Control Parameter and Critical Value for Throwing: An Investigation of Ball Diameter to Hand Length Ratio

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Submitted to the Graduate Faculty of

The Harris School of Nursing and Health Sciences Texas Christian University

In partial fulfillment of the requirements for the degree of

Master of Science

DEC 2007

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ACKNOWLEDGEMENTS

The author wishes to appreciate the following individuals:

Dr. Dan Southard for his favor and willingness to advise on everything of my thesis. If he was not my advisor, I could not ever have done my thesis. He is the best advisor for me. If I will be able to teach any students and do any researches one day, I want to do those things like Dr. Southard. I really appreciate for everything while I study at Motor Behavior Lab in TCU. I really respect Dr. Southard. Thank you so much, Dr. Southard.

My parents (Dongyoon Lee and Yeonhee Kim) for supporting, believing, and loving me. They always support, believe, and love me even though they are unhealthy body conditions. I love them and I really appreciate them for everything.

My two sisters (Jeongrim Lee and Jinsung Lee) for supporting and encouraging me.

Dr. Joel Mitchell and Dr. David Upton for advising and considering my thesis.

Dr. Deborah Rhea, Dr. Melody Phillips, Dr. Matthew Johnson, Dr. Meena Shah, Dr. Carol Pope, Dr. John Gotwals, and Elizabeth Pettijohn for favoring me.

Pradeep Bansal, JD House, and Jain Nitin for assisting data collection of my thesis.

Dr. Kookwoong Seo for first giving me an opportunity to study Biomechanics.

Dr. Younghoon Park, Dr. Changhong Youm, and all Biomechanics Lab members in Pusan National University.

Minsung Kim, Jihoon Lee, Sungil Gong, Dongki Lee, Hyunjun Choi, Haedong Kim, Whanho Chun, Robert Soulliere, Haewha Seok, Hyunha Kim, My graduate classmates and Korean friends in TCU, Hanmaum members, and Sulsong 21th my best friends.

My future lovely wife for coming to me, believing, and loving me.

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CHAPTER 1

Introduction

Dynamic systems theory provides a context to describe and understand how motor patterns change. The dynamic system perspective takes the viewpoint that motor patterns and skill development are self-organizing (Gallahue, 2005). An explanation for the concept "self-organization" requires an understanding of common terms and concepts related to a dynamic or changing system to include stability, attractor state, constraints, control parameter, critical value, and order parameter. A stable state that lacks relative variability and is a preferred pattern of movement is called an attractor state. Constraints are information to the system that set boundaries for behavior and determine the characteristics of attractor states. Constraints originate from three primary sources – individual, environment, and goal (Newell, 1986). If constraints are increased to an adequate level they may instigate change in attractor states. When this occurs constraints become control parameters. Control parameters are non-essential variables. That is, they are variables that are not related to the pattern of movement itself but can initiate a change in pattern when scaled to a sufficient value. The particular value at which control parameters initiate a pattern change is termed a critical value (Thelen and Smith, 1994). The key to changing a motor pattern is to identify control parameters related to task performance and then find the critical values of those variables (Thelen, 1987). When a control parameter is scaled, the system (motor pattern) passes through a region of instability or increased variance in pattern. This region of increased variance is the signature of a critical value and designates a point of change in the system (Thelen, 1989).

Careful description of potential control parameters is an important first step in the dynamical analysis of a developing system (Clark, 1997). Knowing a movement's control parameter is the key to changing a movement pattern. The difficulty lies in the identification of control parameters because they may originate from a wide variety of sources. The key is to control variables that might instigate change and scale up on the suspected control parameter while looking for changes in the relative position of limb segments. When a system changes to a new attractor state change occurs according to an order parameter. Order parameters reflect change in pattern by allowing the system to organize within a context of constraints. The order parameter is usually a mechanical principle that acts to constrain or compress the degrees of freedom available to the elemental components. Order is created in the process of the action without the necessity of centrally monitored direction thus maintaining the self-organizing properties of the movement.

Throwing is a complex skill that requires the coordination of many body segments. The complexity of the skill makes throwing an ideal skill to study from a dynamic system perspective since there are many degrees of freedom or possible patterns to accomplish the goal. To execute a mature throw, the thrower must move several joints through a range of motion with precise timing (Haywood, 2005). The specific movement pattern a person uses to throw a ball may vary considerably depending on personal attributes, environmental, and task requirements (Burton, 1993). For example, a throw that requires less velocity may be accomplished with a different pattern than a throw that requires high velocity. Regardless of possible differences, good throwers maximize the use of the order parameter (open kinetic chain) in order to transfer angular momentum from proximal to distal body segments and thereby increase the velocity of the hand (Southard, 2002).

An open kinetic chain is a system of links (body segments) that are free to vary. Rotation of the more massive proximal segment (trunk) gives the system angular momentum which is transferred to its less massive distal neighbor (humerus). This process continues down the chain resulting in an increase in velocity of the most distal segment (hand). A mature thrower utilizes the open kinetic chain by beginning the throw with a contralateral step forward and pelvic rotation followed by upper spine rotation, humeral arm swing, humeral arm inward rotation, elbow extension, wrist flexion, and release. This action allows the system to transfer velocity to the most distal segment – the hand. A poor thrower does not transfer angular momentum, has no step action, trunk action, and no distal lag of segments (Roberton, 1984; Southard, 1998). Only the arm is active for a poor thrower. Force production is the result of extension of the forearm prior to release of the ball.

Control parameters may instigate change in throwing patterns from a typical poor pattern that does not transfer angular momentum to a typical good pattern that does transfer angular momentum when scaled to a critical value. Southard (1998) determined that mass of arm segments (individual constraint) and velocity (goal constraint) were control parameters that instigate changes in throwing pattern. When immature throwers scaled up on velocity to a critical value their patterns changed to resemble that of a mature thrower. When mass was added to distal segments the level of pattern decreased to a less mature pattern where throwers did not take full advantage of the order parameter. When mass of an immature child's throwing arm was made the same relative value as an adult, throwing level improved. Whereas, velocity and mass are the only experimentally determined control parameters for throwing, there are likely additional constraints that may instigate changes in throwing pattern.

