Change in throwing pattern: Constrained proximal and distal ends of the open kinetic chain.

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Chapter I

Introduction

Dynamic systems is a perspective regarding coordination and control of movement that may be used to explain how motor patterns change. Dynamic systems perspective considers the motor system to be self organizing. In contrast, traditional viewpoints concerning control and coordination explain motor pattern change in reference to centrally stored programs, schemas, and closed loop servomechanisms. Traditional viewpoints assign order and regulation of movement to an a priori prescription and devices that are conceptually separate from that which is regulated (Kelso, 1981). Traditional theories require that feedback regarding motor patterns, motor programs, or schemas be stored and recalled in order to successfully perform a motor skill and change an existing motor pattern. Dynamic systems proponents view the development of skilled behavior and changing patterns as a natural consequence of the dynamics of the individual, goal of the movement, and the environment in which the skill is performed. With dynamic systems perspective, there is no need to store preprogrammed information concerning motor patterns. Nonetheless, for any movement there are always several options regarding a successful completion. That is, there are always more muscle groups available to the system than is necessary to complete the task. Dynamic systems proponents refer to such choices as “degrees of freedom”. In other words, the motor system is always confronted with a choice.

Bernstein (1967) referred to motor system choices or degrees of freedom as the central issue of motor control. Past researchers have considered degrees of freedom as a problem for the motor system. However, recent investigations have questioned whether degrees of freedom is actually a problem or an asset. Several studies (Gelfand &Latash, 1998; Latash, 1996; Latash, 2000; Turvey, 1990; Turvey&Carello, 1996) suggest that the motor system does not solve the degrees of freedom problem by eliminating redundant degrees of freedom. Rather, the motor system uses redundant degrees of freedom to ensure accurate performance of the task. The motor system uses synergies or coordinative structures to utilize the system's many degrees of freedom without complicating the decisions required to complete movements. A synergy or coordinative structure is a neural process that entrains muscle groups to act as a unit toward a specific movement goal (Kelso, Southard, Goodman, 1979). Synergies may allow for segments to compensate for error in order to ensure accuracy of movement. Such action is called segmental compensation. Segmental compensation cannot occur unless movements possess many degrees of freedom.

Throwing is a skill that is complex with many degrees of freedom. It has been investigated from both a mechanical and dynamic systems perspective. From a mechanical view point the segments of a skilled thrower reach their peak velocities in a proximal to distal sequence (Atwater, 1979). This sequence allows for the more massive proximal segments to transfer their angular momentum to their less massive distal neighbors. As the more massive proximal segment decelerates, it transfers momentum to its less massive distal neighbor, its distal neighbor accelerates reaching a peak velocity greater than its proximal neighbor hence conserving angular momentum ($I_1\omega_1=I_2\omega_2$). This transfer can only be accomplished if the arm acts as an open kinetic chain. An open kinetic chain is a system of links or segments where movement of one segment affects all other segments and the most distal segment is open or free to move about its axis (Kreighbaum & Barthels, 1990; Southard, 1989). Such a system provides the performer with numerous possibilities for segmental compensation, while at the same time organizing itself about a single mechanical principle. We know the basic mechanics of throwing but there is considerable debate concerning how skilled throwing patterns develop given its many degrees of freedom and potential for segmental compensation.

Research Questions

Will limb segments compensate or change their pattern of movement if the distal and proximal ends of the open kinetic chain (hand and trunk) are constrained or prevented from normal movement. What effect, if any, will limb constrainment have on the sequence of development for overarm throwing?

Hypothesis of the study

The hypotheses for this study are: (1) There will be no changes in the timing (no segmental compensation) of free moving segments (relative to an unconstrained control group) resulting from the constrainment of the distal or proximal ends of the open kinetic chain; and (2) the development of a throwing pattern will proceed in a distal to proximal sequence.

Significance of the study

This study should provide Kinesiologists with insight concerning how motor patterns compensate for individual constraints. This will help to better understand the dynamic system perspective of movement and how the movement system adapts to individual constraints as well as provide insight to the sequence of skill development.

Chapter II

Review of Literature

The following review of literature will focus on four components: 1) Biomechanics of throwing; 2) summary of Dynamic systems; 3) Interlimb compensation and 4) development of a skilled throwing pattern.

Biomechanics of throwing

The human body is viewed as a linked segment system for the purposes of mechanical analysis. The motion of a given segment is influenced by the forces generated by muscles and gravitational acceleration acting on that segment and by the motion of linked segments. In multi joint limb movements, torque at one joint occurs not only from the muscles acting at that joint but also from interactions due to rotations of other joints (Hollerbach & Flash, 1982). The net torque around one joint is represented as the sum of muscle torque, gravity torque and interaction torque. Therefore the central nervous system (CNS) is required to generate appropriate motor commands taking all these torques into consideration when executing a desired multijoint movement. The motor system takes advantage of torques at each joint in ball throwing by allowing torque to produce a proximal to distal sequence of joint rotation and acceleration (Hirashima, Kudo, & Ohtsuki, 2003).

The motion of a given segment is influenced by the motion of adjacent linked segments. The coupled interaction between the linked segments may be particularly important in free segment motion such as when the distal link is not restrained (Phillips, Roberts, & Huang, 1983). Kinematic observations of faster movements have indicated a rather distinctive relationship between adjacent links undergoing free segment motion. Proximal segments initiate the movement but tend to decrease speed or even reverse direction concurrent with a dramatic increase in angular acceleration and subsequent angular velocity of the distal adjacent segment. This phenomenon has been reported when describing patterns for mature throwers (Atwater, 1970; Cooper & Glasgow, 1976), kickers (Robert & Metcalf, 1968; Zernicke & Roberts, 1976) and runners (Elliot, 1977). Mature throwers display a pattern of distal lag. Distal lag is when the distal segment lags in time behind its proximal neighbor. That is, when executing a throw the distal segment reaches peak velocity after its proximal neighbor (Southard, 1998).

