not a detriment to accuracy when compared with the speed and accuracy condition. However, it should be noted that there is an apparent speed-accuracy tradeoff (Mazyn, et. al., 2006; Newell, Carlton, Kim, & Chung, 1993; Schmidt, Zelaznik, & Frank, 1978). That is, the speed and speed and accuracy conditions were less accurate than the accuracy condition. Increasing velocity of swing improves the pattern of swing but may also reduce the accuracy of shot placement.

Positive lag values indicate that the performer is taking advantage of the open kinetic chain. However, there is no data that indicates what the ideal amount of absolute positive lag is for the golf drive. Southard (2009) determined that the ideal positive lag for throwing varies by both skill level and joint. Experienced throwers had less positive lag at the wrist joint and more positive lag at the elbow joint than inexperienced performers. It is likely that the performers for this study have not yet attained the ideal positive lag for the golf swing. This could be a contributing factor when considering their accuracy data. It may be that accuracy improves as the performer develops the optimum swing pattern. The lag values and velocity differences for novice golfers would need to be compared to the values of an experienced golfer in order to indicate any definite values characteristic of an optimal golf drive.

In conclusion it is possible to positively change the pattern of a complex skill without the aid of instruction. The results support the contention that phylogenetic and ontogenetic skills should not be viewed differently when developing teaching strategies. The results of this study do not indicate that instruction (augmented information) would impair or improve the development of a more effective motor pattern. However, it should be noted that the sequence of instruction should consider the natural development of the skilled behavior. That is, instruction should allow for a match between the intrinsic dynamics of the performer and the task demands of the skill. Scaling up on a constraint allows the performer to naturally progress to a more effective pattern without compromising the individual intrinsic dynamics. Further research regarding a constraints approach and instruction could compare different strategies of instruction with a constraints approach. It should also be noted that while there was a positive change in motor pattern, the performance variable regarding the final horizontal displacement of the ball is not known. That is, increasing velocity improves the swing pattern but there is no data regarding the location of the ball beyond the 5 meter target. Future studies should examine pattern change and final ball displacement. Knowing final displacement would allow for an analysis of performance variables beyond experiments of motor patterns such as final ball location.

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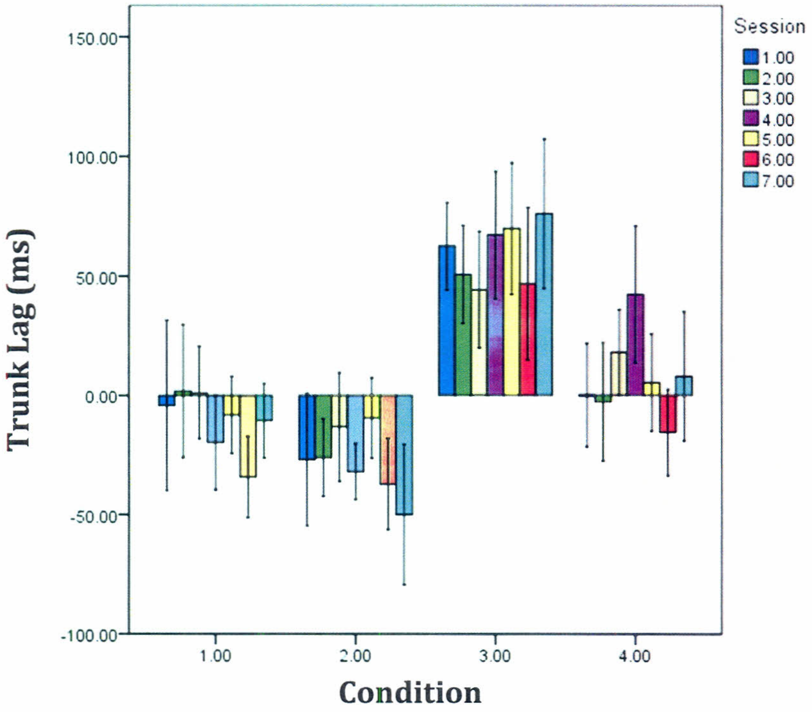


Figure 1. Mean Trunk Lag by Condition and Session.
1 = control, 2 = accuracy, 3 = velocity, 4 = accuracy and velocity

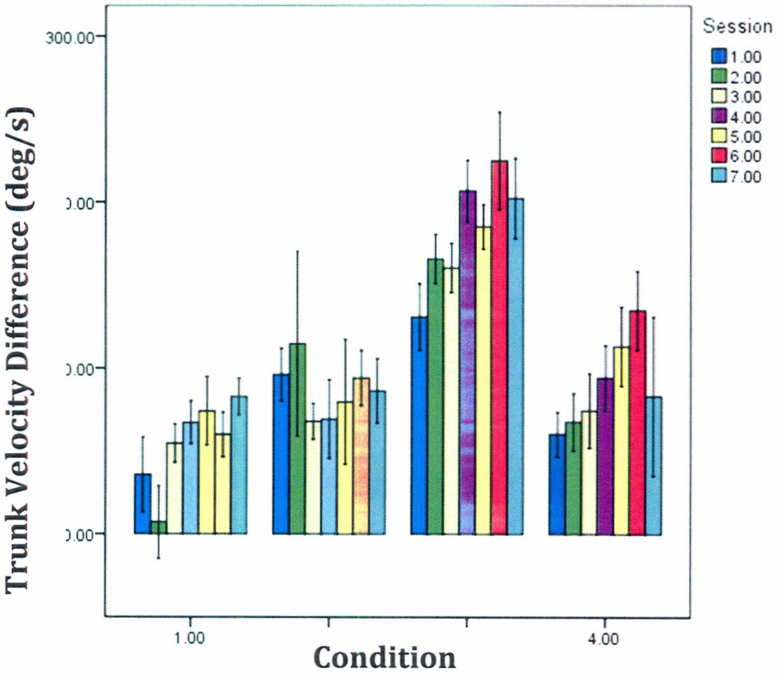


Figure 2. Mean Trunk Velocity Difference by Condition and Session.
1 = control, 2 = accuracy, 3 = velocity, 4 = accuracy and velocity

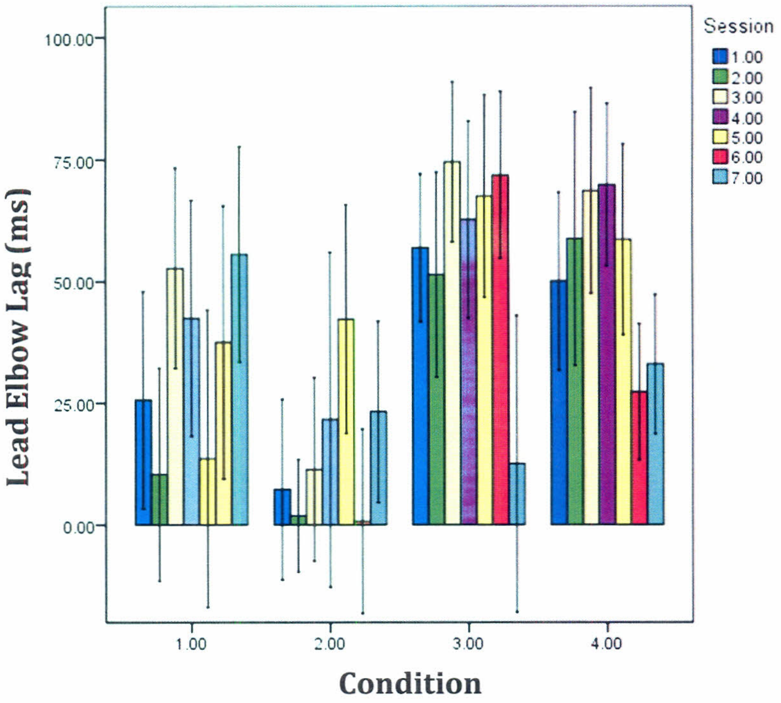


Figure 3. Mean Lead Elbow Lag by Condition and Session.
1 = control, 2 = accuracy, 3 = velocity, 4 = accuracy and velocity