There are three investigations that indicate that ball diameter may be a task constraint and a potential control parameter for throwing. Burton (1992) found that different ball sizes elicit different throwing patterns, and that a critical ball diameter may be reached when it is equal to hand width. Burton required ten males and ten females in each of four grade/age groups to throw balls of varying diameters. The age groups were kindergartners (5-6 yrs), second graders (7-8 yrs), fourth graders (9-10 yrs), and young adults (19-33 yrs). Participants threw styrofoam balls of six different diameters (4.8, 10.4, 14.7, 19.8, 24.4, and 29.5 cm) as hard as possible at a wall 6.7m away. Burton measured the diameter of each participants hand and established a ratio of hand width to ball diameter. He found that as relative ball diameters exceeded hand width subjects used a shorter path to raise the ball to a position near the head (the most common backswing transition was from Level 3 to 2), forearm lag was eliminated (the most common forearm transition was from Level 2 to 1), and participants controlled the ball with two hands for at least part of the backswing. Burton did not systematically control for hand size and could not determine when change occurred within age groups. Bingham (1989) found that large diameter objects (10 and 12.5 cm) tend to be thrown with less elbow flexion and less wrist extension than smaller diameter objects (5 and 7.5 cm). Bingham failed to detail relative changes in limb segments making it impossible to determine whether diameter was a control parameter. Broer (1979) found that if a ball is too large to be grasped, the throwing pattern must be adjusted to a push, which puts the hand behind the ball. The true overhand throw can be used only with an object which is small enough, and of such a shape, that it can be gripped by the fingers. It must be light enough that it can be controlled at a considerable distance from the body. If a ball is too large to be grasped, it will roll off the hand as the motion of the backswing is reversed, since there are no fingers behind the ball to overcome its tendency to continue to move backward. Broer found that heavy objects necessitate an underarm pattern in which gravity assists the thrower at those times when the object is far from the body, or a push shot in which the object is held close to the shoulder, inertia is overcome by total body motion, and all arm and shoulder muscles come into the action simultaneously. Broer reported change but like Bingham and Burton did not systematically detail when change occurred or provide evidence relating to the change in relative position of limb segments. Whereas, each finding suggests that ball diameter is a control parameter, there is no research that has systematically altered ball diameter and quantitatively determined changes in throwing pattern by detailing the relative position of arm segments.

The purposes of this study were to; 1) investigate ball diameter as a control parameter by systematically adjusting the ratio of ball diameter and hand length; 2) determine any differences in pattern change relative to skill level of the thrower; and 3) determine critical values for change in pattern.

It was hypothesized that; 1) increasing the ratio of ball diameter to hand length is a control parameter that will change throwing patterns; 2) there will be no difference in pattern changes by skill level; and 3) a critical value will occur at a ball diameter to hand length ratio of .74. Results from this study should increase our understanding of motor pattern change from a dynamic system perspective. On a practical basis, results should provide information concerning task constraints and the development of efficient throwing patterns.

CHAPTER 2

Method

Participants

Forty university students served as participants for this study. There were no gender restrictions for participants. However, each participant was required to have a hand length equal to the average male hand which is between 18 and 20 cm (Herbert, 1988). Hand length was determined by measuring from the slant distance of the wrist joint to the tip of the longest finger. The average hand length was 18.74 cm with a standard deviation of 0.64 cm. Each participant signed a university approved consent form before participating in this experiment.

Procedure and apparatus

Participants were required to throw a baseball size ball (21 cm circumference and 100 g) at a padded mat that extended from floor level to a height of 2.5 meters and was 3 meters wide. There was no requirement for accuracy but participants were encouraged to hit the mat with the ball. Following five warm-up throws, participants threw three throws to establish maximum velocity. The velocity of throw was recorded with a JUGS radar gun. The greatest maximum velocity was used as a measure to calculate a 50% velocity throw for establishing throwing level and collection of data. Previous research (Southard, 2002) indicates that patterns are most stable at 50% velocity. Data to determine skill classification were collected with a WATSMART Motion Analysis System. Skill classification data were collected at a sampling rate of 200hz. Two infrared cameras were mounted on tripods at a height of 2.2 meters and spaced 3 meters apart and 3 meters from participants. The system was calibrated with a frame of known dimensions prior to data collection sessions. The average spatial error was 2.04 mm. Infrared diodes (IREDS) were placed on the fingernail of the third finger, ulnar styloid, lateral epicondyle, greater tubercle of the humerus opposite the glenoid fossa, and spinous process of the first thoracic vertebra. The power source for the IREDS was placed at the waistband of the participants trousers/trunks and secured with adhesive wrap. Wires from the power source were routed about the participants so as not to impede the throwing motion.

Participants threw 10 times at 50% of maximum velocity. The 10 throws at 50% velocity were digitized from trajectory graphs using commercially prepared software. Throwing level was determined by each participant’s relative use of the order parameter (open kinetic chain). Segmental lag was digitized from trajectory graphs of segmental velocity. Segmental lag was obtained by subtracting the time to peak velocity of the distal segment from its proximal neighbor. A positive value for segmental lag occurred when the distal segment reached peak velocity after its proximal neighbor. A negative value was obtained if the distal segment reached peak velocity before its proximal neighbor. Distal lag (positive lag) was required if the thrower was to utilize the order parameter to increase the velocity of the hand. Participants were placed in attractor Level 1 when they exhibited simple forearm extension with no positive segmental lag. Throwers were categorized as attractor Level 2 when they displayed positive lag for only one segment. Level 3 throwers displayed positive lag for only 2 segments. Level 4 throwers displayed positive lag for all segments (humerus, forearm, and hand). There were no throwers that were categorized as Level 1 and therefore Level 1 throwers were not considered for this study.

The apparatus and procedures for data collection were identical to the establishment of skill classification. The only augmented information that was provided participants was whether velocity of throw was “good” or if they needed to “slow down” or “speed up.” Participants were able to maintain a 50% throwing velocity successfully during collection of data. For data collection, participants threw balls of six different diameters. Each diameter represented a condition of throw. The order of conditions was randomized with 3 conditions completed during one session and the remaining 3 conditions on a separate day. Ball diameters and ratios (Hand length / Ball diameter) were: Condition 1 = 7.3 cm, ratio = 2.56 ; Condition 2 = 12.7 cm, ratio = 1.48 ; Condition 3 = 17.8 cm, ratio = 1.05 ; Condition 4 = 21.6 cm, ratio = .86 ; Condition 5 = 25.4 cm, ratio = .74 ; and Condition 6 = 31.6 cm, ratio = .59.

