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A Biomechanical Analysis of Male and Female Intermediate Hurdlers and Steeplechasers

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A BIOMECHANICAL ANALYSIS OF MALE AND FEMALE INTERMEDIATE HURDLERS AND STEEPLECHASERS

by

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GRADUATE COMMITTEE APPROVAL

of a thesis submitted by

Laurence Bollschweiler

This thesis has been read by each member of the following graduate committee and by majority vote has been found to be satisfactory.

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Date	J. Brent Feland
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BRIGHAM YOUNG UNIVERSITY

As chair of the candidate's graduate committee, I have read the thesis of Laurence Bollschweiler in its final form and have found that (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

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ABSTRACT

A BIOMECHANICAL ANALYSIS OF MALE AND FEMALE

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In the sport of track and field, proper hurdling technique is a complicated combination of various running and jumping kinematics. With most research having been done on sprint hurdling, there is a growing need for research on hurdling events of different lengths. The intermediate hurdles (IH) and the steeplechase (SC) are two events where there are a number of differences in hurdling technique. This study compared the differences in hurdling technique between events (IH and SC) as well as the differences in technique between genders. Subjects for this study consisted of 20 elite intermediate hurdlers (10 male, 10 female) and 20 elite steeplechasers (10 male, 10 female). Subjects were filmed performing their respective events at the 2006 USA Outdoor Track and Field National Championships. A 2-D analysis was performed on each subject to determine differences between events and genders for the following variables: loss of horizontal velocity, peak center of mass relative to hurdle height, horizontal position at peak center of mass, deviation angle at takeoff, hurdle step length, penultimate, and recovery step lengths, takeoff and landing distance, minimum lead leg hip angle, trail leg knee height relative to the hip at peak height, trunk angle at peak height, landing angle, and finally, the ratio of the recovery step to the penultimate step. Significant differences ($p < .05$) were observed in 11 of the 13 variables analyzed. Steeplechasers showed significantly higher values than hurdlers in deviation angle, landing angle, minimum lead leg hip angle, peak height over the barrier, takeoff and landing distances, as well as penultimate, hurdle and recovery step lengths. Trail leg knee height was shown to be higher for hurdlers. Also, female steeplechasers were shown to have a greater trunk angle and loss of horizontal velocity than female hurdlers. Females showed higher values than males in deviation angle, landing angle, minimum lead leg hip angle, and peak height over the barrier. Landing distance, hurdle step length and trail leg knee height were higher for males. Also, female steeplechasers had a longer penultimate step length than males. Several differences in hurdling technique exist between events and gender. Hurdlers appear to place more emphasis on the kinematics which helps to promote a low center of mass hurdle clearance. Steeplechasers, on the other hand, are less pronounced with their hurdling kinematics. This is likely due to the greater economy required of the longer event. Gender differences appear to be, in large part, a function of differences in barrier height. As athletes and coaches go about evaluating and training hurdling technique, it is important to recognize the differences that exist between these different events.

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A Biomechanical Analysis of Male and Female Intermediate Hurdlers and Steeplechasers

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Abstract

In the sport of track and field, proper hurdling technique is a complicated combination of various running and jumping kinematics. With most research having been done on sprint hurdling, there is a growing need for research on hurdling events of different lengths. The intermediate hurdles (IH) and the steeplechase (SC) are two events where there are a number of differences in hurdling technique. This study compared the differences in hurdling technique between events (IH and SC) as well as the differences in technique between genders. Subjects for this study consisted of 20 elite intermediate hurdlers (10 male, 10 female) and 20 elite steeplechasers (10 male, 10 female). Subjects were filmed performing their respective events at the 2006 USA Outdoor Track and Field National Championships. A 2-D analysis was performed on each subject to determine differences between events and genders for the following variables: loss of horizontal velocity, peak center of mass relative to hurdle height, horizontal position at peak center of mass, deviation angle at takeoff, hurdle step length, penultimate, and recovery step lengths, takeoff and landing distance, minimum lead leg hip angle, trail leg knee height relative to the hip at peak height, trunk angle at peak height, landing angle, and finally, the ratio of the recovery step to the penultimate step. Significant differences ($p < .05$) were observed in 11 of the 13 variables analyzed. Steeplechasers showed significantly higher values than hurdlers in deviation angle, landing angle, minimum lead leg hip angle, peak height over the barrier, takeoff and landing distances, as well as penultimate, hurdle and recovery step lengths. Trail leg knee height was shown to be higher for hurdlers. Also, female steeplechasers were shown to have a greater trunk angle and loss

of horizontal velocity than female hurdlers. Females showed higher values than males in deviation angle, landing angle, minimum lead leg hip angle, and peak height over the barrier. Landing distance, hurdle step length and trail leg knee height were higher for males. Also, female steeplechasers had a longer penultimate step length than males. Several differences in hurdling technique exist between events and gender. Hurdlers appear to place more emphasis on the kinematics which helps to promote a low center of mass hurdle clearance. Steeplechasers, on the other hand, are less pronounced with their hurdling kinematics. This is likely due to the greater economy required of the longer event. Gender differences appear to be, in large part, a function of differences in barrier height. As athletes and coaches go about evaluating and training hurdling technique, it is important to recognize the differences that exist between these different events.

Introduction

In the sport of track and field there are three performance variables continually being assessed: running, jumping, and throwing. Hurdling is one event that incorporates both running and jumping. The three outdoor hurdle events currently being run at the international level are the 110 m or 100 m high hurdles (1.07 m and 0.84 m for men and women, respectively), 400 m intermediate hurdles (0.91 m and 0.76 m for men and women, respectively), and 3000 m steeplechase (0.91 m and 0.76 m for men and women, respectively). Over the years, athletes, coaches, and researchers have sought to improve hurdle performance by analyzing hurdling techniques. However, most hurdling research has been directed toward sprint hurdling, with very little emphasis on hurdle events of longer distances.

Biomechanical research has established that the key to successful sprint hurdling is found in the maintenance of horizontal velocity through the hurdle stride (Dyson, 1967; Mann and Herman, 1985; McDonald and Dapena, 1991b). Four factors that play major roles in hurdling kinematics and the maintenance of horizontal velocity are deviation angle at takeoff, body positioning through the hurdle step, approach velocity, and step placement (Alford, 1980; McDonald and Dapena, 1991a; Mero and Luhtanen, 1984; Salo, 1997). Since hurdle heights and race paces are different between events and genders, the specifics of these factors may vary.