The over-arm throw consists of sequentially timed co-ordination of accelerations and decelerations of all body segments. The sequence in which the segments of a skilled thrower reached their peak angular velocity is: pelvis, upper trunk, upper arm, forearm and hand (Atwater, 1979). As each segment accelerates in turn, the succeeding distal segment lags behind, then acquires the speed of the segment moving it and accelerates to reach an even greater angular speed while the proximal segment decelerates. The system attempts to conserve angular momentum generated by proximal segments.

There is evidence to indicate that velocity of throw is more related to body rotation and subsequent distal lag. When extension of the forearm throw was compared with the normal overhand throw utilizing distal lag, the intensities of muscle activity in triceps were similar for both throws but angular range and angular velocity of elbow extension prior to release were almost twice in the normal throw than in forearm throw. The contribution of elbow extension to speed of ball appeared to result not only from power caused by voluntary contraction of triceps but also from torque produced by rotation of the body (Toyoshima Hoshikawa, Miyashita & Oguri, 1974). Such activity is described as similar to a whip with the distal segment increasing velocity as the proximal segment is rotated (Toyoshima et al, 1974).

Dynamic systems perspective

A dynamic system is a system that changes over time (Crutchfield, Farmer, Packard, & Shaw, 1987; Rosen, 1970). Dynamic systems perspective of movement views the motor system as self-organizing. Patterns of movement can emerge from the interaction of system components within the context of a given task and without instruction generated from stored information. Biological systems prefer a certain movement context and this is characterized by consistency of movement patterns. Stable patterns were defined by Abraham & Shaw (1982) as attractor states. Attractor states may be flexible in that they can change to fit the context of the movement.

The attractor state can be defined as a comfortable or dominant state of executing a motor task. These dominant states are defined by an order parameter (Haken, 1977). Order parameters are usually mechanical principles that reflect change in pattern by allowing the system to organize within a context of constraints. For example the order parameter for throwing is the open kinetic chain which allows the motor system to take advantage of a mechanical principle, the transfer of angular momentum. Southard (1989) investigated changes in an arm striking pattern as a result of practicing striking a racquetball with the hand from a batting tee. He found that correlations between angular momentum, angular velocity and moment of inertia substantiate the link between changes in angular momentum and changes in velocity. The sequence of transfer of angular momentum occurred from humerus to forearm, and finally from forearm to hand (Southard, 1989). The order parameter acts to constrain or compress the degrees of freedom available to the elemental components. Order is created in the process of the action. At critical points, the system may lose its ability to maintain attractor states and fluctuations in pattern occur (Thelen, 1989). Following these fluctuations the system may change to a new attractor state according to the mechanical principle or order parameter. Thelen (1986) investigated gait pattern by studying treadmill elicited stepping in seven month old infants and found that when 7 month old infants were supported on a treadmill, they performed a mature adult like gait pattern. Thelen (1986) concluded that in independent locomotion, much of the force is derived not so much from active muscle contraction but by passive and inertial forces built into the stance leg as it is stretched backwards. Thelen and Smith (1994) stated that for stepping pattern, there was no program to be overridden, there was only resonance of biomechanical properties of the legs moving within the context of the environment, thereby assembling into a stable self organized state. Thelen and Smith (1994) determined that the pendular action of the legs was an order parameter for walking. They found that infants that were supported in an upright position utilize the pendular action of the legs to organize a stepping pattern.

For a pattern change to occur, system components must reorganize towards a new attractor state. Control parameters are required for instigating change. A control parameter may be any variable which when scaled beyond some critical value allows the system to organize itself in a different way and attain a new attractor state. Careful description of potential control parameters is an important first step in a dynamical analysis of a developing system (Clark, 1997). Knowing the control parameter for a skill is the key to changing a pattern. Control parameters are non-essential elements to the motor pattern. That is, they are variables that are not part of pattern itself. For example Kelso, Scholz & Schoner (1986) demonstrated that frequency of finger movements act as a control parameter. When the participants scaled up on frequency of anti-phase movement of the index fingers (index finger of one hand moves away while the index finger of other hand moves towards the mid-finger), there was a transition of coordination pattern from anti phase to in-phase coordination pattern (index finger of both hands moves in same direction at the same time). The change for anti-phase to in-phase was dictated by the velocity of finger movement. Frequency of finger movements served as control parameter which when scaled up to a critical value changed the pattern of movement from anti-phase to in phase.

To identify control parameters for a specific movement pattern one has to identify and control essential variables to task performance and then scale up on suspected control parameters (Thelen, 1989). Thelen, Skala and Kelso (1987) found that adding mass to the legs of 6 week old infants resulted in a decrease in rate of kicking of weighted limb and an increase in the rate of kicking of the unweighted limb to maintain a baseline kicking rate. Thelen et al. (1987) concluded that fluctuating changes in parameters such as mass and stiffness in dynamic relation to pattern generation can determine movement outcome. McMahon (1984) studied the gait pattern of horses. He found that as the horse continuously increases its speed, its gait shifted discontinuously from a walk to a trot to a gallop and finally a run with no stable intermediate pattern. He concluded that rate of step cycle acted as a control parameter for gait pattern for quadrupeds. Southard (1998) examined the control parameters for throwing by scaling segmental mass and throwing velocity. He found that increasing the mass of proximal segments of a low level thrower resulted in a sequence of distal lag that relates to a more advanced thrower. Whereas adding mass to the distal segments changed the sequence of lag for high level throwers to resemble throwers at lower levels. Throwing at maximum velocity independent of changes in relative mass resulted in a change in attractor state for throwing. The results provided evidence for relative mass of segments and velocity of throw as control parameters for throwing. Southard (2002) also determined the critical value for the control parameter of velocity. He scaled up on velocity of throwing by requiring subjects to throw in 10% increments from 10% of subjects' maximum throwing velocity to maximum throwing velocity. He found that low level throwers changed patterns at lower velocities than high level throwers. The critical value for level 1 throwers for the wrist joint occurred at 40% and 90% of maximum velocity and at 20% of maximum for the elbow joint. For level 2 throwers, the critical value for the wrist occurred at 10% and 90% of maximum velocity and at 10% of maximum for the elbow joint. For level 3 throwers the critical value for the elbow joint occurred at 10% of maximum and for level 4 throwers, the critical value occurred at 100% for the wrist. Southard concluded that critical values varied according to level and joint.