Quantitative Analysis

Segmental Lag. A 2-way (Level X Condition) MANOVA was performed on the dependent measures of segmental lag (humerus, forearm, hand). The Huynh-Feldt Epsilon was applied to degrees of freedom to account for violation of sphericity assumption, and R^2 was used to determine the effect size of findings. Significant MANOVA was followed by Discriminant Function Analysis in order to identify constructs associated with MANOVA results. Dependent measures identified in the discriminant analysis were subjected to ANOVA. If more than one function was identified, ANCOVA was run following ANOVA with the primary function as a covariate. Sheffe' post hoc was used to identify significant means. An alpha level of .05 was applied to all analyses.

Pattern Variation. Coefficients of variation for segmental lag served to identify possible critical values by determining pattern variability. Separate 2-way ANOVA (Level X Condition) was performed on coefficients of variance for each lag measure. Absolute coefficients of variance were used in analysis to avoid significant differences due only to algebraic sign. Huynh-Feldt Epsilon and R^2 were used to account for sphericity violation and to indicate the effect size of findings respectively. Sheffe's post hoc procedure was used to indicate means responsible for significance. Alpha level was set at .05.

Qualitative Analysis.

Three-dimensional scatterplots were used to help visualize pattern variation and stability of segmental lag within a movement space. Data points for the scatterplots were measures essential to the order parameter (segmental lag). A single data point represented a combination of the three lags for each trial by level and condition.

CHAPTER 3

Results

The results of the discriminant function analyses were presented for level and conditions separately. Huberty (1994) suggests interpreting interactions by identifying constructs from discriminant analysis of simple main effects. The results of discriminant function analyses along with accompanying one-way ANOVA and one-way ANCOVA were considered in interpreting the interaction results.

Segmental Lag

MANOVA. A Level x Condition (3x6) MANOVA for segmental lag of Hand, Forearm, and Humerus indicated significant main effects by Level (Hotelling's Trace = .019), F(6, 3,932) = 6.131, $p < .001$, $R^2 = .15$, and Condition (Hotelling's Trace = .062), F(15, 5,897) = 8.168, $p < .001$, $R^2 = .61$, with a significant Level x Condition interaction (Hotelling's Trace = .047), F(30, 5,897) = 3.086, $p < .001$, $R^2 = .34$. Application of Huynh-Feldt Epsilon did not affect significance.

Discriminant Function Analysis by Level. Box's M test indicated that homogeneity of variance is assumed. The analysis generated two significant functions. Function 1, Wilks' $\lambda = .983$, χ^2 (6, N = 1,987) = 34.148, $p < .001$, $\eta^2 = .117$, explained 79.5% of function variability, and Function 2, Wilks' $\lambda = .996$, χ^2 (2, 1,987) = 7.035, $p < .05$, $\eta^2 = .060$, explained 20.5% of function variability. Three variables entered into both functions: Hand lag, Forearm lag, and Humeral lag. The standardized function and structure matrix coefficients indicated that Forearm lag and Humeral lag defined Function 1 and Hand lag defined Function 2. See Table 1 for standardized and structure matrix coefficients. Group centroid data indicated that Function 1 defined Level 2 and 4, while Function 2 defined Level 4. See Table 1 for group centroid data.

ANOVA and ANCOVA by Level. One-way ANOVA with Forearm lag as the dependent measure indicated a significant main effect for Level, $F(2, 1{,}985) = 6.016$, $p < .01$. Scheffe post hoc analysis indicated that Forearm lag for Level 2 was greater than that of Level 3. One-way ANOVA with Humeral lag as the dependent measure indicated no significant main effect for Level. One-way ANCOVA with Hand lag as the dependent measure and Forearm lag and Humeral lag as covariates indicated no significant main effect for Level. However, the covariate of Forearm lag significantly influenced the dependent measure of Hand lag, $F(1, 1{,}982) = 130.019$, $p < .001$ and the covariate of Humeral lag also significantly influenced the dependent measure of Hand lag, $F(1, 1{,}982) = 14.974$, $p < .001$. See Figure 1 for a representation of mean segmental lag by Level and Condition.

Discriminant Function Analysis by Condition. Box's M test indicated that homogeneity of variance is assumed. The analysis generated three functions; however, only one was significant. Function 1, Wilks' $\lambda = .948$, χ^2 (15, N = 1,987) = 106.652, $p < .001$, $\eta^2 = .223$, explained 94.5% of function variability. The standardized function and structure matrix coefficients indicated that Function 1 was identified by Forearm lag. Group centroid data indicated that positive Forearm lag defined Conditions 1 and 2 and Conditions 5 and 6 were defined by negative Forearm lag. See Table 1 and 2 for standardized coefficients and group centroid coefficients respectively.

ANOVA by Condition. One-way ANOVA with Forearm lag as the dependent measure indicated a significant main effect for Condition, F(5, 1,982) = 15.342, p < .001. Scheffe post hoc analysis indicated that Forearm lag for Conditions 1, 2, 3, and 4 were greater than that of Conditions 5 and 6.

Level x Condition Interaction. A significant interaction indicates that patterns changed across levels and conditions. Changes in patterns are represented by changes in positive or negative values for segments. Interaction effects due to changes in absolute values across conditions and levels may affect an interaction but do not affect potential pattern change. Pattern change is represented by change in relative rather than absolute values. Levels 2 and 4 indicated the most potential in pattern change across increases in ball size. Level 3 throwers maintained consistent relative values for segments which indicates an overall lack of pattern change with size of ball thrown. Level 2 throwers went from negative to positive lag for the humerus from Condition 1 to Condition 2 and remained negative until Condition 6. The forearm for Level 2 throwers was positive except for Condition 5 and 6. For Level 4 throwers the humerus was negative except for Condition 3 and 5. The forearm switched from positive to negative at Condition 3, back to negative at Condition 4, positive at Condition 5, and finally negative at Condition 6. The data indicates that Level 4 throwers had the most consistent change with changes at Conditions 5 and 6 common to both Levels 2 and 4.

Velocity Difference

MANOVA. The Level x Condition MANOVA for velocity difference of the Hand, Forearm, and Humerus indicated significant main effects by Level (Hotelling's Trace = .079), $F(6, 3932) = 25.841$, $p < .001$, $R^2 = .161$, and Condition (Hotelling's Trace = .268), $F(15, 5897) = 35.113$, $p < .001$, $R^2 = .087$, with a significant Level x Condition interaction (Hotelling's Trace = .063), $F(30, 5897) = 4.144$, $p < .001$, $R^2 = .085$.