Deviation angle at takeoff is the angle formed from the center of mass to the toe, relative to horizontal (Figure 1). A smaller deviation angle indicates greater horizontal drive into the hurdle. This helps to promote maintenance of horizontal velocity by reducing gains in vertical velocity during takeoff (Mann and Herman, 1985; McDonald and Dapena, 1991a; Salo, 1997). Both upper body and leg positioning play a key role in maintaining horizontal velocity. A pronounced forward lean at the trunk with both the lead and trail legs becoming nearly parallel to the ground allows the hurdler to clear the obstacle while still exhibiting a limited rise to their center of mass (Brown, 1988). This results in a quick return to the ground where running velocities can be maintained. Differences in deviation angle and body positioning between different hurdle events has yet to be evaluated.

Approach velocity and step placement have a significant effect on hurdling kinematics of sprint hurdling. Studies reveal women tend to show a larger clearance over the hurdle than men (McDonald and Dapena, 1991a; Salo, 1997). These larger clearances found in women are likely due to slower velocities, and result in more time spent in the air. As well, increased approach velocity has been associated with increased takeoff distances and proportionally decreased landing distances (Dyson, 1967). This results in the hurdler reaching peak height before the barrier, and allows for a lower clearance height over the hurdle. Whether similar gender differences in hurdling kinematics exist in other hurdle events, remains undetermined.

The intermediate hurdles and the steeplechase are two hurdle events that have the same hurdle height, yet are run at different velocities. Because of its shorter distance, the intermediate hurdles is run at a much faster pace. Additionally, elite men appear to run both events at significantly faster paces than elite women. Despite these differences in running velocities, very little research has been done to try to understand the differences in hurdling technique between these events. With the exception of two studies (Hunter and Bushnell, 2006; Paschke, 2003), the only literature evaluating hurdling differences in longer events is the subjective observations of coaches and athletes.

Assuming male and female hurdlers and steeplechasers all perform the same general movement through the hurdle step, this study determined the specific kinematic differences that exist due to different event distances and hurdle heights.

Methods

Design

This study was designed to compare the differences in hurdling kinematics between four groups: elite men intermediate hurdlers, elite women intermediate hurdlers, elite men steeplechasers, and elite women steeplechasers. A 2 x 2 factorial design was used. The independent variables were event (intermediate hurdles and steeplechase) and gender (male and female). Dependent variables included several areas of hurdling kinematics (Table 1).

Subjects

Twenty steeplechasers and twenty intermediate hurdlers were filmed at the 2006 USA Outdoor Track and Field National Championships (Indianapolis, IN). In order to maintain an even distribution of gender, 10 men and 10 women were filmed from each event. The 40 athletes used for analysis were the top ten finishers from each event. Thus, this group of subjects represents elite level athletes. This study was pre-approved by the university institutional review board and determined to be exempt from a need for informed consent since the event is considered public domain.

Instrumentation and Data Collection

A Digital Video Camcorder (Cannon Elura 60, Lake Success, NY), running at 60 Hz, was placed perpendicular to the running direction, in line with the hurdle/barrier at a height of 1 m. Cameras were placed approximately 80 m from each hurdle in order to decrease parallax error. Each camera was zoomed to produce a field-of-view sufficient to capture the beginning of the penultimate step to the end of the recovery step of the hurdler in the lane for which it was set up. The sagittal plane around each hurdle was calibrated using hurdle height for 2-D scaling. In an attempt to compare similar phases of each event, filming of the athletes took place at the approximate mid-point of each race. For the steeplechase, this was chosen as barrier three on the fourth lap. For the intermediate hurdles, hurdle number four was chosen as an appropriate mid-race hurdle to be analyzed.

A 2-D analysis was performed using the Peak Motus Version 8.2 (Vicon Peak, Colorado Springs, CO), with sampling conducted at 60 Hz. A 21-point spatial model was used to evaluate all variables involving center of mass measurements. Angular and distance measurements were evaluated by digitizing the points relative to each variable (Table 1).

Variables

The following variables were evaluated between events and between genders: Peak center of mass relative to hurdle height, horizontal position at peak center of mass, deviation angle at takeoff, hurdle step length, penultimate, and recovery steps lengths, takeoff and landing distance, minimum lead leg hip angle, trail leg knee height relative to the hip at peak height, trunk angle at peak height, landing angle, and finally, the step ratio of the recovery step to the penultimate step (Table 1; Figures 1, 2, 3, and 4).

Statistical Analysis

The means of all thirteen dependent variables were normalized by hurdle velocity. Differences between events and genders were tested using a 2 x 2 factorial ANOVA, with Tukey post hoc comparisons. Alpha level was set at 0.05.

Results

After accounting for differences in running velocity, a factorial analysis of variance revealed significant main effects across 11 of the 13 dependent variables ($p < 0.001$). Several strong differences were observed between steeplechasers and hurdlers overall. Measurements concerning deviation angle, landing angle, minimum lead leg hip angle, peak height over the barrier, takeoff and landing distances, as well as penultimate, hurdle, and recovery step lengths were all significantly higher for steeplechasers than hurdlers (Table 2). Also, trail leg knee height relative to hip height was shown to be significantly higher for hurdlers (Table 2). One other difference was observed among females that was not observed among males. Table 3 shows trunk angle greater among female steeplechasers than hurdlers ($F_{3,36} = 23.25$, $p < 0.001$).

There were also several strong differences between males and females. Measurements concerning deviation angle, landing angle, minimum lead leg hip angle, and peak height over the barrier were all significantly higher for females than males (Table 4). Landing distance, hurdle step length, and trail leg knee height relative to hip height were shown to be significantly higher for males (Table 4). One other difference was observed among steeplechasers that was not seen among hurdlers. Table 3 shows penultimate step length was greater among female steeplechasers than males ($F_{3,36} = 4.45$, $p < 0.005$).

There were no significant differences between any groups for either the ratio of the recovery step to the penultimate step or horizontal position at peak center of mass.

Because the statistical analysis was done using data normalized by differences in running velocity, Table 5 entails the means of all variables before accounting for velocity.

Discussion

Event Differences

A low center of mass clearance over the hurdle allows an athlete to better maintain horizontal velocity (Scholich, 1985). Three of the variables analyzed in this study greatly influence a hurdler's ability to maintain a low center of mass through the hurdle step (Alford, 1980; Benson, 1993; Harvey, 1985; Mann and Herman, 1985; McDonald and Dapena, 1991b). They are minimum lead leg hip angle, trail leg knee height at peak height, and trunk angle (forward lean) at peak height. The results of this study revealed smaller lead leg hip angles and greater trail leg knee heights (relative to the hip) among hurdlers. It also revealed smaller trunk angles among female hurdlers compared to female steeplechasers. Obtaining this position of a high lead leg kick and trail leg lift (greater hip abduction), coupled with a strong forward lean requires large amounts of energy. Due to the vast need for energy conservation over a length of 3000 m, it is possible that steeplechasers may sacrifice a lower hurdle clearance for greater economy of movement.