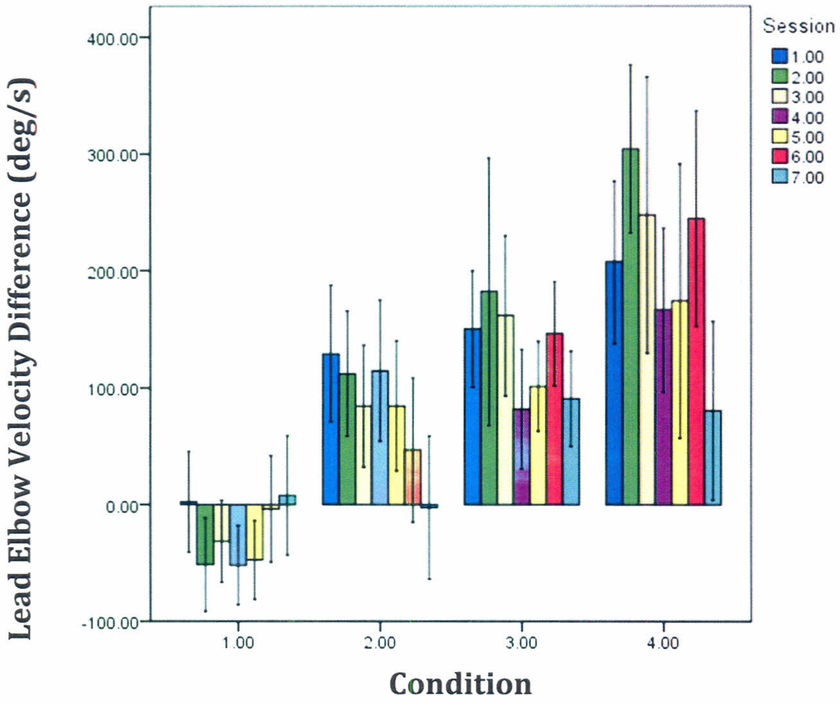


Figure 4. Mean Lead Elbow Velocity Difference by Condition and Session.
1 = control, 2 = accuracy, 3 = velocity, 4 = accuracy and velocity

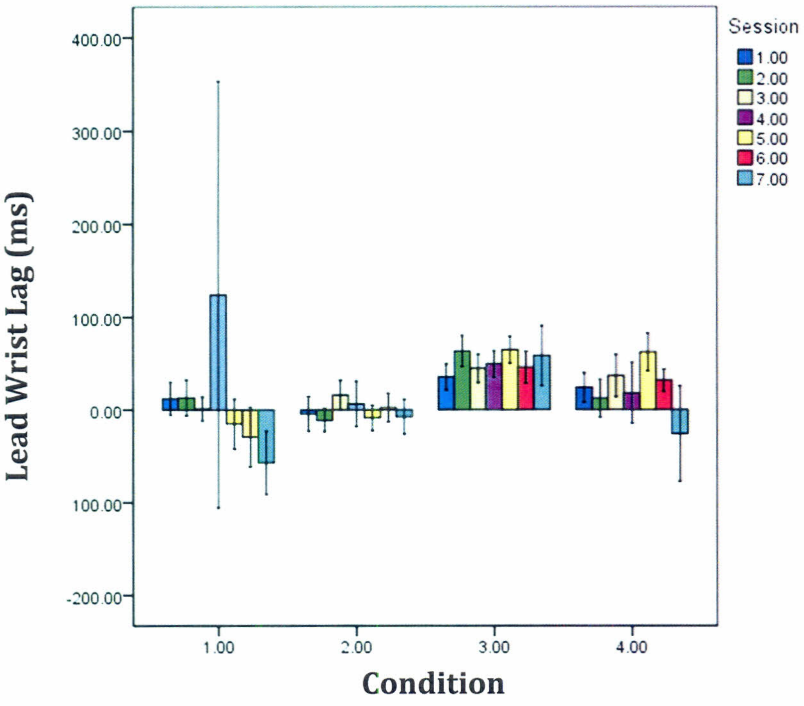


Figure 5. Mean Lead Wrist Lag by Condition and Session.
1 = control, 2 = accuracy, 3 = velocity, 4 = accuracy and velocity

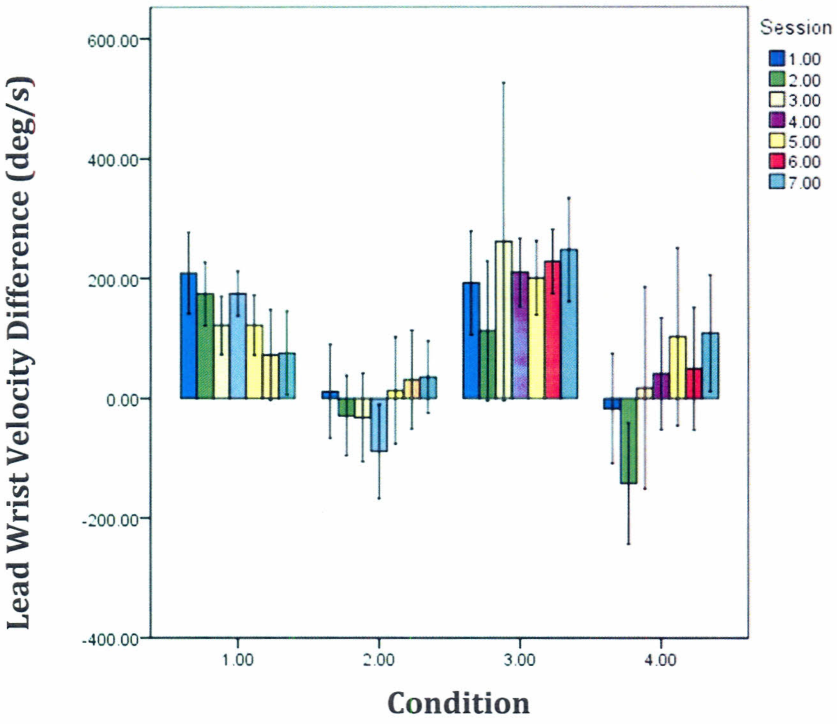


Figure 6. Mean Lead Wrist Velocity Difference by Condition and Session.
1 = control, 2 = accuracy, 3 = velocity, 4 = accuracy and velocity