Discriminant Function Analysis by Level. Box's M test indicated that homogeneity of variance can be assumed. The analysis generated two significant functions. Function 1, Wilks' $\lambda = .938$, χ^2 (6, N = 1,987) = 126.104, $p < .001$, $\eta^2 = .230$, explained 85.8% of function variability, and Function 2, Wilks' $\lambda = .991$, χ^2 (2, 1,987) = 18.275, $p < .001$, $\eta^2 = .096$, explained 14.2% of function variability. Three variables entered into both functions: Hand-Forearm difference to peak velocity, Forearm-Humerus difference to peak velocity, and Humerus-Trunk difference to peak velocity. The standardized function and structure matrix coefficients indicated that Hand-Forearm velocity difference and Forearm-Humerus velocity difference defined Function 1. Hand-Forearm velocity difference defined Function 2. Group centroid data indicated that Level 2 and 4 were defined by Hand-Forearm and Forearm-Humerus difference and Level 4 was defined by Hand-Forearm difference.

ANCOVA by Level. One-way ANCOVA with Hand-Forearm velocity difference as dependent measure and Forearm-Humerus velocity difference as the covariate indicated a significant main effect for Level, $F(2, 1{,}984) = 29.343$, $p < .001$, $R^2 = .093$. The covariate of Forearm-Humerus velocity difference significantly influenced the dependent measure of Hand-Forearm velocity difference, $F(1, 1,984) = 123.152$, $p < .001$. Scheffe post hoc analysis indicated that Hand-Forearm velocity difference of Levels 3 and 4 were greater than that of Level 2.

Discriminant Function Analysis by Condition. Box's M test indicated that homogeneity of variance can be assumed. The analysis generated three functions; however, only two functions were significant. Function 1, Wilks' $\lambda = .705$, χ^2 (15, N = 1,987) = 693.581, $p < .001$, $\eta^2 = .535$, explained 96.9% of function variability, and Function 2, Wilks' $\lambda = .987$, χ^2 (8, 1,987) = 25.482, $p < .01$, $\eta^2 = .106$, explained 2.8% of function variability. The standardized function and structure matrix coefficients indicated that Function 1 was defined by Hand-Forearm velocity difference. Function 2 was defined by Forearm-Humerus velocity difference. Group centroid data indicated that Hand-Forearm velocity difference defined Conditions 1, 2, 4, and 6. See Table 3 for coefficients and centroid data.

ANCOVA by Condition. One-way ANCOVA with Hand-Forearm velocity difference as the dependent measure and Forearm-Humerus velocity difference as the covariate indicated a significant main effect for Condition, $F(5, 1,981) = 54.416$, $p < .001$, $R^2 = .179$. The covariate of Forearm-Humerus velocity difference significantly influenced the dependent measure of Hand-Forearm velocity difference, $F(1, 1,981) = 250.202$, $p < .001$. Scheffe post hoc analysis indicated that Hand-Forearm velocity differences of Conditions 1 and 2 were greater than that of Conditions 3, 4, 5, and 6.

Level x Condition Interaction. Negative values for velocity difference would indicate that velocity was not transferred even though positive segmental lag is present.

The only negative velocity values were for the hand at Conditions 5 and 6 for Level 1. Therefore, the velocity difference data serves to confirm the transfer of angular momentum for segments but does not help identify pattern change.

Coefficient of Variance

ANOVA by Level and Condition. Separate 2-way ANOVAs (Level x Condition) were performed on coefficient of variance for segmental lag. Results indicated no significant main effects or interaction. See Figure 3 for a representation of coefficient of variance of segmental lag by Level and Condition.

Qualitative Analysis

The scatterplots of segmental lag served to confirm the quantitative analysis. That is, that variance was similar across levels and conditions. However, the scatterplots do indicate a tendency of increased variance for larger circumference balls, particularly for Levels 3 and 4.

CHAPTER 4

Discussion

Results of this study indicate that increasing the ratio of ball diameter to hand length is a control parameter that changes throwing patterns. The data indicate that when the ratio of hand length to ball diameter reached .74 throwing patterns changed. The changes in pattern represented by segmental lag were different according to throwing level. Level 2 was affected by changes in forearm lag and Level 4 was affected by both forearm lag and humeral lag changes. The hypothesis indicating no difference in pattern change by throwing level is rejected. The lack of significance for coefficients of variance indicated that the third hypothesis predicting a critical value was not supported.

Results indicated that changes in pattern were best defined by changes in the relative position of forearm lag irrespective of level and condition. A change in humeral lag was important only to those throwers that took full advantage of the open kinetic chain. The results confirm earlier findings of Broer (1977) and Burton (1992) that report a pattern change to a pushing motion when the ball is difficult to grasp. However, results also are counterintuitive regarding hand lag. That is, one would expect a decrease in hand lag as the ball becomes more difficult to grasp. Data from this study indicates that hand lag remained generally constant across conditions and levels. In fact, only the most mature throwers exhibited a change from positive to negative lag with an increase in ratio. A factor that may have related to pattern change by level was the fact that throwers initially designated as mature did not demonstrate humeral lag with smaller balls during data collection. This is not a predicted behavior since adult level 4 throwers are typically stable throwers (Southard, 2002).

The hypothesis that a critical value would occur at a hand length ratio of .74 was not supported. If a control parameter has been determined then a critical value must exist. That is, control parameters change motor patterns and therefore a critical value was definitely attained as a result of throwing larger diameter balls. A key variable in identifying a critical value is variance in the position of the limb segment during the movement. Increased variance is a precursor to pattern change. Southard (2002) determined that critical values for the control parameter of velocity vary by both segment and skill level. Southard also demonstrated that following a change to a new pattern segmental variation decreased and stable performance returned. It is likely that the critical value for changing motor pattern is between a .86 and .74 hand length to ball ratio. The data from this study likely reflect the beginning of variance as the critical value is approached (ratio of .86) and the end of variance following the change (ratio of .74). Consequently, there were no significant main effects or interaction in the coefficients of variance. Future studies examining hand to ball ratio should concentrate on ratio values between .86 and .74 in order to pinpoint a critical value for pattern change.