Interlimb compensation

There are many more elements available to the motor system than those necessary to solve a motor task (Latash, Danion, Scholz, & Schöner, 2005). To further complicate the issue, a motor task formulated at a certain level of analysis does not prescribe a single particular pattern at a lower, multielement level. The controller (motor system) always seems to be confronted with a problem of choosing a particular way of solving each particular problem. (Turvey, 1990). Gelfand & Tsetlin (1966) formulated a principle of non-individualized control in which systems are not controlled individually, but united in task specific or intention specific structural units. These structural units are organized by the motor system in a flexible, task-specific way for a particular purpose. Such structural units are termed synergies or coordinative structures. Domkin, Latash, Johansson & Jaric (2002) studied a pointing task by requiring the subjects to move a pointer with one hand and moving a target with the other hand. The subjects practiced the pointing task with both arms while attempting to be as fast and accurate as possible. They found that the ratio of components not affecting the task variable to components affecting the task variable (R_v) is greater for stabilization of vectorial distance between target and pointer (bimanual synergy) than stabilization of trajectory of each arm (unimanual synergy). They concluded that the joints of both arms for the bimanual pointing task were united in a bimanual synergy rather than the superimposition of two unimanual synergies. Kelso, Southard, and Goodman (1979) required subjects to move the hands lateral and away from the midline of the body to targets of disparate difficulty. Movement time to each target would be predicted by Fitts' law (1954). Fitts found that movement time = $\log_2 (2A/W)$, where A is the amplitude of movement and W is the width of the target. Therefore movement time is directly proportional to movement distance and inversely proportional to target width. Kelso et al. (1979) found that paired movements to targets of equal or unequal difficulty were terminated simultaneously. Even when the task demands were different, the hands performed in a unitary manner. Their data indicated the existence of coordinative structures or synergies by demonstrating the entrainment of muscle groups controlling the upper limbs to act in a unified way when moving targets of disparate difficulty. Synergies help the motor system to control structural elements by acting in a unified way towards a particular movement goal. In the process synergies may allow the system to compensate for errors during a movement to ensure accuracy.

The Central Nervous System (CNS) does not try to find a unique solution for the problem of kinematic redundancy by eliminating degrees of freedom (DOF). Rather, the motor system uses the apparently redundant choices to ensure more accurate performance of the task. Bernstein (1967) studied the kinematics of striking movements. He examined a professional blacksmith striking a chisel with a hammer. He noticed that variability of the trajectory of the tip of the hammer over a series of strikes was smaller than the variability of the trajectories of the individual joints of the arm. Bernstein (1967) concluded that the joints were not acting independently but were correcting each other's errors. Latash & Zatsiorsky (1998) explained this phenomenon as the principle of error compensation or the principle of minimal interaction. The principle of minimal interaction states that the effects of a change in the output of an element on a structural unit is minimized by changes in the output of other elements (Gelfand & Latash, 1998).

Several studies have examined the compensatory activities of segmental elements during multi-element movement. Abbs & Gracco (1984) evaluated the contribution of afferent information to the control of speech movements by applying unanticipated loads to the lower lip during generation of combined upper lip - lower lip speech gestures. Compensatory responses in multiple facial muscles and lip movements were observed, but speech goals were never disrupted. This suggested that for complex movements, adjustments of subcomponents will not disrupt the goal of the task. Changes in lower and upper lip torque was compensated by remaining degrees of freedom. Li, Latash & Zatskiorsky (1998) studied ramp force production by four fingers acting in parallel. During ramp force production, participants were asked to increase the pressing force of the fingers for 5 sec. and maintain maximum force for 5 sec. This was followed by decline in force before getting to zero in 5 sec. The study showed that variance of total force at higher force levels was smaller than sum of variances of individual finger forces. This finding indicates that during a multi-finger task remaining fingers compensate for the variances in force production of one finger. In another study, subjects were asked to produce a constant force with three fingers of a hand and then to tap a few times with one of the fingers (Latash, Li and Zatsiorsky, 1998). During the first tap, the tapping finger lost contact with the surface and stopped contributing to the total force. The other non-tapping fingers showed an out of phase increase in their forces such that over 90% of the lost force was compensated for. These results suggest that there is a degree of error compensation among the fingers that tends to stabilize total force. Studies involving segmental compensation serve as evidence to indicate that limb segments and fingers act in a synergistic fashion and compensate for each other in a variety of motor tasks. If one segment during a movement changes its intended path other segments will compensate for this change in order to accomplish the movement goal.

Development of skilled Throwing pattern

The sequence of change for developing throwing pattern has logically paralleled the sequence of segmental velocity for a mature throw. That is, development is assumed to take place in a proximal to distal sequence. Halverson, Roberton and Langendorfer (1982) completed a longitudinal study of the development of throwing for children from

6 to 13 years. They filmed the forceful over arm throws of more than 70 kindergarten children. The children were filmed over 3.3 years for forceful throwing. They described the children's progress through developmental sequences from proximal to distal (trunk, humerus, and forearm) actions. In a more recent study, Langendorfer and Roberton (2002) explained the developmental relationships for throwing across components. They provided evidence that trunk action during development of throwing is the first to occur, followed by the humerus and finally the forearm action. Langendorfer and Roberton observed 14 of the possible 27 combinations (throwing profiles) of developmental steps of three components (forearm, humerus, and trunk). They found a tendency for children to change from no trunk rotation to trunk rotation before the upper arm and forearm advanced to higher level. They also hypothesized that trunk rotation may serve as a control parameter for pattern change. Southard (2006) has presented an opposing point of view. He investigated throwing from a dynamic systems perspective and found that throwing develops distal to proximal. That is, the hand is the first segment to display distal lag and the trunk is last. He divided throwers into four levels according to their use of the order parameter (open kinetic chain) to allow for transfer of angular momentum. He found that encouraging trunk rotation without increasing velocity (control parameter) does not help to develop a throwing pattern. In fact, encouraging trunk rotation without increasing velocity impeded development of a global pattern. Southard determined that when participants scaled up on velocity with no instruction the first segment to demonstrate distal lag was the hand. He concluded that instructions to rotate the trunk required more practice to reach a mature pattern than simply scaling up on the control parameter. See figure 1 for trajectory graph that represent immature and mature throwing

patterns.