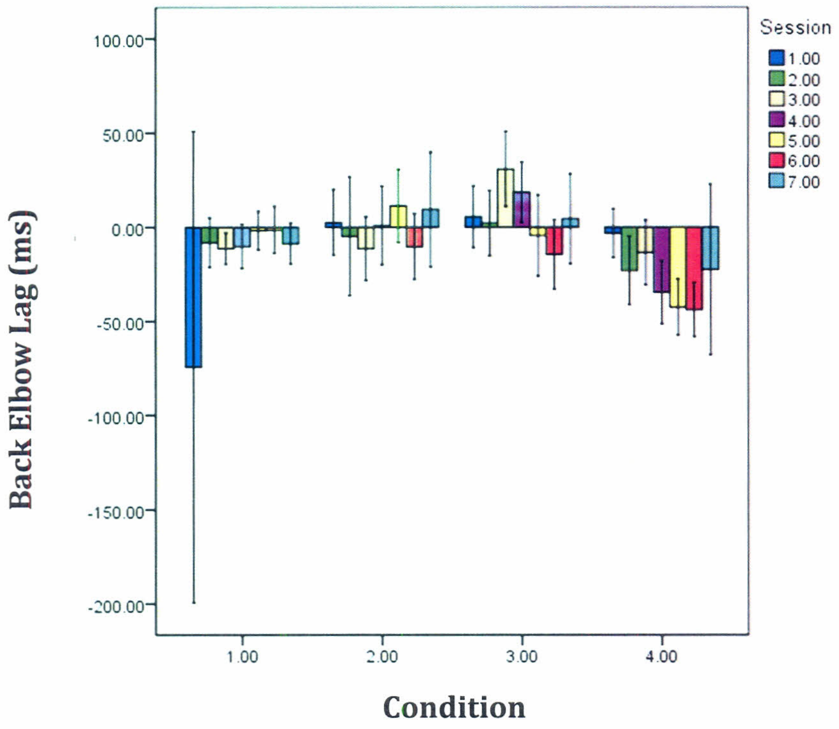


Figure 7. Mean Back Elbow Lag by Condition and Session.
1 = control, 2 = accuracy, 3 = velocity, 4 = accuracy and velocity

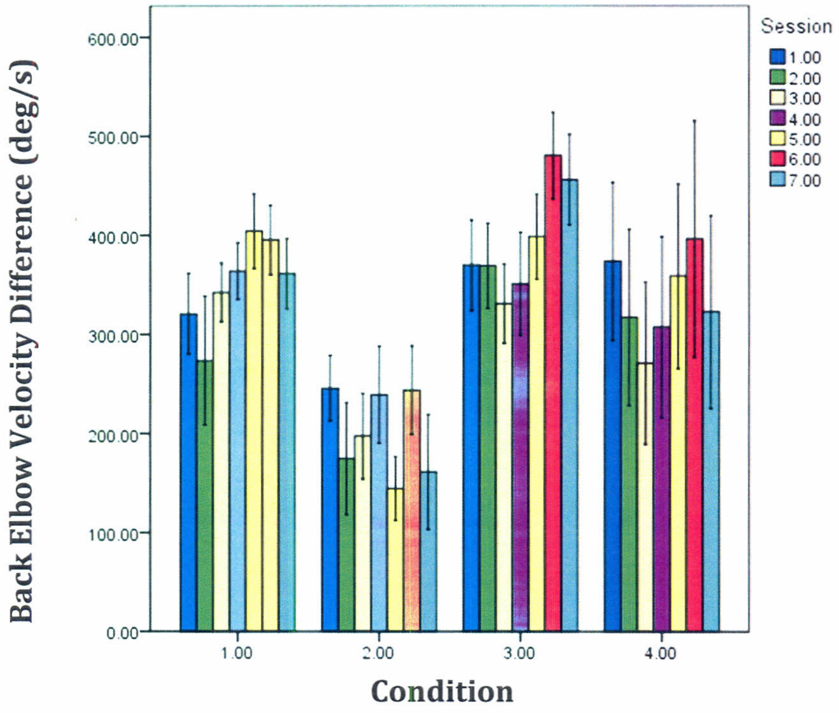


Figure 8. Mean Back Elbow Velocity Difference by Condition and Session.
1 = control, 2 = accuracy, 3 = velocity, 4 = accuracy and velocity

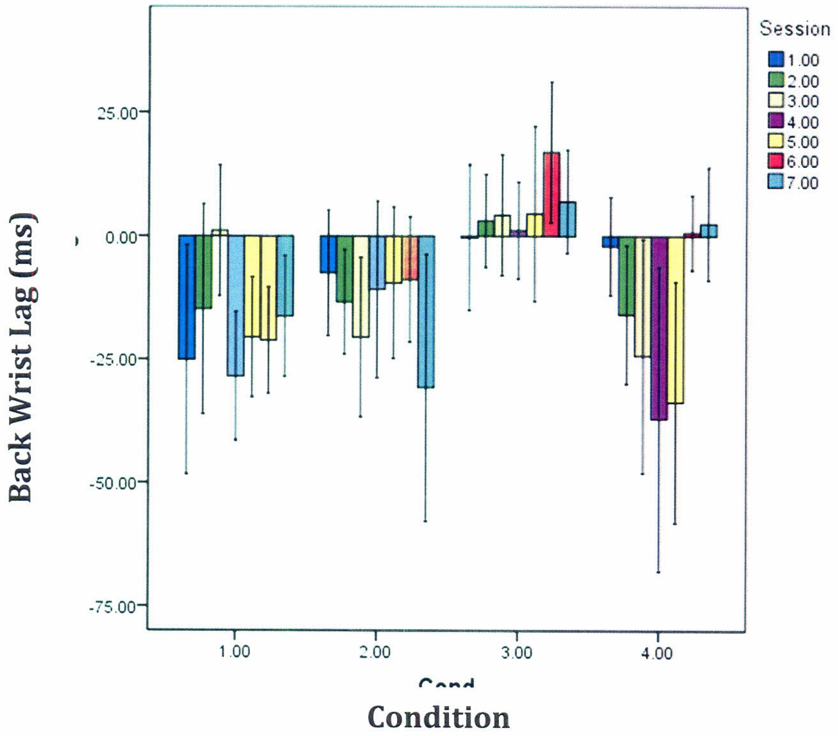


Figure 9. Mean Back Wrist Lag by Condition and Session.
1 = control, 2 = accuracy, 3 = velocity, 4 = accuracy and velocity

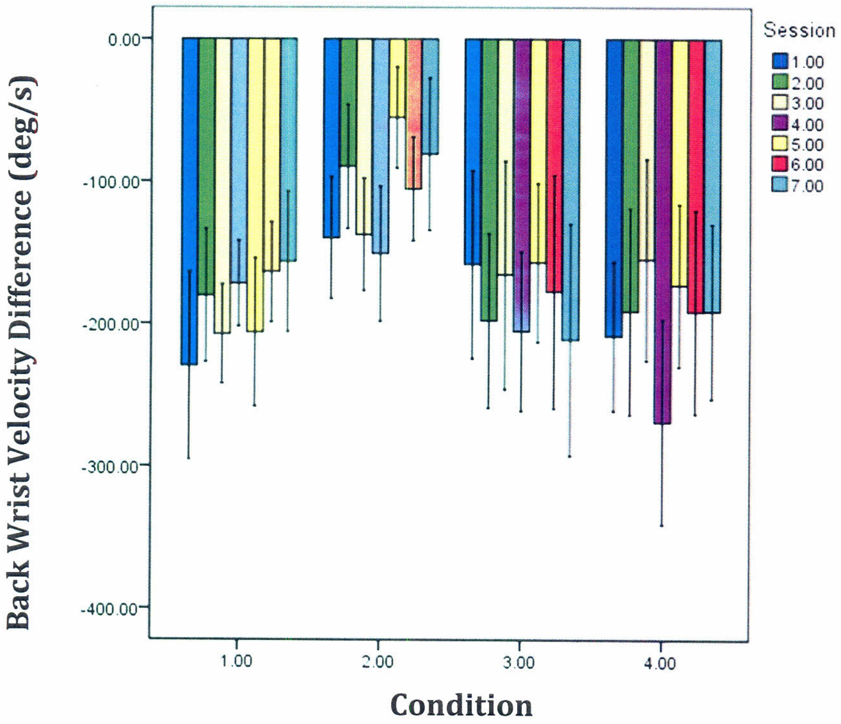


Figure 10. Mean Back Wrist Velocity Difference by Condition and Session.
1 = control, 2 = accuracy, 3 = velocity, 4 = accuracy and velocity