In conclusion, increasing the hand to ball ratio changes the throwing pattern at a ratio between .86 and .74. When change occurs throwers are still attempting to take advantage of the open kinetic chain by maintaining as much distal lag as possible. The lag that is sacrificed most often is positive lag between the forearm and humerus. On a practical basis, care should be taken to insure that the size of the ball is appropriate for the thrower’s hand (ratio greater than .74) if positive change in throwing pattern is the goal of practice.

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Table 1.

Standardized discriminant function and structure matrix coefficients for Levels

Coefficients	Discriminant Function		Structure Matrix	
	1	2	1	2
Hand lag	.178	.693	-.041	.782
Forearm lag	1.218	-.210	.570	-.667
Humeral lag	1.018	.481	.308	.661

Functions at group centroids for Levels

Levels	Function	
	1	2
2	-.157	.093
3	.079	-.004
4	-.198	-.124

Standardized discriminant function and structure matrix coefficients for Conditions

Coefficients	Discriminant Function	Structure Matrix
	1	1
Hand lag	.491	.859
Forearm lag	1.161	.214
Humeral lag	.296	-.346

Table 2.

Functions at group centroids for Conditions

Conditions	Function
	1
1	.267
2	.257
3	.024
4	.033
5	-.291
6	-.296

Standardized discriminant function and structure matrix coefficients for Levels

Coefficients	Discriminant Function		Structure Matrix	
	1	2	1	2
H-F Velocity Difference	-.677	.743	-.791	.610
F-Hu Velocity Difference	.543	.652	.570	.280
Hu-T Velocity Difference	.491	.686	.315	.531

Functions at group centroids for Levels

Levels	Function	
	1	2
2	.464	-.061
3	-.075	.057
4	-.301	-.227

Table 3.

Standardized discriminant function and structure matrix coefficients for Conditions

Coefficients	Discriminant Function	Structure Matrix
	1	1
H-F Velocity Difference	.776	.368
F-Hu Velocity Difference	.893	.430
Hu-T Velocity Difference	.775	.436

Functions at group centroids for Conditions

Conditions	Function
	1
1	1.019
2	.604
3	-.025
4	-.328
5	-.512
6	-.772

Figure Captions

Figure 1. The Segmental Lag for each segment by condition in Level 2, 3, and 4

Figure 2. The mean value of velocity difference for Level 2, 3, and 4 in each segment and condition

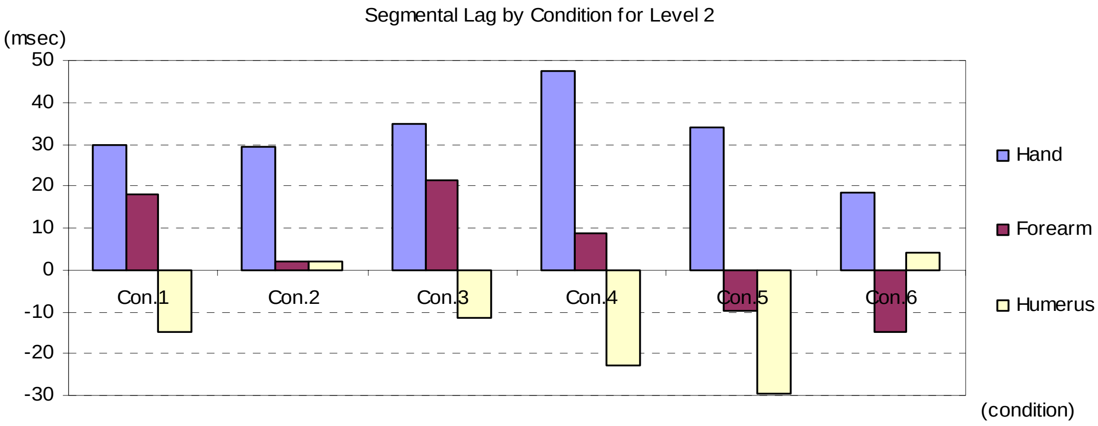
Figure 3. Coefficient of variance of segmental lag by Level and Condition.

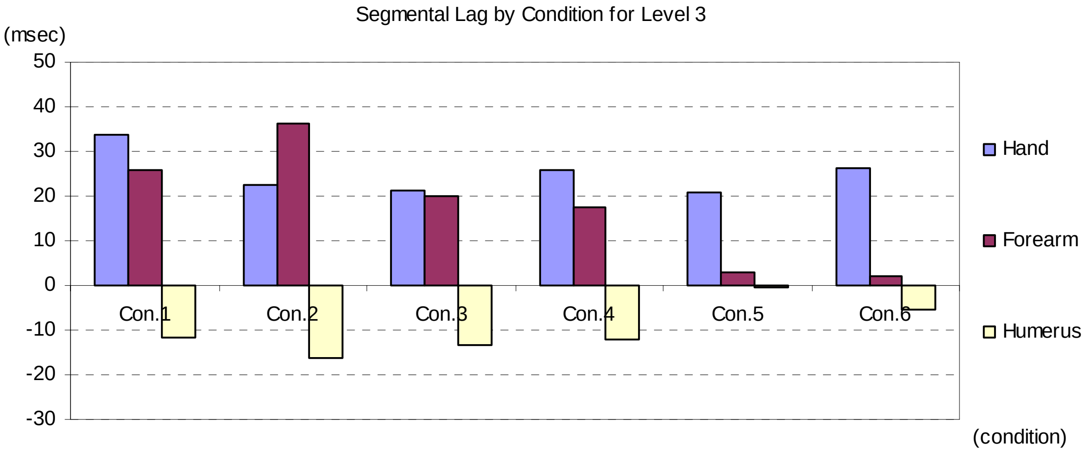
Figure 4. Scatterplot of Segmental lag by Level 2

Figure 5. Scatterplot of Segmental lag by Level 3

Figure 6. Scatterplot of Segmental lag by Level 4

Figure 1.