Evidence to this theory is given in the analysis of peak height. Steeplechasers had a greater peak height of the center of mass above the barrier than hurdlers. Due to the lower running speed of steeplechasers, they are forced to jump higher to ensure barrier clearance since they must spend more time with their body above each barrier. Also, a higher barrier clearance may be a result of safety measures. In contrast to a hurdle, a steeplechase barrier does not collapse when struck. Hitting a barrier often results in a fall and sometimes even injury.

The results for overall hurdle step length were larger among hurdlers. However, after accounting for running velocity, steeplechasers cover more distance. With horizontal velocity normalized, hurdle step length becomes a direct result of peak height and body positioning at takeoff and landing. As steeplechasers jump higher, they also cover more distance. This larger hurdle step length coincides with larger takeoff and landing distances. A larger takeoff distance could also help steeplechasers achieve greater height over the barrier. Additionally, it could be a result of more room for leg clearance due to lack of leg kick and lack of collapsing hurdles.

Deviation angle is the angle at takeoff between the center of mass and horizontal with the takeoff foot as the vertex. Smaller deviation angles have been shown to lower center of mass, allow for a quicker return to running and limit loss of horizontal velocity (Mann and Herman, 1985; McDonald and Dapena, 1991a; Salo, 1997). Results of this study showed intermediate hurdlers to have significantly smaller deviation angles. This coincides with the peak height and hurdle step length results. As a hurdler takes an aggressive deviation angle into the hurdle, it allows them to keep the center of mass low and shortens the hurdle step. This provides them a quick return to running and a smaller loss of horizontal velocity.

After accounting for hurdle velocity, landing angle (the angle at touchdown between the center of mass and horizontal with the landing foot as a vertex) was shown to be smaller among hurdlers. This is likely due to the increased speed at which hurdlers move their legs through the hurdle. A pronounced leg raise coupled with a lower barrier clearance forces the hurdlers to rapidly pull their lead leg through as they approach the ground. This places the foot further under the body at touchdown. Economy of movement may also help explain landing angle differences. Normally a hurdler tries to decrease their landing angle because angles greater than 90 degrees have been shown to cause additional braking and contribute to loss of horizontal velocity (Dyson, 1967; Mann, 1983; McInnis, 1978). Although steeplechasers may benefit from utilizing a smaller landing angle to minimize braking, economy of movement should also be considered. During the stance phase of running, energy is stored and released as braking and propulsion is observed (Winter and Bishop 1992). This economical movement may explain the differences in landing angles.

After accounting for hurdle velocity, steeplechasers were shown to have both a larger penultimate step length and recovery step length. Since steeplechasers must gain a greater peak height, they use a greater deviation angle. The longer penultimate step follows from the step length required to produce a larger deviation angle. Similar reasoning may explain the longer recovery step found among steeplechasers. As steeplechasers touch down with a greater landing angle and energy is stored and released, a subsequently greater vertical velocity can be produced. This greater vertical velocity at the beginning of the recovery step would lead to a greater flight time and may explain the longer step.

Gender Differences

Several of the observed event differences are very similar in nature to the differences found among genders. Males were shown to have a smaller lead leg hip angle as well as raise their trail leg higher than females. Like hurdlers, the higher leg kick and trail leg knee height among males are likely an attempt to maintain a lower center of mass through the hurdle step. The observed lower peak height found among males is evidence to this. Since male steeplechasers have previously been shown to be more affected by the barrier than female steeplechasers (Hunter and Bushnell, 2006), it is also possible that males may be forced to adjust their technique by raising their trail leg higher to avoid contact with the barrier.

Deviation angle also plays a major role in peak height. As males take off with a smaller deviation angle, it allows them to maintain a lower center of mass and lower clearance of the barrier. It is likely the higher barrier requirement for the men could play a role in all variables related to peak height. Because they are forced to jump higher than the women, more attention may be focused on lower clearance and sooner return to running.

Proper hurdling technique is to time the hip extension of the lead leg so the front foot lands only slightly ahead of the center of mass (Dyson, 1967). This results in a landing angle slightly larger than 90°. Similar to the difference between hurdlers and steeplechasers, landing angle was shown to be significantly smaller (closer to 90°) for males than females. This is likely due to differences in body positioning and hurdle clearance. Similar to hurdlers, the pronounced leg raise coupled with the lower barrier clearance found among males, forces them to rapidly pull their lead leg through as they approach the ground. This places the foot further under the body at touchdown.

Differences in barrier requirements may also play a role in hurdle step length. Males were shown to have both a greater hurdle step length and landing distance than females. As males are forced to jump higher, this results in greater flight time. Longer step lengths and landing distances are likely a direct result of this increased flight time. Finally, female steeplechasers were observed to have a greater penultimate step length after accounting for velocity. This too may be related to the lower barrier height found among women, but the reason remains unclear.

Two variables in which there were no significant results are the ratio of recovery step length to penultimate step length as well as horizontal position of peak height. Recovery step length for each group was shown to be similarly smaller than their respective penultimate step length. Finally, all groups reached peak height between 0.07 m and 0.19 m prior to the hurdle. This indicates all groups are implementing “downhill hurdling,” a common practice among most hurdlers to help in minimal jumping height while lead and trail legs can clear the hurdle or barrier without touching.

Conclusion

As athletes and coaches go about evaluating and training hurdling technique, it is important to remember the differences that exist between events and between genders. For instance, steeplechasers tend to take off with a greater deviation angle in order to obtain the appropriate peak height – a height which we have shown to be significantly higher than hurdlers. As well, hurdlers appear to perform the tasks that help promote a low center of mass clearance over the hurdle. These include a high kick of the lead leg, raising the trail leg high and away from the body, and a pronounced forward lean. Due to the high energy demands of these tasks and the economy required for steeplechasers, they tend to perform them on a smaller scale.

Although less understood, some gender differences are worth noting. Males have shown to maintain smaller deviation angles, greater leg kick of the lead leg and higher knee height of the trail leg. All of these variables help to maintain a low center of mass through the hurdle, allowing the runner to have a quick return to running. Males were also shown to have smaller landing angles than females. Smaller landing angles help to minimizing horizontal braking and loss of horizontal velocity. Although males have a lower barrier clearance than females, they have a taller barrier which forces them to jump higher than the females. These gender differences are likely a result of this higher barrier requirement.

References

Alford, J. (1980). Basic steeplechasing. *Modern Athlete and Coach, 18,* 29-32.

Benson, T. (1993). Steeplechasing - The art of interrupted running (Reprint). *Track and Field Quarterly Review, 93,* 27-29.

Brown, G. (1988). Clearance technique differences in the high and 400 m hurdles. *Modern Athlete and Coach, 26,* 39-41.