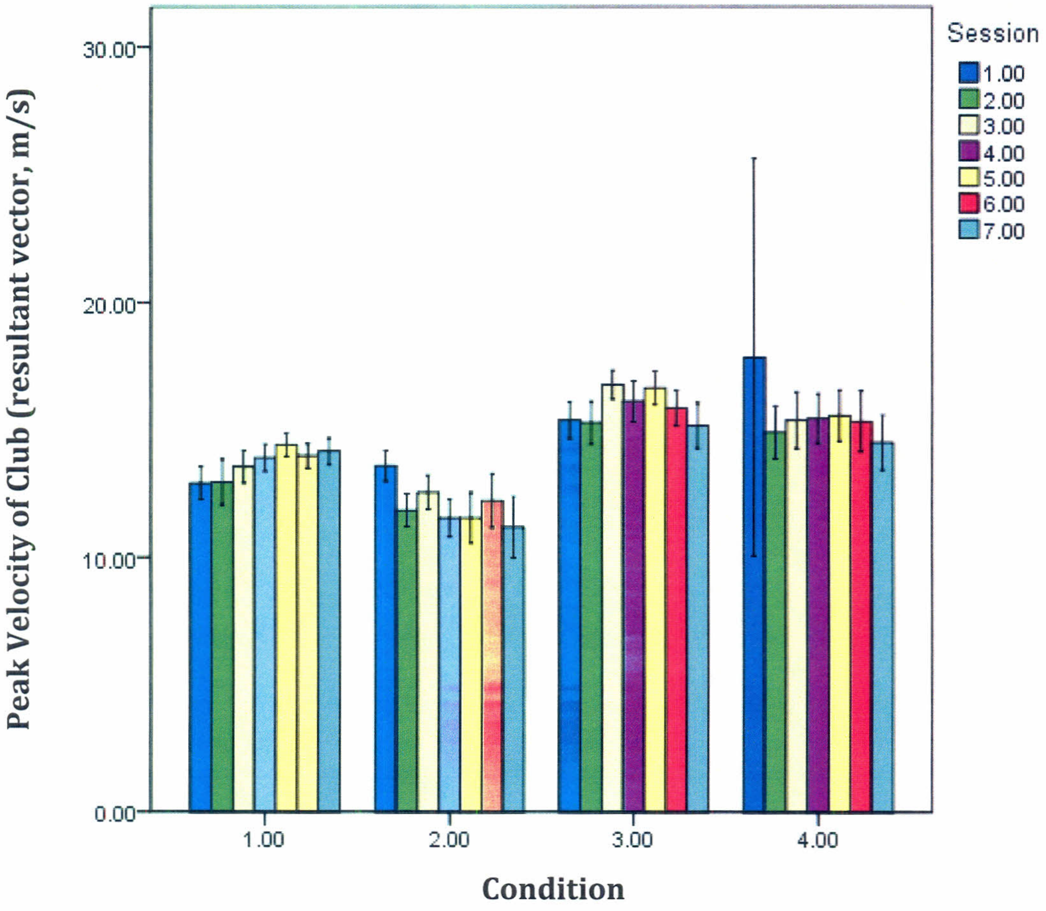


Figure 11. Mean Peak Club Velocity by Condition and Session.
1 = control, 2 = accuracy, 3 = velocity, 4 = accuracy and velocity

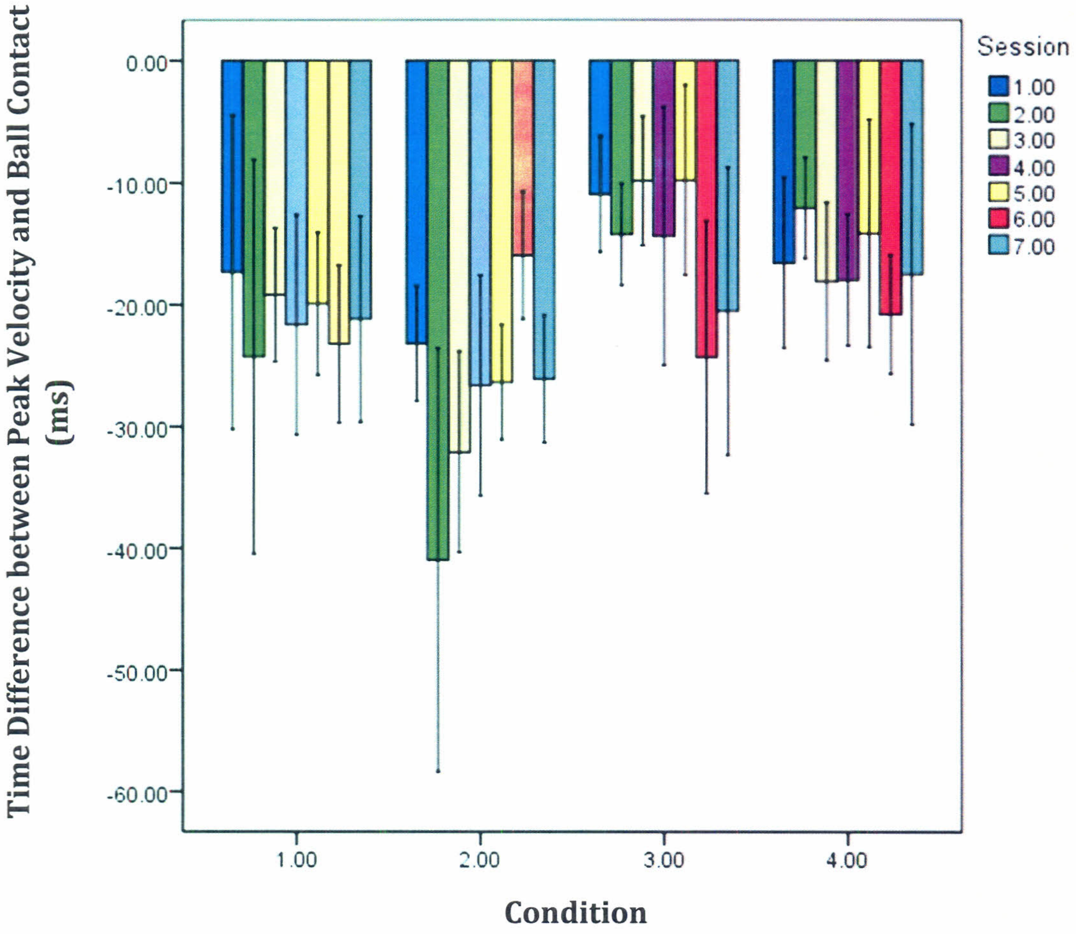
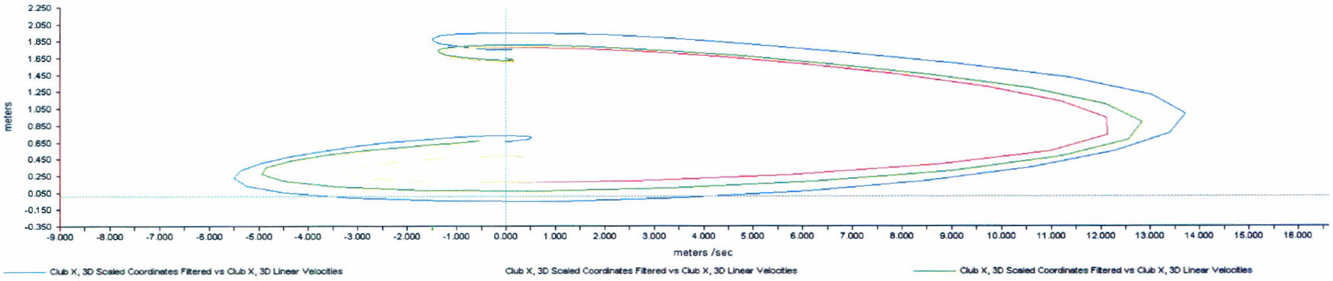
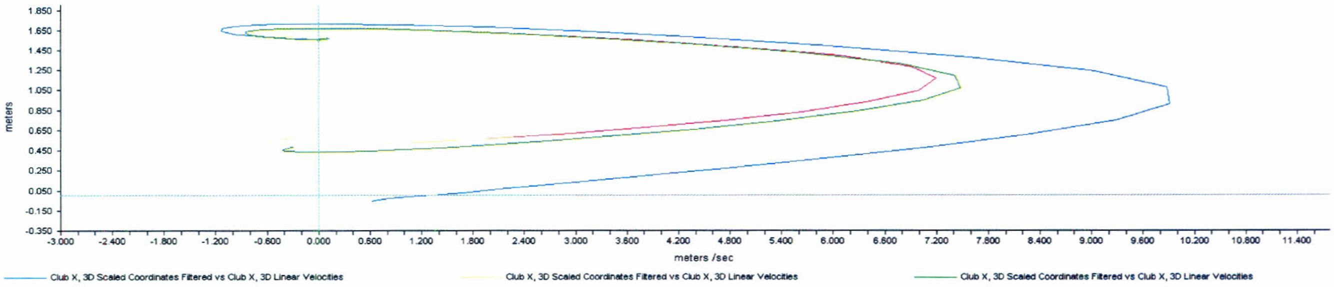