Segmental Lag by Condition for Level 2


Segmental Lag by Condition for Level 3

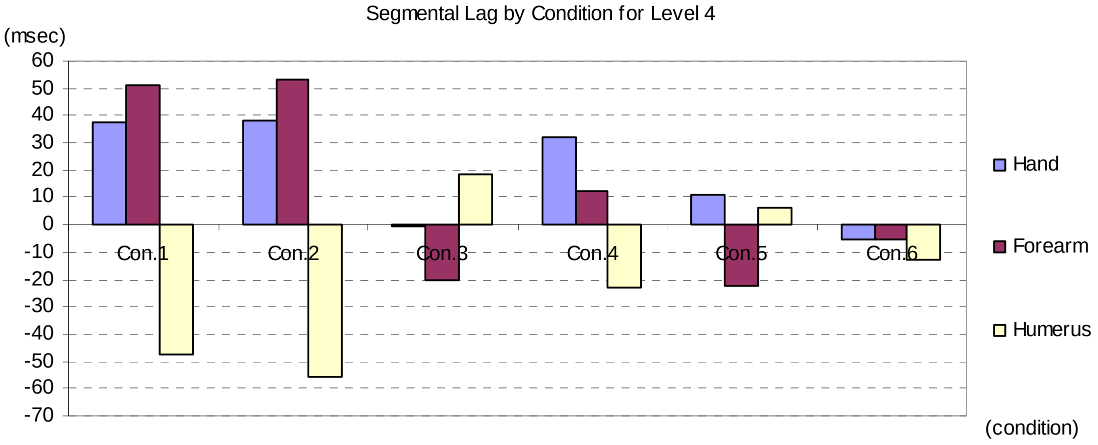
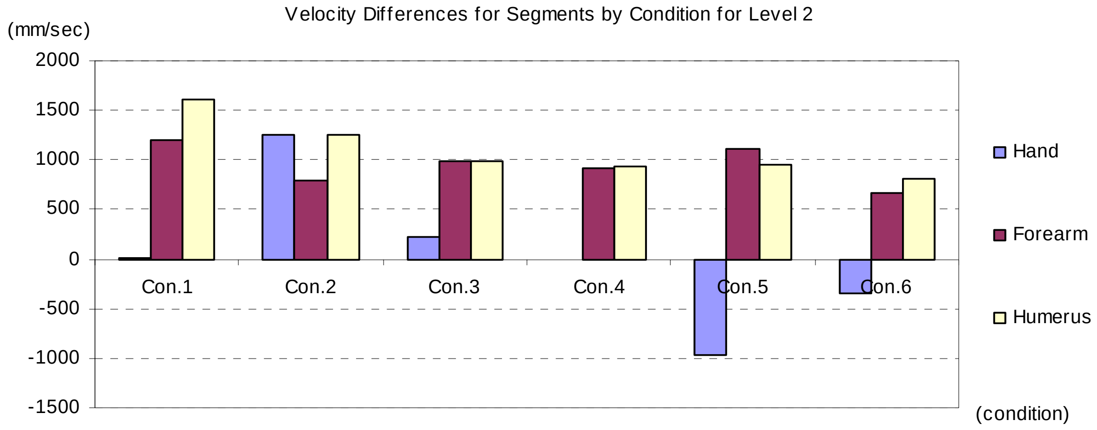
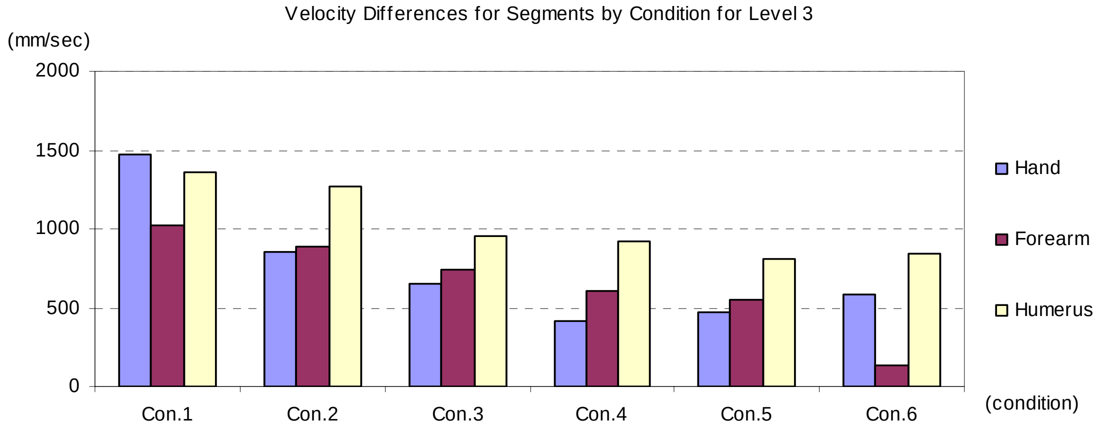

Segmental Lag by Condition for Level 4

Figure 2.