Dyson, G. H. G. (1967). Hurdling and steeplechasing. In *The Mechanics of Athletics* (4th Ed.), London: University of London Press LTD. 125-134.

Hunter, I., and Bushnell, T. D. (2006). Steeplechase barriers affect women less than men, *Journal of Sports Science and Medicine, 5,* 318-322.

Mann, R. (1983). The elite athlete project - sprints and hurdles. *Track Technique, 84,* 2672-2675.

Mann, R., and Herman, J. (1985). Kinematic analysis of Olympic hurdle performance: women's 100 meters. *International Journal of Sport Biomechanics, 1,* 163-173.

McDonald, C., and Dapena, J. (1991a). Linear kinematics of the men's 110 m and women's 100 m hurdles races. *Medicine and Science in Sports Exercise, 23,* 1382-1391.

McDonald, C., and Dapena, J. (1991b). Angular momentum in the men's 100 m and women's 100 m hurdles races. *Medicine and Science in Sports Exercise, 23*, 1392-1402.

McInnis, A. (1978). Applying sprint sense to hurdling. *Track Technique, 74*, 2348-2350.

Mero, A. and Luhtanen, P. (1984). A biomechanical analysis of top hurdling. *Modern Athlete and Coach, 22*, 3-6.

Paschke, D. G. (2003) A biomechanical analysis of steeplechase barrier clearance techniques: hurdle and step-on. *Kinesiology Abstracts, 17(1).*

Salo, A. (1997). 3-D biomechanical analysis of sprint hurdles at different competitive levels. *Medicine and Science in Sports Exercise, 29*, 231-237.

Scholich, M. (1985). Steeplechase technique. *Modern Athlete and Coach, 23*, 20-21.

Winter, D. A., and Bishop, P. J. (1992). Lower extremity injury-biomechanical factors associated with chronic injury to the lower extremity. *Sports Medicine*, *14(3),* 149–156.

Table 1: Variables measured and methods for determining variables

Variable	Methods
Deviation angle at takeoff	Hip joint, toe at takeoff, horizontal axis from the takeoff toe
Landing angle	Hip joint, toe at touch-down, horizontal axis from the takeoff toe
Lead-leg hip angle	Lead leg knee joint, hip joint, and shoulder joint
Trail-leg knee height	Difference between trail leg knee joint and hip joint heights
Trunk angle	Shoulder joint, hip joint, horizontal axis from the hip joint
Hurdle step	Horizontal position of toe at touch down minus horizontal position of toe at takeoff
Takeoff distance	Horizontal coordinate of the front edge of the barrier minus horizontal position of toe at takeoff
Landing distance	Horizontal coordinate of toe at touch down minus horizontal position of the front edge of the hurdle
Penultimate step	Horizontal position of toe at takeoff of the penultimate step minus horizontal position of toe at touch down of the penultimate step
Recovery step	Horizontal position of toe at takeoff of the recovery step minus horizontal position of toe at touch down of the recovery step
Step ratio	Recovery step length divided by penultimate step length
Peak center of mass	Hurdle height subtracted from peak center of mass
Horizontal position at peak center of mass	Horizontal coordinate of front edge of the hurdle subtracted from horizontal position of peak center of mass

Table 2: Event Differences

Group means-normalized by hurdle velocity

	Hurdlers	Steeplechasers	P-value	$F_{(3,36)}$
Deviation Angle	7.37	13.09	<0.001	326.61
Landing Angle	12.46	18.31	<0.001	639.86
Minimum Hip Angle (lead-leg)	8.31	12.32	<0.001	40.58
Peak Height over barrier	0.05	0.10	<0.001	218.71
Horizontal position of Peak Height	-0.01	-0.02	0.397	0.74
Knee Height relative to Hip (trail-leg)	-0.03	-0.05	<0.001	27.41
Take-off Distance	0.26	0.30	<0.001	23.86
Landing Distance	0.20	0.25	<0.001	22.19
Hurdle Step Length	0.46	0.55	<0.001	123.00
Recovery Step Length	0.19	0.23	<0.001	35.40
Step Ratio (Recovery:Penultimate)	0.81	0.78	0.347	0.91

Table 3: Gender-Specific Event Differences/Event-Specific Gender Differences

Group means normalized by hurdle velocity

	MIH (A)	FIH (B)	MSC (C)	FSC (D)
Trunk Angle at Peak Height	4.02^{D}	$3.10^{C,D}$	4.89^{B}	$6.41^{A,B}$
Penultimate Step Length	$0.24^{C,D}$	$0.23^{C,D}$	$0.28^{A,B,D}$	$0.31^{A,B,C}$

MIH-Male Intermediate Hurdles, FIH-Female Intermediate Hurdles, MSC-Male Steeplechase, FSC-Female Steeplechase

Note: Superscripts (A,B,C,D) denote differences between groups @ $p < .05$ in the Tukey post hoc comparison.

Table 4: Gender Differences

Group means-normalized by hurdle velocity

	Male	Female	P-value	$F_{(3,36)}$
Deviation Angle	9.76	10.71	0.005	9.04
Landing Angle	14.48	16.28	<0.001	60.65
Minimum Hip Angle (lead-leg)	9.61	11.02	0.030	5.08
Peak Height over barrier	0.07	0.08	0.016	6.38
Horizontal position of Peak Height	-0.02	-0.02	0.443	0.60
Knee Height relative to Hip (trail-leg)	-0.03	-0.04	0.001	13.37
Take-off Distance	0.28	0.28	0.890	0.02
Landing Distance	0.24	0.22	0.043	4.43
Hurdle Step Length	0.52	0.49	0.008	7.93
Recovery Step Length	0.21	0.21	0.637	0.22
Step Ratio (Recovery:Penultimate)	0.81	0.79	0.415	0.68

Table 5: **Group means**

Means not normalized by hurdle velocity

	MIH (A)	WIH (B)	MSC (C)	WSC (D)
Deviation Angle (degrees)	63.55	64.47	73.52	71.40
Landing Angle (degrees)	107.13	109.34	101.11	101.96
Minimum Lead Leg Hip Angle (degrees)	65.78	78.08	70.39	66.64
Peak Height over Barrier (m)	0.42	0.45	0.57	0.56
Horizontal Position of Peak Height (m)	-0.18	-0.08	-0.07	-0.19
Trail Leg Knee Height Relative to Hip (m)	0.24	0.28	0.23	0.28
Trunk Angle at Peak Height (degrees)	36.81	25.57	28.59	33.43
Takeoff Distance (m)	2.43	2.09	1.73	1.61
Landing Distance (m)	1.86	1.67	1.60	1.21
Hurdle Step Length (m)	4.29	3.76	3.33	2.82
Penultimate Step Length (m)	2.18	1.93	1.65	1.66
Recovery Step Length (m)	1.73	1.59	1.35	1.23
Loss of Horizontal Velocity (%)	11.3	8.1	12.3	16.0
Hurdle Velocity (m/s)	9.15	8.29	5.88	5.26