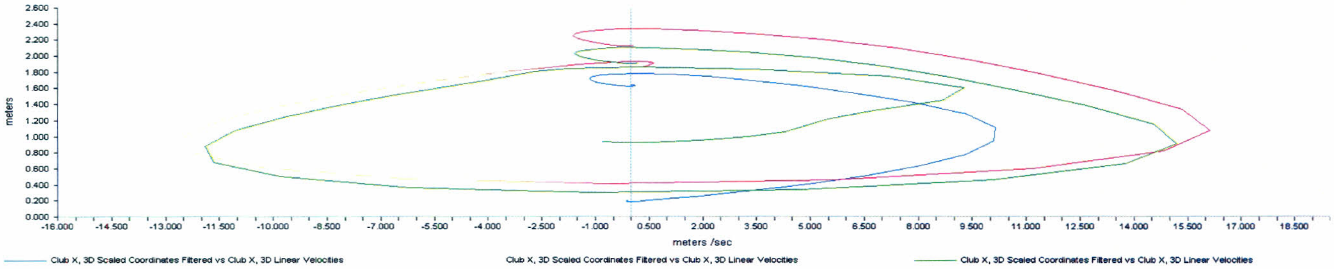
Figure 12. Mean Time Difference between Peak Club Velocity and time of Contact by Condition and Session. Negative values indicate peak velocity occurred prior to contact. 1 = control, 2 = accuracy, 3 = velocity, 4 = accuracy and velocity



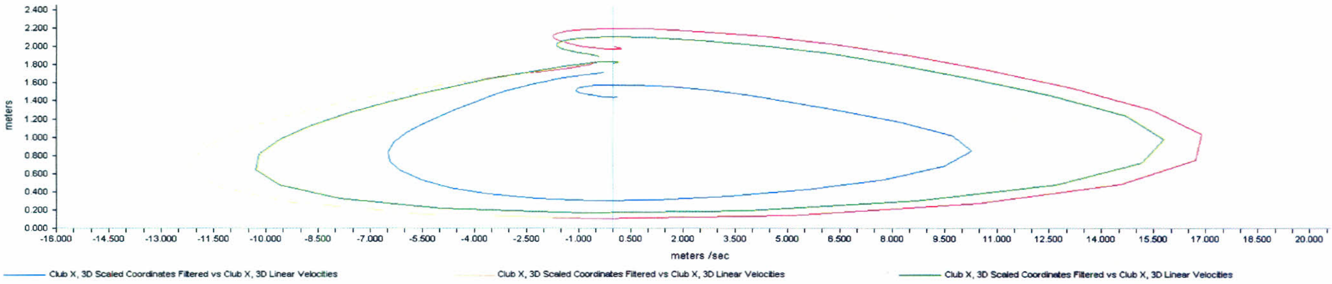
Phase Plane of Session 1, 6, and 7 for Condition 1.



Phase Plane of Session 1, 6, and 7 for Condition 2.



Phase Plane of Session 1, 6, and 7 for Condition 3.



Phase Plane of Session 1, 6, and 7 for Condition 4.

Figure 13. Phase Planes indicate changes in displacement and velocity of club during the swing. Note that only the velocity conditions develop a backswing indicated by negative displacement and velocity on the phase plane.
1 = control, 2 = accuracy, 3 = velocity, 4 = accuracy and velocity

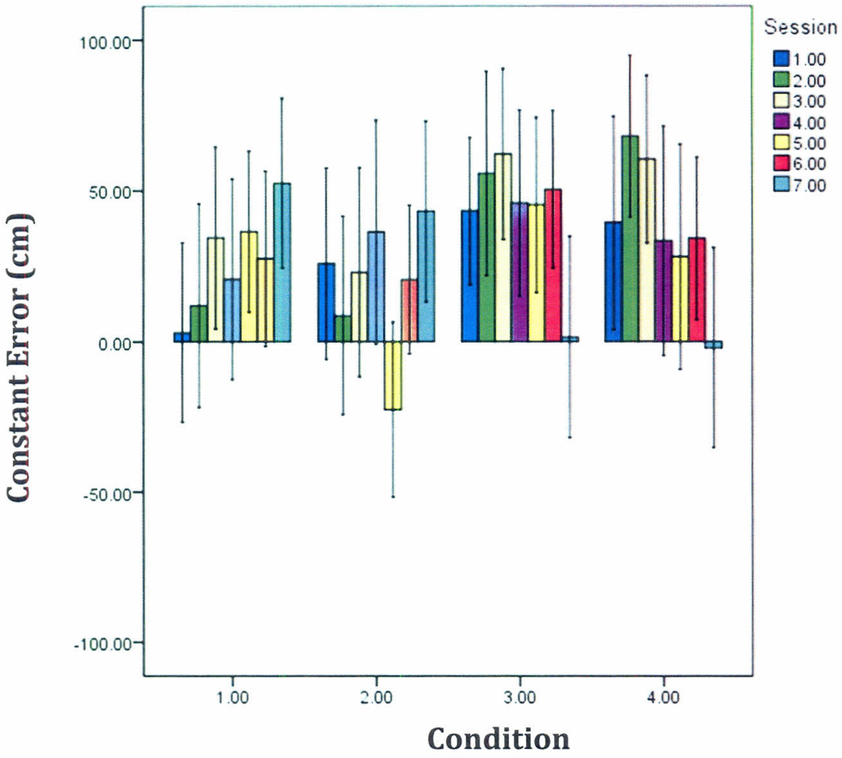


Figure 14. Mean scores for Constant Error by Condition and Session. Positive values are to the right of target. Negative values are to the left of target.
1 = control, 2 = accuracy, 3 = velocity, 4 = accuracy and velocity