Purpose of the study

The purposes of this study are to examine 1) how the upper limb segments make adjustments for throwing in order to compensate for a constrained distal and proximal segment; and 2) determine if trunk rotation or hand lag is the initial change toward a mature pattern of throw. Data from this study should provide Kinesiologists with a better understanding of how segments in an open kinetic chain compensate when constrainment occurs. Also, data should help determine whether rotating the trunk or distal hand lag is of primary importance in initially developing a throwing pattern.

Chapter III

Method

Participants

Participants were 21 healthy, right arm dominant, university students (18-25 years). Participants signed an informed consent form approved by the university prior to participation.

Apparatus

Data were collected at a sampling rate of 200 Hz. with a WATSMART motion analysis system (Northern Digital Inc.). Two infrared cameras were mounted on a tripod and set to a height of 2 meters. The cameras were located 2 meters apart and were centered on the throwing motion. The distance between the two cameras was 3 meters. The arrangement of cameras easily contained the throwing motion. The system was calibrated by using a frame of known dimensions before each data collection (the range of error for data collection was = 1.06-9.46 with a mean of 4.5). Infrared emitting diodes (IREDS) were used as markers and placed at five locations. The locations were the nail of the middle finger, ulnar styloid, lateral epicondyle, glenohumeral axis, and spinous process of the first thoracic vertebra . The IREDS attached on each segment were 5 mm. in diameter. Infrared emitting diodes were held in place by double back adhesive tape and self adhesive tape. The power source for IREDS was secured to the participants lower back with self adhesive tape. Wires from the power source were routed so as not to interfere with a throwing motion. The throwing velocity was monitored with a Jugs radar gun.

Procedure

Participants were randomly placed in one of three conditions. Condition1 required participants to throw a baseball size ball to a mat located 5 meters away. Participants were encouraged to throw at maximum velocity without regards to accuracy and received no augmented information except encouragement to increase throwing velocity. Participants were required to throw with the non dominant limb (left handed). The non-dominant limb has been shown to display an immature pattern of throwing regardless of throwing level for the dominant limb (Southard, 2006). An initial immature pattern was required so as to investigate the sequence of throwing development. Participants in condition 1 performed 2 throwing sessions per week for 3 weeks for a total of six sessions. Participants completed 10 trials per session.

Condition 2 was identical to Condition 1 except that the hand was constrained during throwing trials. Constrainment was accomplished by placing a rigid wrist brace (2cmX10 cm) on the back of the hand and forearm. The brace was used to prevent extension of the hand beyond a point in line with the forearm thereby preventing distal lag of the hand. Condition 3 was identical to Condition 1 except that the trunk was constrained. Constrainment of the trunk was accomplished by requiring participants to throw from a seated position in a chair. To further prevent rotation of the trunk, participants were secured to the back of the chair by placing self adhesive wrap about the trunk and back of chair. Participants in each condition were instructed to throw at maximum velocity. There was no augmented information provided to participants other than encouragement to increase throwing velocity. At the completion of three weeks of practice participants returned to the lab following 1 week of no practice to complete a retention session. The retention session required participants in each condition to throw 10 trials without any constrainment and at their maximum velocity. Each participant was required to warm up prior to data collection by completing 5 throws at a sub maximal velocity.

Design of the study and statistical analyses

A between subject design was utilized for this study. Segmental lag and peak velocity differences were the dependent measures. Segmental lag is the time to peak velocity (TTPV) of the distal segment minus TTPV of its proximal neighbor. Time to peak velocity (TTPV) is the relative time from a common starting point to the point at which each segment reaches its peak velocity. Segmental lag was determined in milliseconds, and the relative position of segments determined a positive or negative value. Positive lag is when the distal segment reaches peak velocity after its proximal neighbor. Negative lag is when the distal segment reaches peak velocity before its proximal neighbor. Peak velocity differences were determined by subtracting PV of the distal segment minus PV of its proximal neighbor. Peak velocity differences were determined in mm/sec. and provide additional information about the systems' use of the transfer of angular momentum. A positive value of PV difference indicated that peak velocity attained by the distal segment is greater than its proximal neighbor. Positive segmental lag does not mean the motor system is taking advantage of the order parameter unless there is also positive velocity difference between segments. Peak velocity (PV) and time to peak velocity (TTPV) were digitized from trajectory graphs using commercially prepared software for the WATSMART system.

Separate two way (Condition x Session) MANOVAs were used to determine the significance for segmental lag and velocity differences. Significant MANOVA was followed by Univariate ANOVA to determine variables responsible for significance. A Scheffe' Post-Hoc test was used to determine dependent measures responsible for significant ANOVA. Statistical significance was set at $p<.05$ for all analyses. Huyhn-Feldt adjustment was used to account for the violation of Law of Sphericity. Effect size was represented by R^2.