Velocity Differences for Segments by Condition for Level 2


Velocity Differences for Segments by Condition for Level 3

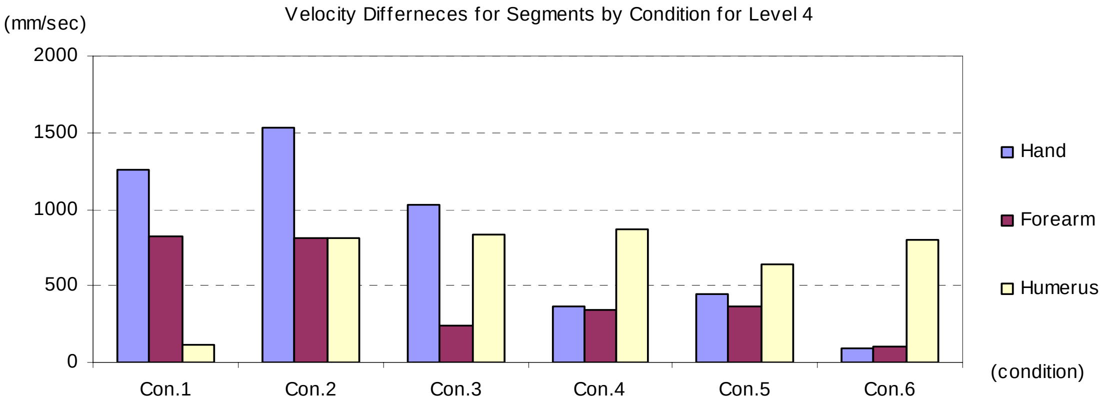
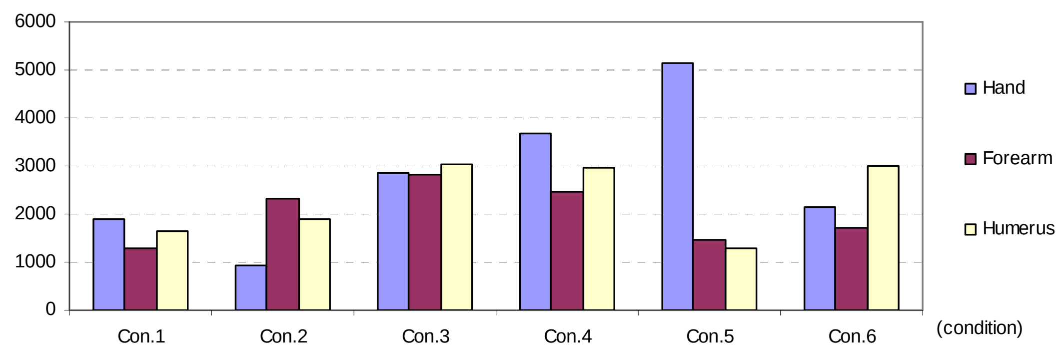
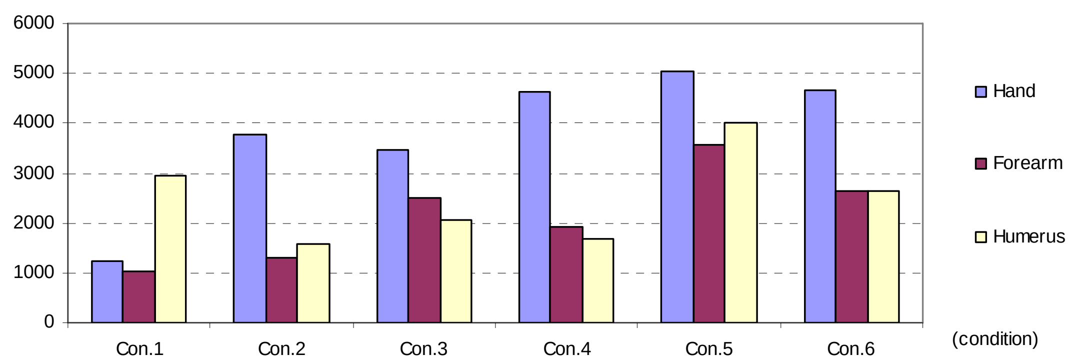

Velocity Differneces for Segments by Condition for Level 4

Figure 3.

Coefficient of Variance for Segments by Condition for Level 2



Coefficient of Variance for Segments by Condition for Level 3



Coefficient of Variance for Segments by Condition for Level 4

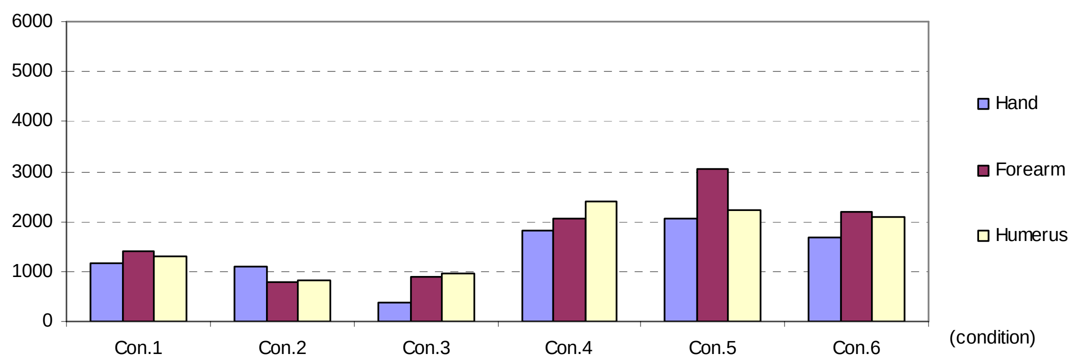
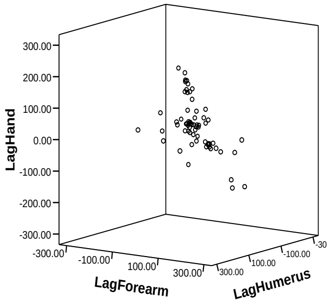


Figure 4.



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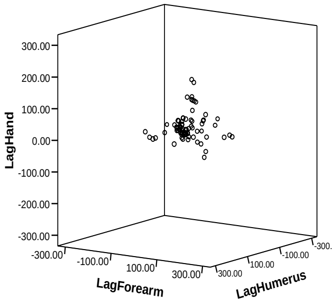

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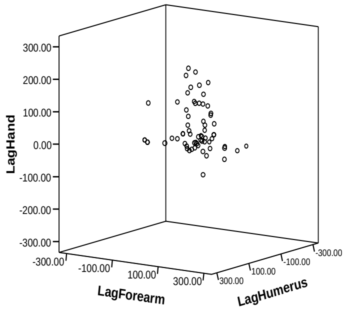

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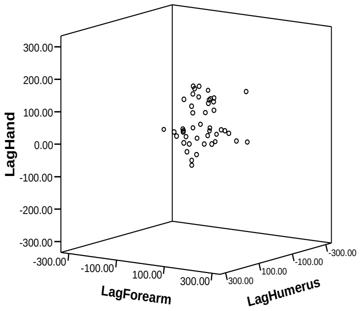

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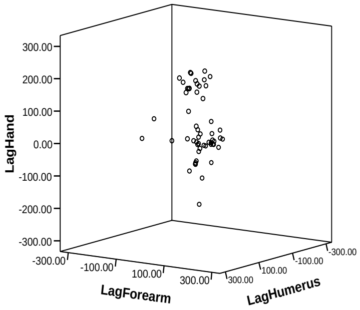

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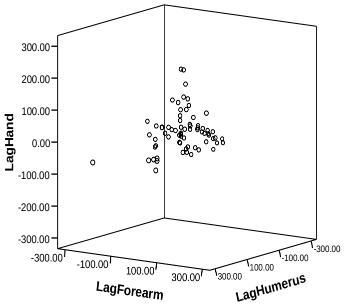

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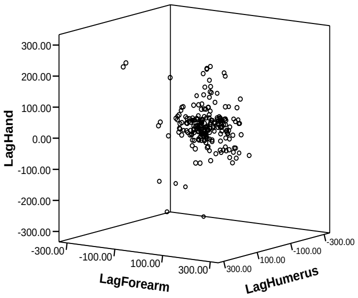
Figure 5.