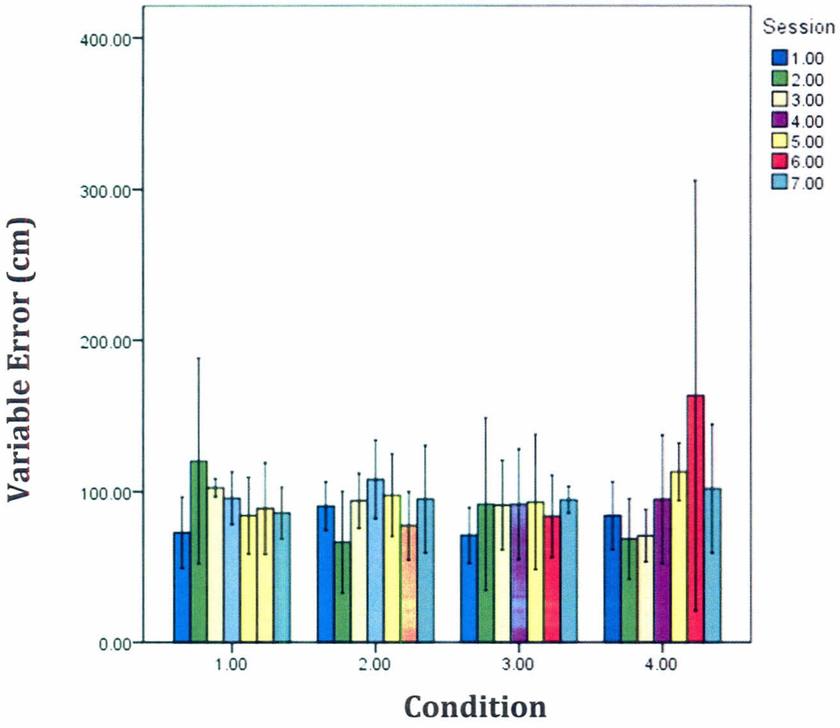


Figure 15. Mean Variable Error by Condition and Session.
1 = control, 2 = accuracy, 3 = velocity, 4 = accuracy and velocity

Abstract

LEARNING AN ONTOGENETIC SKILL: A CONSTRAINTS APPROACH

By Josephine Ferrandino, M.S., 2013
Department of Kinesiology
Texas Christian University

Thesis Advisor: Dan Southard, Ph.D.

This study examined the effects of goal constraints (accuracy, velocity, or both) on the performance and learning of an ontogenetic skill. Participants were undergraduate female college students (N=16), with no prior golf experience. Participants were randomly placed into one of 4 groups – Control, Accuracy, Velocity, or Accuracy and Velocity. Participants in all groups practiced a golf swing for 6 sessions and returned one-week following practice for a retention session. All participants were told that the goal of the golf swing was to hit the ball with both velocity and accuracy. There was no instruction concerning the swing given to participants in any of the four conditions. Participants in the Control group received no augmented information during practice or retention. The participants in the Accuracy condition were reminded to emphasize accuracy during practice sessions. The participants in the Velocity condition were encouraged to increase their velocity of swing during practice sessions. The participants in the Accuracy and Velocity condition were encouraged to focus on increasing both velocity of swing and accuracy during practice sessions. Analysis of motor pattern change indicated that participants in the velocity conditions improved their swing with practice and retained their swing better than those in the Accuracy alone condition and Control condition. It was concluded that scaling up on the constraint of velocity will improve

the use of the order parameter (open kinetic chain). Results indicate that complex skills such as a golf swing can be learned without the aid of instruction by scaling up on a constraint that becomes a control parameter.

Appendix A:

Human Subjects Proposal

INSTITUTIONAL REVIEW BOARD

PROTOCOL REVIEW REQUEST

The TCU Institutional Review Board (IRB) is responsible for protecting the welfare and rights of the individuals who are participants of any research conducted by faculty, staff, or students at TCU. Approval by the IRB must be obtained prior to initiation of a project, whether conducted on-campus or off-campus. While student research is encouraged at both the undergraduate and graduate level, only TCU faculty or staff may serve as Principal Investigator and submit a protocol for review.

Please submit this protocol electronically to Dr. David Cross, IRB Chair, Dr. Janis Morey, Director of Sponsored Research, and Barbara McGinnis. Also submit a consent document, HIPAA form if applicable, Protecting Human Research Participants Training certificates, recruitment materials, and any questionnaires or other documents to be utilized in data collection. A template for the consent document and HIPAA form, instructions on how to complete the consent, and a web link for the Protecting Human Research Participants Training are available on the TCU IRB webpage at www.research.tcu.edu. **IRB Committee meetings will be held the first Tuesday of each month.** Submission deadline for the protocols is at least ten (10) business days (not counting weekends and holidays) before meetings.

1. **Date:** 17 August 2012
2. **Study Title:** Learning an Ontogenetic Skill: A Constraints Approach
3. **Principal Investigator (must be a TCU faculty or staff):** Dan Southard
4. **Department:** Kinesiology
5. **Other Investigators: List all faculty, staff, and students conducting the study including those not affiliated with TCU.**
   Josi Ferrandino – graduate Assistant
6. **Project Period:** September 2012 – August 2013
7. **Funding Agency:** NA

8. **Amount Requested From Funding Agency:** NA

9. **Due Date for Funding:** NA

10. **Purpose: Describe the objectives and hypotheses of the study and what you expect to learn or demonstrate:**

    The primary objective of this study is to determine if the HKB Model of motor pattern change is applicable to an ontogenetic skill. It is hypothesized that skill levels of individuals learning a golf swing (ontogenetic skill) will increase without instruction by scaling up on a control parameter. Also, the relative phase of joint angles for individuals learning a golf swing will increase in variability prior to transitioning to a new skill level. The increased variability will be followed by a new and more stable pattern of performance

11. **Background: Describe the theory or data supporting the objectives of the study and include a bibliography of key references as applicable.**

    The HKB model (Haken, Kelso, & Bunz, 1985) for motor pattern change comes from a Dynamic Systems (self-organizing) perspective on motor control and coordination. The model predicts that when scaling up on a control parameter (a variable unrelated to the movement pattern but capable of instigating a pattern change) there is increased variability in the phase relationship of limbs at a critical value (point where the control parameter initiates change in coordination). The increased variability is followed by transition to a new pattern of movement that favors the order parameter (mechanical concept about which the pattern of movement organizes itself). The transition results in an increase in skill level. The HKB model is drastically different from other ideas regarding the improvement of skill performance because the transitions to new skill levels are self-organizing and therefore not consciously directed by the performer. There is ample evidence that the HKB model is effective in changing patterns for rhythmical activities such as the oscillating movements of limbs (e.g. Kelso, 1995, Kelso and Scholz, 1985, Kelso & Jeka, 1992) and for fundamental skills such as throwing (Southard, 2006), striking (Southard, 2003), and walking (Thelen & Smith, 1994). However, the model has yet to be tested when learning an ontogenetic skill. An ontogenetic skill is a skill that, theoretically, cannot be learned without directing the performer towards a specific pattern.