MIH-Male Intermediate Hurdles, FIH-Female Intermediate Hurdles, MSC-Male Steeplechase, FSC- Female Steeplechase

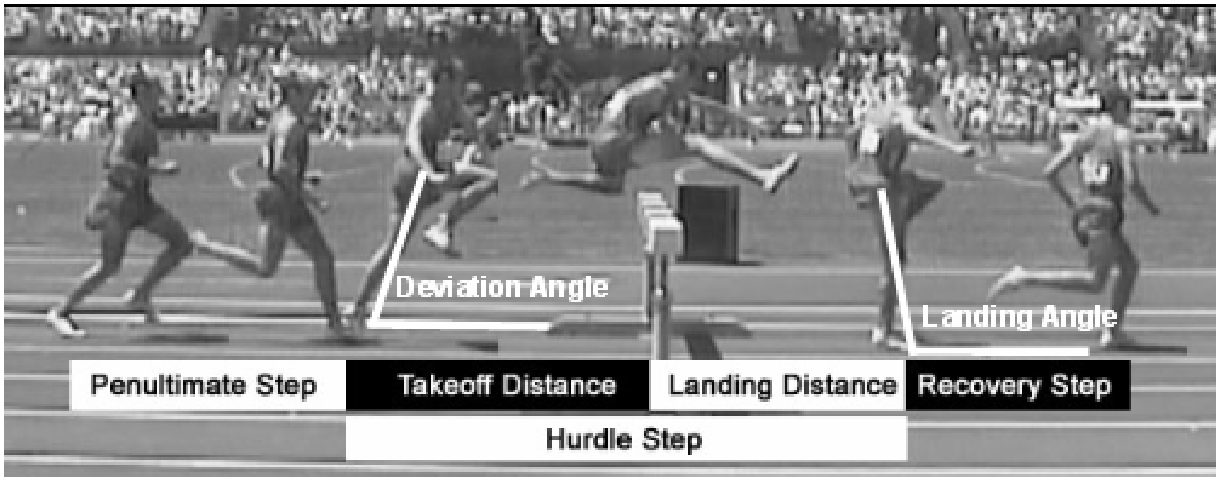

Figure 1: Visual description of step lengths, takeoff distance, landing distance, deviation angle and landing angle