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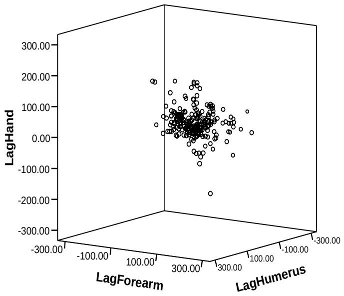

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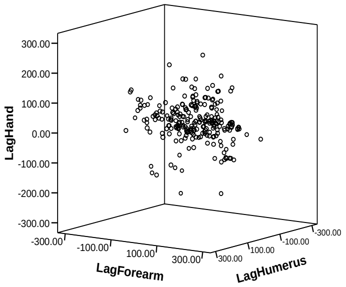

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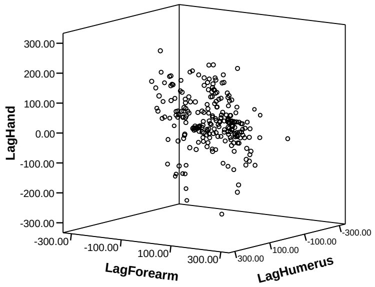

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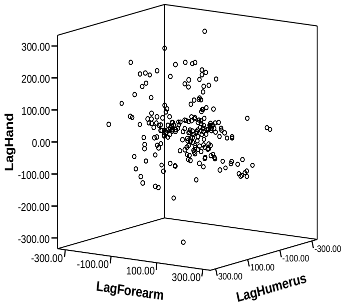

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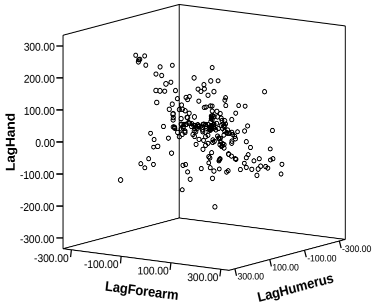
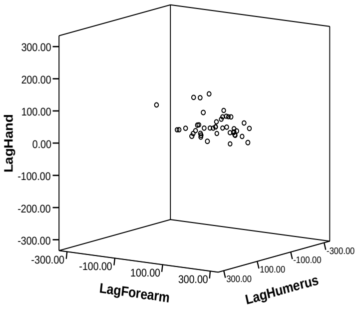


Con. 6

Figure 6.



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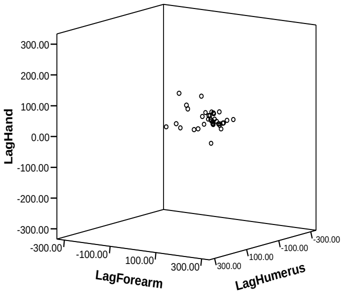

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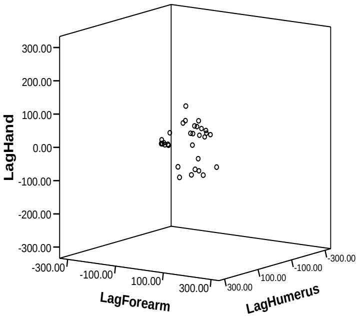

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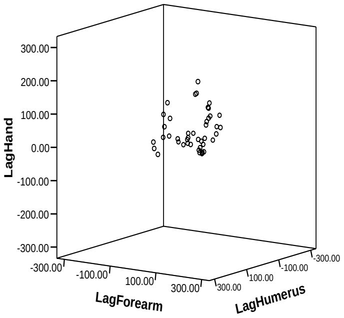

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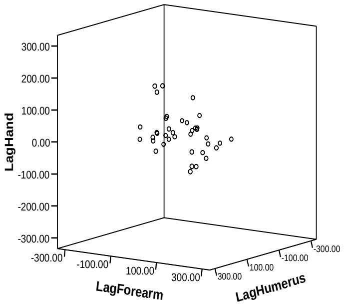

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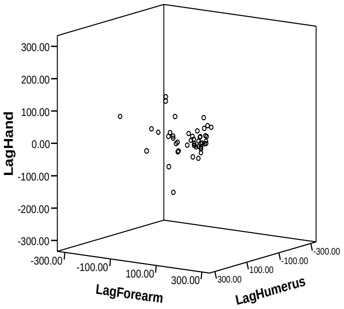

Con. 6

ABSTRACT

Control Parameter and Critical Value for Throwing: An Investigation of Ball Diameter to Hand Length Ratio

By Changwoo Lee, M.S., 2007.

Department of Kinesiology

Texas Christian University

Thesis Advisor: Dan Southard, Ph.D.

The purposes of this study were to; 1) investigate ball diameter as a control parameter by systematically adjusting the ratio of ball diameter and hand length; 2) determine any differences in pattern change relative to skill level of the thrower; and 3) determine critical values for change in pattern. Forty university students served as participants for this study. The average hand length was 18.74 cm with a standard deviation of 0.64 cm. Participants threw 10 times at 50% of maximum velocity. There was no requirement for accuracy. Segmental lag was digitized from trajectory graphs of segmental velocity. For data collection, participants threw balls of six different diameters. The only augmented information that was provided participants was whether velocity of throw was “good” or if they needed to “slow down” or “speed up.” Participants were able to maintain a 50% throwing velocity successfully during collection of data. A Level X Condition (3x6) MANOVA was performed on the dependent measures of segmental lag and velocity difference (humerus, forearm, hand). Coefficients of variation for segmental lag served to identify possible critical values by determining pattern variability. Three-dimensional scatterplots were used to help visualize pattern variation and stability of segmental lag

within a movement space. Results of this study indicate that increasing the ratio of ball diameter to hand length is a control parameter that changes throwing patterns. The data indicate that when the ratio of hand length to ball diameter reached .74 throwing patterns changed. The lack of significance for coefficients of variance indicated that a critical value was not supported. Changes in pattern were best defined by changes in the relative position of forearm lag irrespective of level and condition. A change in humeral lag was important only to those throwers that took full advantage of the open kinetic chain. Hand lag remained generally constant across conditions and levels. In fact, only the most mature throwers exhibited a change from positive to negative lag with an increase in hand to ball diameter ratio. Increasing the hand to ball ratio changes the throwing pattern at a ratio between .86 and .74. When change occurs throwers are still attempting to take advantage of the open kinetic chain by maintaining as much distal lag as possible. The lag that is sacrificed most often is positive lag between the forearm and humerus. On a practical basis, care should be taken to insure that the size of the ball is appropriate for the thrower's hand if positive change in throwing pattern is the goal of practice.