Chapter IV

Results

Segmental Lag

MANOVA indicated a significant main effect for condition, (Wilks' lambda =.888, F(6,2352)=23.90, R^2=.035, p<.001) and for session (Wilks' lambda=.922, F(18,3326)=5.388, R^2=.171, p<.001), as well as a significant condition x session interaction (Wilks' lambda= .877, F(36,3475)=4.373, R^2=.129, p<.001). Follow up univariate ANOVA indicated that forearm lag (F (2,1178) =50.255, p<.001), and humeral lag (F (2,1178)=38.143, p<.001) were responsible for the main effect by condition. Forearm lag (F (6,1178)=10.724, p<.001) and humeral lag (F(6,1178)=4.893, p<.001) were responsible for the significant main effect by session. Hand lag (F (12,1178)= 2.424, p=.004), forearm lag (F(12,1178)=6.981, p<.001) and humeral lag (F(12,1178) = 5.847, p<.001) were responsible for the significant interaction. Post hoc analysis of condition X session interaction indicated that greater values for forearm and trunk lag in the constrained trunk condition and positive hand lag in the control condition were responsible for the significant interaction. The data indicate that in the unconstrained condition (control group) the hand experienced positive lag (session 3) before the trunk. The forearm experienced positive lag for all conditions and sessions. Apparently the humerus does not lag in order to compensate for a constrained hand and the hand does not lag to compensate for the constrained trunk. However, it should be noted that the only condition to experience positive hand lag in the retention session (session 7) was the trunk constrained condition (Condition 3). See figure 2 for a graphic representation of segmental lag by condition and session.

Peak velocity differences

MANOVA indicated significant main effects by condition (Wilks' lambda= .515, F(6,2352)=154.383, R^2=.137, p<.001), and session (Wilk's lambda =.802, F(18,3326) = 15.037, R^2=.169, p<.001) with a significant condition and session interaction (Wilk's lambda = .746, F (36,3475) =10.089, R^2 =.294, p<.001). Follow up univariate ANOVA shows that Peak velocity differences for the hand (F (2, 1178) =53.006, p<.001), forearm (F (2, 1178)=53.298, p<.001) and humerus (F (2, 1178)=142.263, p<.001) were responsible for the main effect by condition. Peak velocity differences for the hand (F (6, 1178) =3.196, p=.004), forearm (F (6, 1178) = 13.162, p<.001) and humerus (F (6, 1178) = 8.579, p<.001) were responsible for the significant main effect by session. Peak velocity differences for the hand (F (12, 1178) = 5.295, p<.001), forearm (F (12, 1178) = 4.588, p<.001) and humerus (F (12, 1178)=13.163, p<.001) were responsible for the significant interaction. Post hoc analysis of the condition X session interaction indicated that peak velocity differences for the hand were positive across sessions for the trunk constrained condition. Negative values for peak velocity differences of the hand were experienced by the hand constrainment condition for all sessions and session 2 and 7 for the control condition. Peak velocity differences for the forearm and humerus were positive across condition for all sessions. The peak velocity data indicate that angular momentum was transferred due to consistent positive segmental lag. That is, there were no instances where segmental lag was positive but peak velocity differences were negative for any segment by condition or session. See figure 3 for a graphic representation of peak velocity differences by condition and session.

Chapter V

Discussion

The results of the study do not support the first hypothesis that no changes in the timing (no segmental compensation) of free moving segments (relative to an unconstrained control group) will occur as a result of constrainment of the distal or proximal ends of the open kinetic chain. The results of the study support the second hypothesis that development towards a mature throwing pattern (defined by positive segmental lag) occurs in the distal segments first. The unconstrained control group was the only group to attain positive hand lag during the six practice sessions. Surprisingly, when the trunk was constrained there was no positive hand lag during practice. Apparently, hand lag is the first to appear but may require the interaction of the remaining segments. This assumption is supported by past research that indicates the inter-relationship of segments during throwing (Joris, Edwards van Muyen, Schenau, and Kemper, 1985; Hirashima, Kudo, and Ohsuki, 2003; Putnam, 1993). The proximal segments transfer angular momentum to distal neighbors and distal neighbors exert torque on proximal neighbors. It is not possible to determine if constraining the hand affected humeral lag since humeral lag was consistently negative throughout condition and sessions. However, constrainment of the trunk apparently prevented the hand from experiencing positive lag during practice. Notice that there is no positive hand lag in condition 3 (trunk constrainment) compared to the control conditions. This finding further supports the interactive nature of limb segments in order to develop a more skilled pattern. The lack of positive lag for the hand in condition 3 compared to the control condition also supports a change in timing resulting from limb constrainment. That is, when the trunk is constrained the system compensates by maintaining negative hand lag during practice sessions. Interestingly, the only conditions where there was positive hand lag at the retention session were the constrained conditions. The lack of positive lag during constrainment but appearance of positive lag without constrainment in the retention session further supports the interaction of all segments during the task of throwing. That is, positive hand lag may require the movement of the trunk in addition to movement of the forearm. Since humeral lag did not occur in session 7, it may be that movement of the trunk in the X axis is important to hand lag. Data indicates that for the retention session that the trunk did not precede the humerus in peak velocity but was free to move in the X axis during the throw. Distal hand lag in the 7th session may also be a further indication of the sequence of skill development. That is, when segments were free to move without constrainment, the only change was hand lag. The pattern of lag for constrained condition is similar to that of the control group in the 3rd session. In conclusion, constrainment of the trunk or the hand while throwing results in segmental compensation of remaining free moving segments of the limb. The development of throwing pattern follows a distal to proximal sequence since the hand is the first segment to show distal lag.

Throwing is a skill which is required for many sports such as baseball, basketball, football and, softball. The understanding of sequence of development and effect of constraints on development of mature or skilled throwing patterns may help to develop an effective instructional strategy for coaches and physical education teachers. Data indicates that free movement of the trunk may be important to developing hand lag. This should not be interpreted to mean that instruction should concentrate on trunk rotation. On the contrary, initial trunk rotation is not the sequence for natural development of the throw. Instruction should be limited to scaling up on non-essential variables (control parameters). It would be difficult to instruct throwers to obtain hand lag since this lag is primarily a product of the dynamics of the throw relative to the open-kinetic chain. The best strategy would be to scale up on a control parameter and allow the system to self-organize. Practice should be accomplished without constraints that might change the natural sequence of pattern change.