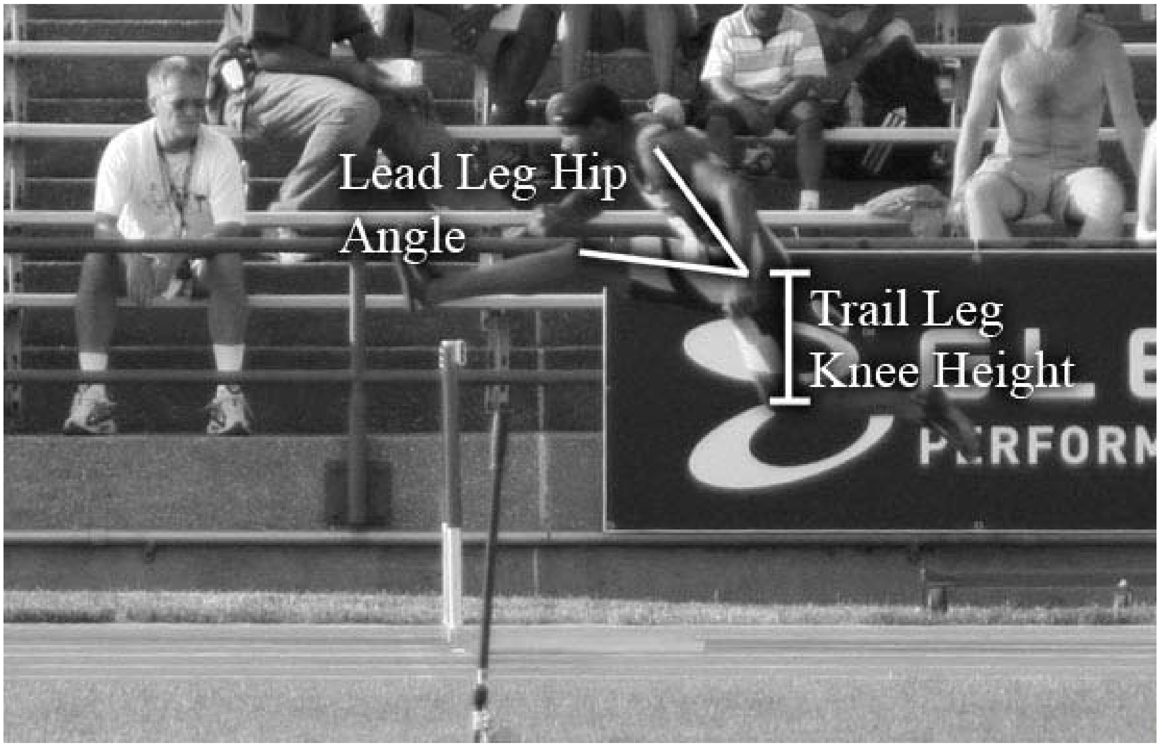

Figure 2: Visual description of hip angle and knee height

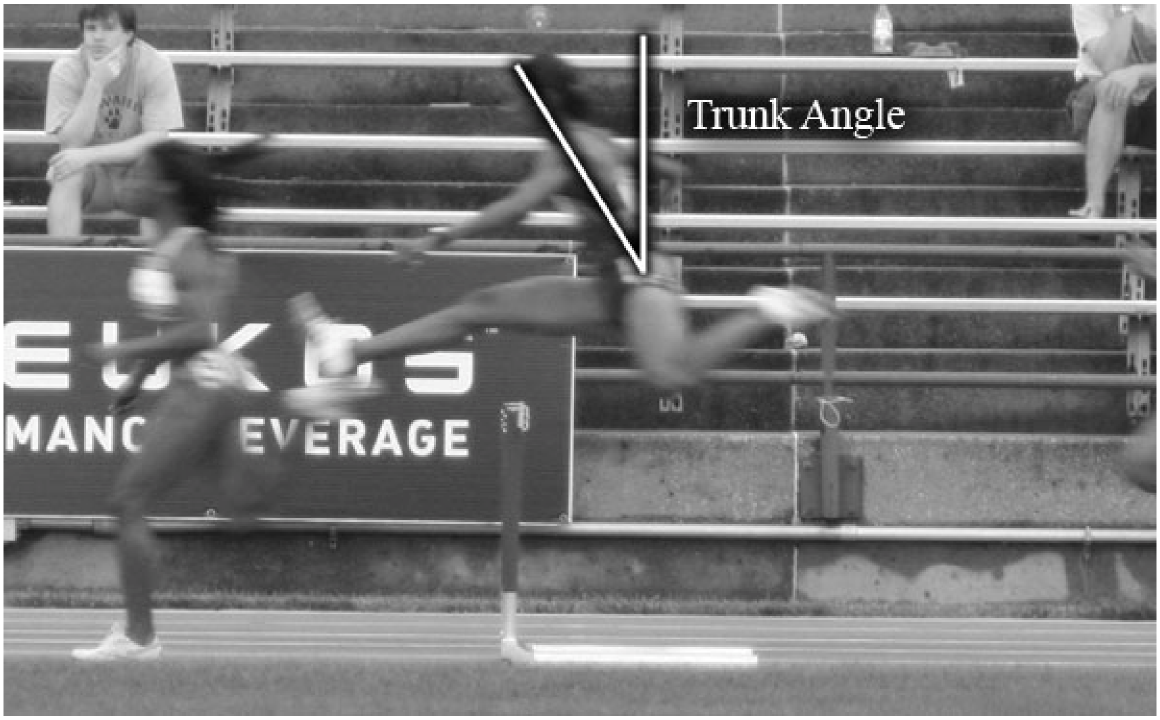

Figure 3: Visual description of trunk angle

Figure 4: Visual description of peak center of mass and horizontal position at peak center of mass

Appendix A

Prospectus

Chapter 1

Introduction

In the sport of track and field there are three performance variables continually being assessed: running, jumping and throwing. Hurdling is one event that incorporates both running and jumping. The three hurdle events currently being run at the international level are the 110 m or 100 m high hurdles (1.07 m and 0.84 m for men and women, respectively), 400 m intermediate hurdles (0.91 m and 0.76 m for men and women, respectively), and 3000 m steeplechase (0.91 m and 0.76 m for men and women, respectively). Over the years, athletes, coaches, and scientists have worked to improve hurdle performance by increasing our understanding of optimal running and hurdling techniques. Most hurdling research has been directed toward sprint hurdling, with very little emphasis on hurdle events of longer distances.

Biomechanical research has established that the key to successful hurdling is found in the maintenance of horizontal velocity through the hurdle stride (Dyson, 1967; Mann, 1985; McDonald, 1991b). Four factors that play major roles in hurdling kinematics and the maintenance of horizontal velocity are deviation angle at takeoff, body positioning through the hurdle step, approach velocity, and step placement. Since hurdle heights and race paces are different between events and genders, the specifics of these factors may vary.

Deviation angle at takeoff is the angle formed from the center of mass to the toe, relative to horizontal. A smaller deviation angle indicates greater horizontal drive into the hurdle. This helps to promote maintenance of horizontal velocity by reducing gains in vertical velocity during takeoff (Mann and Herman, 1985; McDonald and Dapena, 1991a; Salo, 1997). Upper body and leg positioning also plays a key role in maintaining horizontal velocity. A pronounced forward lean at the trunk with both the lead and trail legs becoming nearly parallel to the ground, allows the hurdler to clear the obstacle while still exhibiting a limited rise to their center of mass (Brown, 1988). This results in a quick return to the ground where running velocities can be maintained. Differences in deviation angle and body positioning between different hurdle events has yet to be evaluated.

Approach velocity and step placement have a significant affect on hurdling kinematics of sprint hurdling. Studies reveal that women tend to show a larger clearance over the hurdle than men (McDonald and Dapena, 1991a; Salo, 1997). These larger clearances found in women are likely due to slower velocities and result in more time spent in the air. As well, increased approach velocity has been associated with increased takeoff distances and proportionally decreased landing distances (Dyson, 1967). This results in the hurdler reaching peak height before the barrier, and allows for a lower clearance height over the hurdle. Whether similar differences in hurdling kinematics exist in other hurdle events, remains undetermined.

The intermediate hurdles and the steeplechase are two hurdle events that have the same hurdle height, yet are run at significantly different velocities. Because of its shorter distance, the intermediate hurdles is run at a much faster pace. Additionally, elite men appear to run both events at significantly faster paces than elite women. Despite these differences in running velocities, very little research has been done to try to understand the differences in hurdling technique between these events. Currently, the only literature evaluating hurdling differences in longer events is the subjective observations of coaches and athletes.

In order to understand the effect of different distances and different speeds on hurdling technique, an analysis of intermediate hurdlers and steeplechasers needs to be completed. This study will determine the kinematic differences between elite intermediate hurdlers and steeplechasers, as well as gender differences in these events.

Purpose Statement

The purpose of this study is to compare the differences in hurdling kinematics between

- elite men intermediate hurdlers
- elite women intermediate hurdlers
- elite men steeplechasers
- elite women steeplechasers

Hypotheses

1. When comparing gender differences within each event, women will
    - exhibit a greater loss of horizontal velocity over the hurdle;
    - produce a greater deviation angle;
    - exhibit a shorter hurdle step;
    - exhibit a shorter takeoff distance and a shorter landing distance;
    - produce a higher peak center of mass relative to the hurdle;
    - reach peak center of mass closer to the hurdle;

- exhibit a larger minimum lead leg hip angle as well as a larger minimum trail leg hip angle;
- exhibit a smaller maximum trunk angle;
- produce a smaller landing angle;
- exhibit a greater ratio of the recovery step to penultimate step;

2. When comparing event differences, steeplechasers will
   - exhibit a greater loss of horizontal velocity over the hurdle;
   - produce a greater deviation angle;
   - exhibit a shorter hurdle step;
   - exhibit a shorter takeoff distance and a shorter landing distance;
   - produce a higher peak center of mass relative to the hurdle;
   - reach peak center of mass closer to the hurdle;
   - exhibit a larger minimum lead leg hip angle as well as a larger minimum trail leg hip angle;
   - exhibit a smaller maximum trunk angle;
   - produce a smaller landing angle;
   - exhibit a greater ratio of the recovery step to penultimate step;

Limitations

1. Video analysis will be conducted on a two dimensional study, rather than three dimensional.
2. This study does not account for environmental factors that may have an influence on hurdling performance.

3. This study does not account for variability due to differences in hurdler's height.

Delimitations

1. The sample will include 20 intermediate hurdlers (10 male and 10 female) and 20 steeplechasers (10 male and 10 female) from the USA National Track and Field Championships.
2. Results are applicable to elite male and female intermediate hurdlers and steeplechasers.
3. The subjects will be divided into 4 groups of 10 – Men's intermediate hurdles, Women's intermediate hurdles, Men's steeplechase and Women's steeplechase.

Definition of Terms

Step – Foot contact of one foot until contact of the opposite foot.