References

Haken, H., Kelso. J.A.S., & Bunz, H. (1985). A theoretical model of phase transitions in human
Hand movements. *Biological Cybernetics, 51, 347-356.*

Kelso, J.A.S. (1995). *Dynamic Patterns: The Self-organization of Brain and Behavior.* Cambridge:

MA: MIT Press.

Kelso, J.A.S., & Jeka, J.J. (1992). Symmetry breaking dynamics of human interlimb coordination. *Journal of Experimental Psychology: Human Perception and Performance,* 18, 645-668.

Kelso, J.A.S., & Scholz, J.P. (1985). Nonequilibrium phase transitions in coordinated biological Motion: Critical fluctuations. *Physics Letters A. 118, 279-284*

Southard, D.L. (2003). Warm-up with baseball bats of varying moments of inertia: Effect on bat Velocity and swing pattern. *Research Quarterly for Exercise and Sport.* 74, 270-276.

Southard, D.L. (2006). Changing throwing pattern: Instruction and Control Parameter. *Research Quarterly for Exercise and Sport.* 77, 316-325.

12. **Subject Population: Describe the characteristics of the participant population including the inclusion and exclusion criteria and the number of participants you plan to recruit:**

    Participants will be 40 students attending Texas Christian University enrolled in the primary investigator's classes. Gender is not an issue and all volunteers are welcome to participate. Participants can not have any physical disabilities that could prevent them from swinging a golf driver. Participants will be inexperienced at the game of golf. Inexperienced is defined as never hit a golf ball.

13. **Recruitment Procedure: Describe your recruitment strategies including how the potential participants will be approached and precautions that will be taken to minimize the possibility of undue influence or coercion. Include copies of the recruitment letters, leaflets, etc. in your submission.**

    Participants will be recruited through announcement in the primary investigator's classes. The primary investigator will explain the requirements and expectations of participants. It will be stressed that participation is completely voluntary. Participants will be awarded extra credit and students that choose not to participate will be afforded alternative opportunities to earn extra credit. Students will understand that not participating in extra credit cannot lower their grade – extra credit can only improve grades.

14. **Consenting Procedure: Describe the consenting procedure, whether participation is completely voluntary, whether the participants can withdraw at any time without penalty, the procedures for withdrawing, and whether an incentive (describe it) will be offered for participation. If students are used as participants, indicate an alternative in lieu of participation if course credit is provided for participation. If a vulnerable population is recruited, describe the measures that will be taken to obtain**

surrogate consent (e.g., cognitively impaired participants) or assent from minors and permission from parents of minors.

There will be no monetary compensation for participation. However, students in the primary investigator's classes will be offered extra credit for their participation. Students who choose to participate for extra credit will receive 10 points. The 10 points will be awarded in addition to other points students earn in class (possible 500 pts). Participation can only improve the participant's point total. Students that choose not to participate may be awarded extra credit by completing a library assignment (review and report on 3 Biomechanics journal articles) related to class content. The library assignment will be equal to time spent as a participant. Students that choose to participate will gain first-hand knowledge of data collection procedures in Motor Control/Biomechanics. Participants will also be afforded the opportunity to view and interpret their own data at the completion of the study. Participants are free to withdraw from the study at any time without penalty. Potential participants will be required to read and sign a consent document (Appendix A) that provides the details regarding participation in the study.

15. <u>Study Procedures:</u> **Provide a chronological description of the procedures, tests, and interventions that will be implemented during the course of the study. Indicate the number of visits, length of each visit, and the time it would take to undergo the various tests, procedures, and interventions. If blood or tissue is to be collected, indicate exactly how much in simple terms. Flow diagrams may be used to clarify complex projects.**

Participants will report to the Motor Behavior Laboratory (Room 035 – Rickel Academic Wing of Rec Building) for all data collection procedures. Participants will be initially assessed to determine that they have a low skilled golf swing. Low skilled is defined by the degree to which the participant takes advantage of the open kinetic chain. The initial assessment can be accomplished through simple visual inspection. Participants will first complete stretching exercises for the upper torso followed by five warm-up swings without a ball. Participants will then attempt to hit a practice golf ball off of a standard tee to a padded mat located 5 meters to their front. Participants may swing at their preferred velocity and no instruction will be offered for the 5 warm-up or 5 assessment swings. Eligible participants will be randomly placed into one of four conditions (10 participants per condition). Each Condition requires that participants complete 6 practice sessions (3 sessions per week for 2 weeks) with 12 swings per session. Only one session is allowed within a 24 hr period. At the completion of the 6 practice sessions participants will not practice for one week and return for a retention session. The retention session will consist of 12 trials without any emphasis on velocity and or accuracy. A warm-up similar to the assessment session will precede each data collection session. Each session will take approximately 20 minutes.

Participants in Condition 1 (Control Condition) will be required to strike the golf ball 12 times without any emphasis on velocity of swing or accuracy of ball placement. Participants in the Control Condition will not receive instruction nor augmented information concerning their performance. Participants in Condition 2 (Velocity Condition) will not receive instruction nor augmented information concerning their pattern of swing. Participants in Condition 2 will be encouraged to hit the golf ball with greater velocity (velocity is a control parameter for skills utilizing the open kinetic chain) following the 4th, 8th, and 12th trials. They will also be informed of their average velocity for the previous session and be reminded to increase velocity at the beginning of each successive session. Participants in Condition 3 (Accuracy Condition) will not receive instruction nor augmented information concerning their pattern of swing. Participants in Condition 3 will be encouraged to hit the ball at a preferred velocity and be as accurate as possible (accuracy is a control parameter that typically decreases the efficiency of movement patterns utilizing the open kinetic chain). Accuracy will be determined by ball placement relative to a target placed on the padded mat. The target will be a single line (8 cm wide) drawn vertically on the center of the mat. Accuracy will be recorded in the X axis only. Participants in Condition 3 will receive information and encouragement concerning their accuracy following the 4th, 8th, and 12th trials. Participants in Condition 3 will receive a chart of their ball placement during the previous session at the beginning of each successive session. Participants in Condition 4 (Velocity and Accuracy) will not receive instruction nor augmented information concerning their pattern of swing. Participants in Condition 4 will be encouraged to hit the ball with greater velocity and be as accurate as possible. Participants in Condition 4 will receive information and encouragement concerning velocity and accuracy every 4th, 8th, and 12th trial. Participants in Condition 4 will also receive information and encouragement concerning their velocity and accuracy at the beginning of each practice session.

Swing patterns will be assessed using an infrared 3D motion analyzer. Harmless infrared emitting markers (1 cm in diameter) will be placed on data points (distal and proximal anatomical landmarks of limbs and torso) using double-back adhesive tape. A marker will also be placed on the head of the driver. An infrared detector will collect data regarding the position and velocity of each represented body segment and commercially prepared software will create phase planes (displacement graphed with velocity) and trajectory graphs (kinematic data graphed over time) for each represented segment as well as joints formed by adjoining segments.