Future studies that examine this issue should consider reproducing the conditions of the present study. However, rather than end the practice at 6 sessions, all conditions should continue practice for six more sessions with no constraints. This would allow the examination of the possibility that positive hand lag is a function of no constraints. That is, the constrained conditions in follow up sessions should have patterns similar to the control conditions during the first 6 sessions.

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Figure Captions

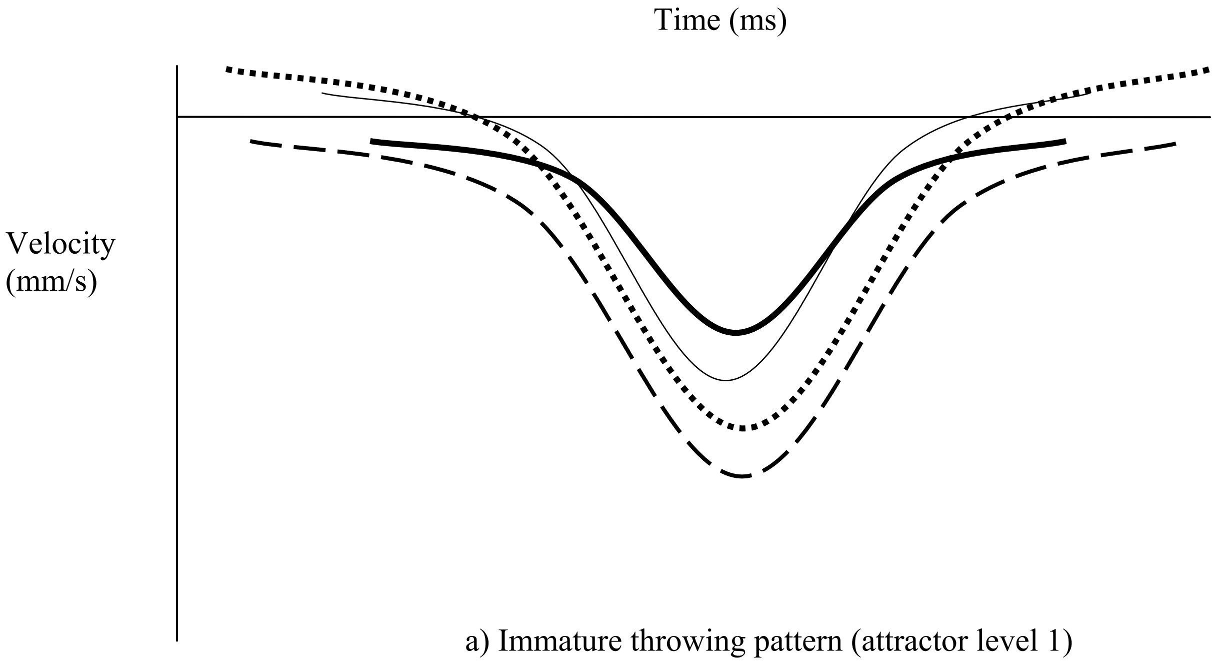
Figure 1. Trajectory graphs showing relative position of limb segments during
a) immature throwing pattern, b) mature throwing pattern.

Figure 2. Graph showing interaction between means for segmental lag by session for control, hand constrained and trunk constrained conditions.

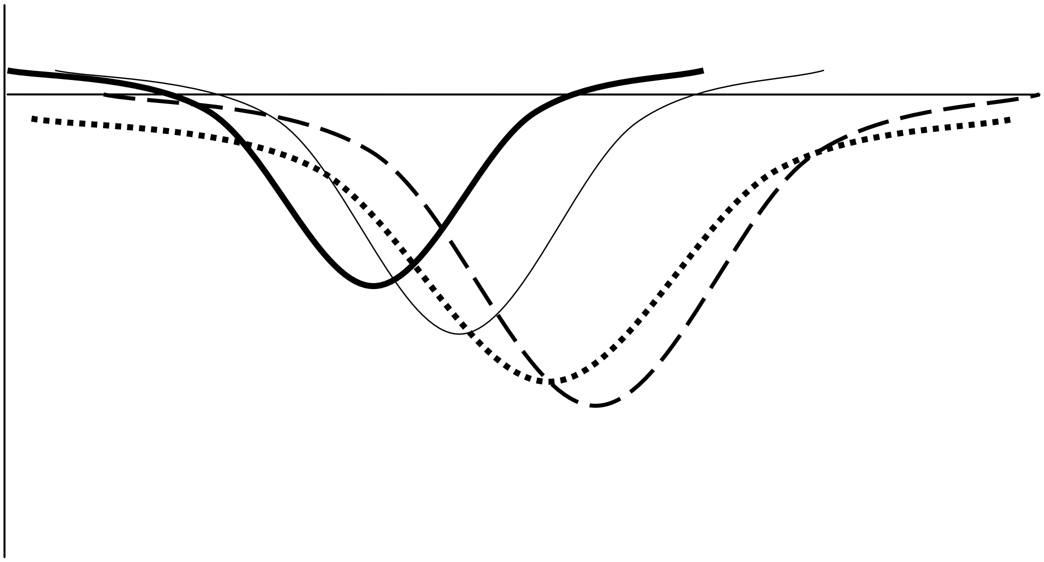
Figure 3. Graph showing interaction between means for peak velocity differences by sessions for control, hand constrained and trunk constrained conditions.

Figure 1.

Trajectory graphs for overarm throwing



a) Immature throwing pattern (attractor level 1)



b) Mature throwing pattern (attractor level 4)

Figure 2.