Penultimate step – The step just prior to takeoff.

Hurdle step – The step from takeoff before the hurdle to landing after the hurdle.

Takeoff distance – The distance from toe-off to the front of the hurdle.

Landing distance – The distance from the front of the hurdle to touchdown.

Recovery step – The first step following touchdown.

Deviation angle – The angle formed from the center of mass to the toe, relative to horizontal.

Landing angle – The angle formed from the center of mass to the toes at touchdown, relative to horizontal.

Lead leg hip angle – The angle formed from the shoulder to the hip and out to the knee joint of the lead leg.

Trail leg hip angle – The angle formed from the shoulder to the hip and out to the knee joint of the trail leg.

Trunk angle – The angle formed from the shoulders to the hips, relative to horizontal.

Loss of velocity – The difference between recovery and penultimate step velocities.

Significance of Study

The significance of this study deals with two main areas of interest: gender differences and event differences. We know that there are kinematic differences between male and female sprint hurdlers, but do similar gender differences exist in hurdling events of longer distances? If they do, what are the specific differences? Second, very little is known about the possible kinematic differences between different hurdling events. If there are differences, what are they? By establishing objective research and understanding to these hurdle events, coaches and athletes will have a clearer comprehension of hurdling mechanics specific to their event. With this understanding, hurdling technique can be trained specifically for each event, rather than generally. This can result in eliminating poor mechanics and improving performance.

Chapter 2

Review of Literature

Over the years, coaches, athletes, and scientists have worked tirelessly to find ways to improve performance and find success. In the sport of track and field, a major factor to optimizing performance has always been the understanding of critical points of technique. As a result, scientists use biomechanical analysis of different track and field events to assist in this understanding. They have done and continue to do much for the enhancement of the sport. One area of interest in track and field yet to be studied extensively is hurdling. Some previous research has been done on the kinematics of sprint hurdling (Mero and Luhtanen, 1984; Mann and Herman, 1985; Brown, 1988; McDonald and Dapena, 1991a; McDonald and Dapena, 1991b; Chow, 1993; Salo, 1997), but little has been done on hurdle races of longer distances.

Two such hurdle races are the intermediate hurdles and the 3000 m steeplechase. The intermediate hurdles have been an Olympic event since 1900 and 1984 for men and women, respectively. In this event, athletes are required to clear 10 hurdles while running a distance of 400 m (1 lap). The steeplechase is an even longer distance event requiring hurdling. Over a distance of 3000 m (approximately 7 laps), steeplechasers are required to hurdle 35 barriers with seven of them being followed by a 3.66 m water pit. The men’s steeplechase events have been contested on an international level for over 150 years, while the first international women’s steeplechase made its debut at the 2005 World Championships in Helsinki. Both the intermediate hurdles and the 3000 m steeplechase use hurdle heights of 0.91 m and 0.76 m for men and women, respectively. A significant difference between events is the fact that there are no lane assignments in steeplechase, while lane assignments do exist in the intermediate hurdles. Steeplechasers are forced to deal with the burden of having to hurdle over the barriers with other runners in their lane. Also, with approximately 80 m between barriers, steeplechasers cannot use a regular stride pattern between hurdles. As a result, stride adjustments must be made prior to each barrier clearance.

In order to understand the components of successful hurdling, one must have a full comprehension of the necessary performance descriptors and body kinematics of competitive hurdling. Direct performance descriptors are the variables used in describing a hurdler's overall performance (Mann and Herman, 1985). Some common performance descriptors are horizontal velocity, hurdle height and hurdle distance. Although performance descriptors produce little information regarding the movement patterns that produce the performance, they do help determine the nature of the performance. Body kinematics, on the other hand, include those movement patterns which do produce the performance (Mann and Herman, 1985). Some body kinematics that are commonly evaluated are takeoff and landing angles, hip angles during flight, trunk angles during flight, as well as takeoff and landing step lengths. By evaluating the body mechanics of individuals during performance we can gain a greater understanding of the nature of the performance descriptors associated, and thus establish greater insight into how to enhance overall performance.

There are many factors which contribute to optimal hurdling technique in both the intermediate hurdles and steeplechase. Over the years, coaches and scientists have done their best to describe both the direct performance descriptors and body kinematics which lead to optimal performances. With the inception of the women's steeplechase in international competition, a renewed interest in gender differences has also developed.

When discussing hurdling technique in the steeplechase, it is important to understand that differences exist in steeplechase hurdling strategies. There are two ways of clearing the barriers – the step-on technique and the hurdle technique. It is generally accepted that from a biomechanical viewpoint, the hurdle technique is superior to the step-on technique (Dyson, 1967; Popov, 1983; Hunter and Bushnell, 2006). Recently however, one study has been published which disagrees with this statement. Paschke (2004) found the step-on technique to be superior to the hurdle technique in trajectory angle, initial horizontal velocity, and final horizontal velocity. Despite this finding, athletes and coaches have chosen to continue using the more traditional hurdle technique to clear the barriers. Therefore, this study will evaluate hurdling of steeplechasers who clear the barrier using the hurdle technique.

In an attempt to fully understand the direct performance descriptors which lead to optimal performance, it is important to evaluate hurdling technique both generally and specifically between different events and different genders. It is generally accepted that success in any hurdling event is dependant upon the maintenance of horizontal velocity through the hurdle stride (Dyson, 1967; Mann and Herman, 1985; McDonald and Dapena, 1991b). In jumping and hurdling events, it has been shown that increases in vertical velocity at takeoff are associated with decreases in horizontal velocity (Hay *et al.*, 1986; McDonald and Dapena, 1991b). Therefore, it has been suggested that the best way to maintain horizontal velocity through the hurdle stride is to minimize vertical velocity at takeoff (Mann and Herman, 1985; McDonald and Dapena, 1991b) In order to clear the hurdle, there will always be some amount of increased vertical velocity, but a flatter clearance over the hurdle allows an athlete to better maintain horizontal velocity (Scholich, 1985). Mann and Herman (1985) describe this motion as “out and over” rather than “up and over”. A flat clearance of the hurdle allows the athlete to return to the track quickly while maintaining a smooth running rhythm. This maintenance of running rhythm is said to be a key factor in steeplechasing success (Dyson, 1967; Alford, 1980; Griak, 1982; Benson, 1993).

Performance descriptors differ somewhat between genders. In steeplechasing, for instance, barrier clearance has been shown to disrupt the running rhythm (stride lengths) of men more than women (Hunter and Bushnell, 2006). In sprint hurdling, women have been shown to have higher clearances over the hurdles than men. Additionally, women tend to reach peak height prior to reaching the hurdle while men tend to peak directly above the hurdle (McDonald and Dapena, 1991a; Salo, 1997). It is believed that reaching peak height before the hurdle would better facilitate a shorter landing step and allow an athlete to regain ground contact sooner and in a superior landing position (Mann and Herman, 1985). This also promotes a lower hurdle clearance while still avoiding kicking the hurdle. It is uncertain if the same gender trends occur in the longer hurdling events. However, a shorter landing step appears to be ideal for both genders in all hurdling events.