16. **<u>Data Analyses:</u> Describe how you will analyze your data to answer the study question.**

Phase planes will be digitized to determine the relative position and velocity of each segment and joint at peak value during the swing. Changes in the relative position of segmental and joint data will indicate a change in pattern of swing. Separate two-way (Condition X Session) MANOVAs will be used to determine significant changes in pattern for the dependent measures of segmental and joint distal lag. Significant MAOVA will be followed by univariate ANOVA to determine variables responsible for significance. Scheffe post hoc procedure will determine means responsible for significant main effects or interactions. Huyhn-Feldt procedure will be used to help compensate for sphericity violation and Omega Square will determine the effect size of the data. Distal lag is determined by subtracting the time to peak velocity of the proximal segment/joint from its distal neighbor (trunk-humerus; humerus-forearm; forearm-hand/club).

Two-way ANOVAs (Condition X Session) will be used to determine differences in accuracy. The dependent measures will be constant and variable error in the X axis.

Partial Correlation procedures will be used to determine the relationships between selected dependent measures both within and between pattern change and accuracy variables.

17. **Potential Risks and Precautions to Reduce Risk: Indicate any physical, psychological, social, or privacy risk which the subject may incur. Risk(s) must be specified. Also describe what measures have been or will be taken to prevent and minimize each of the risks identified. If any deception is to be used, describe it in detail and the plans for debriefing.**

Data will be collected within the confines of the Motor Behavior Laboratory. The only people present during data collection will be the participant, primary investigator, and graduate assistant. There is some risk of muscle strain while swinging the golf club. The risk is minimized by warm-up prior to data collection. Data collection will halt immediately if any participant complains of pain experienced due to data collection. Deception will not be used. There are no anticipated psychological or social risks associated with this study.

18. **Procedures to Maintain Confidentiality: Describe how the data will be collected, de-identified, stored, used, and disposed to protect confidentiality. If protected health information is to be re-identified at a later date, describe the procedure for doing so. All signed consents and hard data must be stored for a minimum of 3 years in a locked filing cabinet (and locked room) in the principal investigator's office, lab, or storage closet at TCU. Your professional society may recommend keeping the materials for a longer period of time.**

Data will be derived from phase planes and trajectory graphs. Data will be represented by number with no way of identifying data with a particular individual. There is no protected health information required for this study. All data and signed consents will be stored in a locked cabinet in the Motor Behavior Laboratory for five years.

19. **Potential Benefits: Describe the potential benefits of the research to the participants, to others with similar problems, and to society.**

Participants will experience first-hand how motor control and biomechanical data is collected. In addition, each participant is encouraged to view and interpret their own data with the supervision of the primary investigator. The results of this study should provide kinesiologists with a better understanding of why motor patterns change and how to increase skill levels.

20. **Training for Protecting Human Research Participants: Submit training certificates for all the study investigators. The training link is available on the TCU IRB webpage at www.research.tcu.edu.**

21. **Check List for the Items That Need to be Submitted: Please combine all the files into one pdf document before submitting the materials electronically to the IRB. To prevent any delay in the approval of your protocol, use the most recent template for the protocol, consent document, and HIPAA form by downloading them from www.research.tcu.edu each time you prepare your materials.**

a.	Protocol	x
b.	Consent document	x
c.	HIPAA form if applicable	na
d.	Protecting Human Research Participants Training certificate for each investigator	x
e.	Recruitment fliers, letters, ads, etc.	na
f.	Questionnaires or other documents utilized in screening and data collection	x

Appendix B:

Texas Christian University
Fort Worth, Texas

CONSENT TO PARTICIPATE IN RESEARCH

Title of Research: Skill Transition and Changes in Coordination Variability

Funding Agency/Sponsor: NA

Study Investigators: Dr. Dan Southard – primary investigator
Ms. Josi Ferrandino – research assistant

What is the purpose of the research?
To determine how people learn motor skills.

How many people will participate in this study?
40 students at TCU.

What is my involvement for participating in this study?
You will be assigned to a condition that will require you to practice a golf swing 2 times a week for 3 weeks at the Motor Behavior Laboratory. One week following your last practice you will be required to return to the Motor Behavior Lab for one last session. For each session you will have harmless markers placed on your limbs and torso as data collection points. A motion analysis system will then identify the markers as you swing the golf club and create graphs that represent your golf swing.

How long am I expected to be in this study for and how much of my time is required?
The study will last 4 weeks. Each of the 7 sessions will take approximately 20 minutes of your time. It will take about five minutes to apply the markers and about 15 minutes to complete the practice swings. We will schedule sessions at your convenience.

What are the risks of participating in this study and how will they be minimized?

There is some risk of muscle strain from swinging a golf club 12 times per session. Risk is minimized by requiring that you warm-up adequately before participating in each session. Also, if you experience any pain while participating, I will stop data collection.

What are the benefits for participating in this study?
At the end of the study you will have an opportunity to view and discuss your data with the primary investigator. The study also affords you the opportunity to learn about data collection in the areas of Motor Control and Biomechanics.

Will I be compensated for participating in this study?
You will be awarded 10 points extra credit for your participation. The 10 points will be added to your total points earned at the end of class.

What is an alternate procedure(s) that I can choose instead of participating in this study?
If you do not participate in the study you can choose to earn extra credit by reporting on 3 Biomechanics articles from Kinesiology Journals.

How will my confidentiality be protected?
There will be no way for anyone other than the primary investigator to match your data with your name. Also, the only people that will be present at data collection are the primary investigator and the research assistant. Data will be stored in a locked computer during data collection. Following the study, data will be stored in a locked cabinet. Only the principal investigator and assistant will have access to the data.

Is my participation voluntary?
Yes.

Can I stop taking part in this research?
You may withdraw from the study at any time without penalty.

What are the procedures for withdrawal?
You should contact Dr. Southard in person, by email (d.southard@tcu.edu), or by phone 817.257.6869 and express your desire to withdraw.

Will I be given a copy of the consent document to keep?
Yes.

Who should I contact if I have questions regarding the study?
You should contact the principal Investigator Dr. Dan Southard (d.southard@tcu.edu) phone 817.257.6869 or the research assistant Josi Ferrandino(j.ferrindino@tcu.edu) phone

Who should I contact if I have concerns regarding my rights as a study participant?
Dr. David Cross, Chair, TCU Institutional Review Board, (d.cross@tcu.edu) Phone 817.257.6416.

Your signature below indicates that you have been read the information provided above, you have received answers to all of your questions and have been told who to call if you have any more questions, you have freely decided to participate in this research, and you understand that you are not giving up any of your legal rights.

Participant Name (please print): ________________________________

Participant's Signature: ______________________ **Date:**__________

Investigator's Signature: ______________________ **Date:**__________

Certificate of Completion

The National Institutes of Health (NIH) Office of Extramural Research certifies that **Dan Southard** successfully completed the NIH Web-based training course “Protecting Human Research Participants”.

Date of completion: 09/10/2008

Certification Number: 89437

Certificate of Completion

The National Institutes of Health (NIH) Office of Extramural Research certifies that Josie Ferrandino successfully completed the NIH Web-based training course “Protecting Human Research Participants”.

Date of completion: 08/17/2011

Certification Number: 726341