Means for segmental lag by condition and session

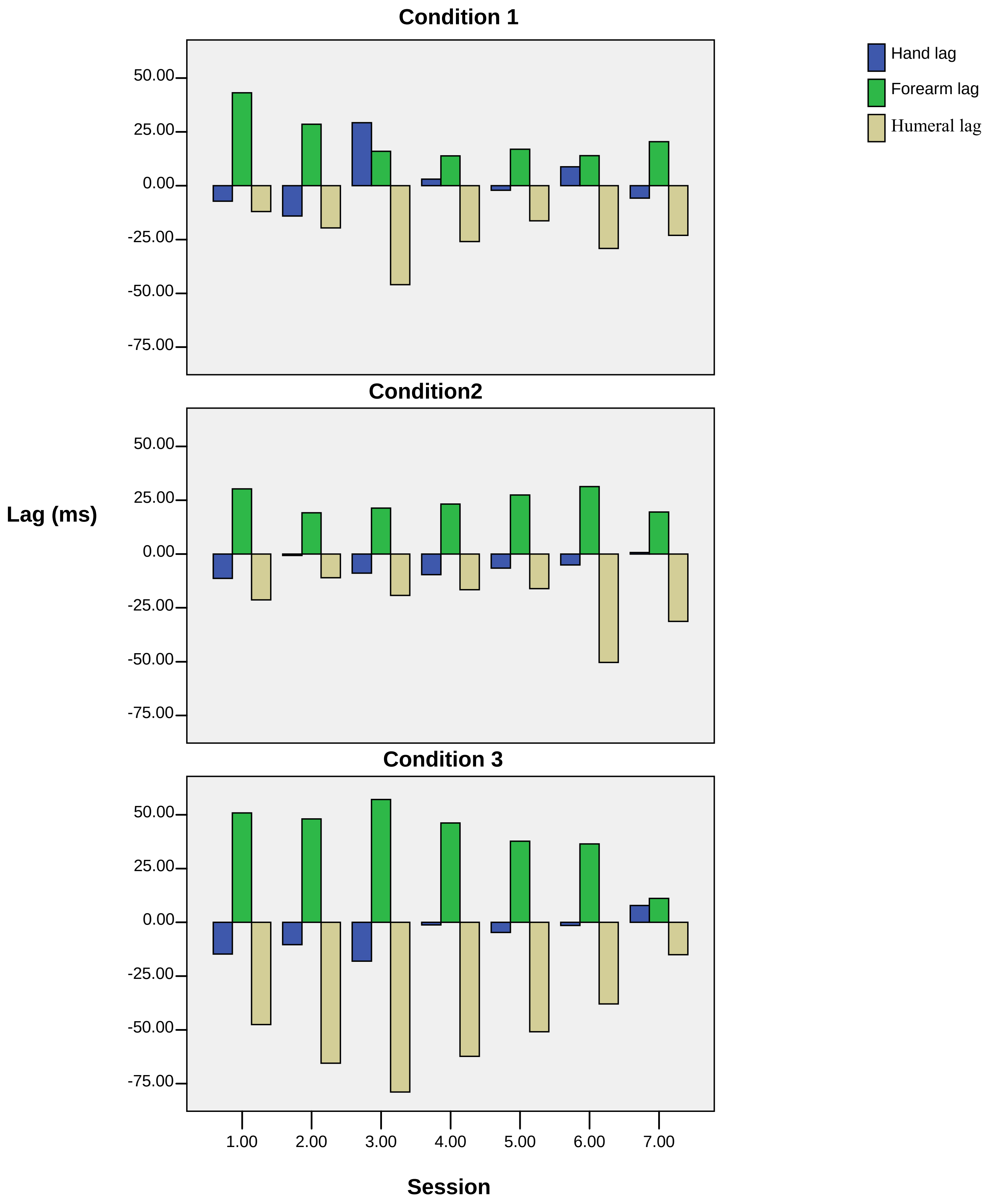
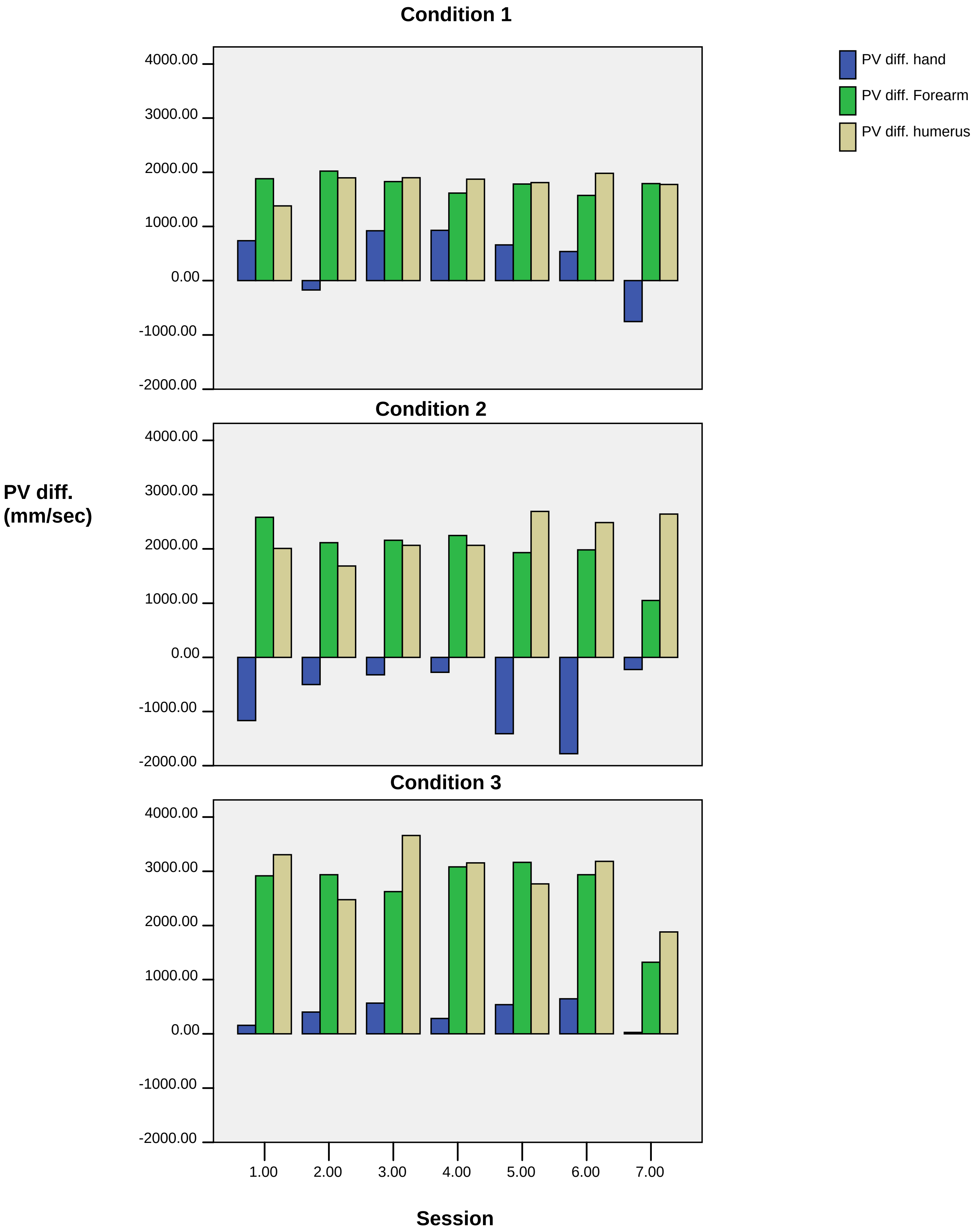


Figure 3.

Means for peak velocity differences by condition and session



ABSTRACT

Change in Throwing Pattern: Constrained proximal and Distal ends of an Open Kinetic chain

By Pradeep Bansal, M.S., 2007

Department of Kinesiology

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Thesis Advisor : Dan Southard, Ph.D.

The purposes of the study were to; 1) examine how the upper limb segments make adjustments for throwing in order to compensate for a constrained distal and proximal segment; and 2) determine if trunk rotation or hand lag is the initial change toward a mature pattern of throw. Twenty one right hand dominant college age students (age 18-25) participated in this study. Participants were placed in three conditions. Condition 1 required participants to throw with their non dominant arm at their maximum throwing velocity without any constrainment. Participants performed 2 throwing sessions per week for a total of six sessions with 10 throwing trials per session. Condition 2 was identical to Condition 1 except that the hand was constrained during throwing trials. Condition 3 was identical to Condition 1 except that the trunk was constrained during throwing trials. A retention session with no constraints followed the six practice sessions. A WATSMART motion analysis system was used to collect data using infrared emitting diodes (IREDS) placed at five anatomical locations. Two separate two way MANOVAs (condition x session) were performed on dependant measures of Segmental lag, and peak velocity differences (hand - forearm, forearm - humerus, humerus - trunk). Follow up One way Univariate ANOVA served to identify the variables responsible for significant

MANOVA. Results indicated that constrainment of distal and proximal ends of an open kinetic chain results in compensatory activity in free moving limb segments. When the trunk was constrained negative hand lag was maintained during practice sessions. When the hand was constrained humeral lag was consistently negative throughout all sessions. Results support the interactive nature of limb segments. It was concluded that development of throwing pattern follows a distal to proximal sequence.

Written Summary

This experiment is designed to help movement scientists understand the factors that contribute to the coordination and control of movement. In addition to providing data that addresses coordination and control of movement, participants will have the opportunity to participate in the analysis of movement by viewing and interpreting their own data.

Should you provide your consent, you will be required to throw a baseball size ball with the non-dominant arm (left arm) at a padded mat located 5 meters in front of you. You will be randomly placed in one of three conditions. Condition 1 will require that you throw the ball at maximum velocity towards the padded mat without any constraints. Condition 2 will require to throw the ball at maximum velocity at the mat while your wrist is constrained with a brace. The brace will prevent wrist extension during the throw. The brace will be placed so as not to cause any pain during the throwing motion. Condition 3 will require you to throw the ball while your trunk is constrained by throwing from a seated position. Your trunk will be secured to the back of a chair by placing self adhesive wraps about your trunk and the back of chair. Each condition will consist of 2 throwing sessions per week for 3 weeks for a total of six sessions. There will be an additional 7th session in which the participants in all three conditions are required to throw without any constraints. This condition will be following one week with no practice. Data collection sessions will consist of a warm-up (stretching followed by warm-up throws) at submaximal velocity and 10 throwing trials per session at maximum velocity. In order to collect data during the trials I will attach small (5mm) infrared emitting diodes (IREDS) to the back of your neck, shoulder, elbow, wrist, and middle finger of your throwing arm. IREDS are attached with double-back adhesive tape and emit harmless infrared light. There is minimal risk of muscle strain that could occur during trials. If you notice pain or any discomfort while performing trials, let me know immediately and I will discontinue data collection. Should you need medical attention following completion of trials, you should contact your personal physician.

Participants are free to withdraw their consent and discontinue participation at any time without penalty or prejudice. If you have any questions regarding procedures, I will be happy to address them.

I have discussed the above points with the participant. It is my opinion that the participant understands the risks, benefits, and obligations involved with this project.

____

Investigator

Consent Form

Project Title**:** Change in throwing pattern: constrained proximal and distal ends of an open kinetic chain.

I, _____________________________, hereby certify that I have been told by Pradeep Bansal.: student of M .S Kinesiology in the Department of Kinesiology about research concerning motor coordination and control and its purposes. I have been told about the procedures to be followed. I understand the possible discomforts, risks, and possible benefits relating to this project.

A written summary of what I have been told is attached. I have been given an adequate opportunity to read the summary.

I understand that I have the right to ask questions about any procedure and to withdraw my consent and participation in the project at any time without prejudice to me.

I hereby freely consent tot take part in this project.

_____________________________ _______________

Signature of Participant Date

If you have any questions at any time concerning this project or your rights as a participant, please call: Pradeep Bansal (732) 948-1922 , Principal Investigator , Dr. Dan Southard (257-6869), faculty professor, Department of kinesiology or Dr. Debbie Rhea, (257-6861) Chair, human subjects committee department of kinesiology.