Speed plays a major role in identifying differences in technique between events. One of the difficulties in steeplechase hurdling is that the race is run at a much slower pace. The slower you run, the more difficult it is to maintain ideal hurdling mechanics (Hislop, 1985). Slower speeds coming into the hurdle result in higher jumps over the hurdle and thus greater losses in horizontal velocity (Alford, 1980; McDonald and Dapena, 1991a). The sprint hurdles are a good example of this. One might think that the lower hurdle height for the women would facilitate a flatter hurdle clearance than men, but due to slower speeds, women are forced to jump higher to clear the obstacle (McDonald and Dapena, 1991a). Faster approach speeds seem to permit more of a horizontal drive through the obstacle, thus limiting excess gains in vertical velocity (Dyson, 1967). As a result, many steeplechase coaches feel that a slight acceleration before each hurdle can promote a flatter hurdle stride and help to maintain horizontal velocity (Dyson, 1967; Alford, 1980). Other coaches discourage acceleration in and out of the hurdle stride because of the excess amount of energy expenditure that occurs (Stolley, 1996). Instead, maintaining a consistent overall velocity before, after, and during hurdle clearance becomes the major focus. Regardless of the approach strategies, most coaches agree that barrier clearance in the Steeplechase should be approximately 5-10 cm higher than that of the intermediate hurdles (Adams, 1979; Benson, 1993).

Takeoff distance and landing distance play an important role in hurdling. Takeoff distance is defined as the distance from toe-off to the front edge of the hurdle. Obtaining a proper takeoff distance helps the athlete clear the hurdle without the excessive gains in vertical velocity which may cause them to waste time in the air, stand too erect, or disrupt their normal running rhythm. If too close or too far away at takeoff, the hurdler is forced to jump higher in an attempt to either miss the obstacle or to avoid landing on it. It is important to note that takeoff distances must be commensurate with approach speeds (Dyson, 1967). The correct takeoff distance combined with the wrong approach speed can have a significantly negative effect on hurdle clearance. It appears that as approach speed increases, so does the optimal takeoff distance (Dyson, 1967). Like increased approach speed, increased takeoff distance seems to allow the hurdler a more horizontal drive over the obstacle (Mero and Luhtanen, 1984). It is generally agreed that the optimal takeoff for the men's steeplechase is about 1.2 m to 1.5 m behind the barrier (Griak, 1982; Hislop, 1985). Optimal distances for women steeplechasers or intermediate hurdlers are not yet known.

Landing distance can play a strong role in an athlete's ability to quickly return to the ground and regain a strong running rhythm. This is defined as the distance of an individual's center of mass from the barrier to the point of touchdown. In sprint hurdling, a reduced landing distance is believed to promote a quick and smooth return to running rhythm (Dyson, 1967; Mann and Herman, 1985). Whether shorter landing distances are also common among hurdling events of longer distances has yet to be determined. Landing distance is usually a function of the location of peak height and approach speed. Reaching peak height prior to the hurdle allows the athlete to touch down closer to the hurdle following clearance (Mann and Herman, 1985). Dyson explains this relationship by stating that increases in approach speed result in increases in takeoff distances with proportional decreases in landing distances (Dyson, 1967). This concept of shortened landing distances in sprint hurdling may also be useful in longer hurdling events. The same coaches who promote optimal steeplechase takeoff distances of 1.2 m – 1.5 m also promote optimal landing distances of ~1.0 m (Griak, 1982; Hislop, 1985).

Specific body kinematics before, after, and during the hurdle clearance play a major role in the direct performance descriptors previously discussed. For the most part, hurdling kinematics are centered around what the hips and legs are doing throughout the hurdle step. Evaluating body kinematics requires an understanding of both general hurdling kinematics as well as differences specific to each event or each gender.

Deviation angle at takeoff plays a major role in maintaining horizontal velocity. Deviation angle is defined as the angle formed from the center of mass to the toes at toe-off, relative to a horizontal plane. The optimal deviation angle on hurdle performance remains undefined. However, obtaining full extension of the trail leg at both the hip and knee has been shown to be very critical in obtaining the forward propulsion necessary in sprint hurdling (Mann and Herman, 1985). Salo *et al*. (1997) determined that a smaller deviation angle at takeoff results in an increased horizontal velocity in sprint hurdling. Similar results can be expected with the higher velocities of the intermediate hurdles, but may not be common among the slower velocities of the steeplechase.

In order to reduce vertical velocity at takeoff and maintain a flat hurdle clearance, it is essential that the legs perform specific movements through the air. During takeoff, the lead leg remains flexed to reduce the moment of inertia during the leg drive (Mann and Herman, 1985). It is generally accepted that a key element of successful sprint hurdling is a strong leg drive of the lead leg (Harvey, 1985; McDonald and Dapena, 1991b; Benson, 1993). Mann and Herman (1985) have shown that a fast and strong leg drive allows the athlete to have a shorter takeoff distance. Assuming vertical velocity stays the same, a shorter takeoff distance will result in a shorter hurdle step length. Less time in the air correlates with more time on the ground where horizontal velocity can be easily maintained (Fisher, 1982). As the lead leg approaches a height parallel to the ground, the knee should be extended till it is slightly flexed, allowing the leg to pass over the obstacle (Mann and Herman, 1985). This slight flexion at the knee allows the athlete to have a forward lean through the air as well as promotes a quicker downward swing upon hurdle clearance. A delayed flexion of both the hip and knee of the trail leg helps to ensure a full leg split (scissor kick) at takeoff. This keeps the hurdler close to the ground and helps to prevent them from leaping over the hurdle and gaining excess jump height (Alford, 1980; Mann and Herman, 1985).

Leg positioning after hurdle clearance and at touchdown is also very important. Upon clearance of the hurdle, a simultaneous extension of the lead leg and flexion of the trail leg should occur. This extension of the lead leg should continue through ground contact, resulting in an increased backward velocity at the foot (Mann, 1983). This helps to reduce horizontal breaking as the foot contacts the ground. In connection with lead leg extension is foot location at touchdown. It is generally accepted that one of the best ways to minimize horizontal braking is to place the foot almost directly under the body, slightly in front of the body’s center of mass (Dyson, 1967; McInnis, 1978; Mann, 1983). Landing angle is defined as the angle formed from the center of mass to the toes at touchdown, relative to vertical. A landing angle slightly greater than 90° provides the optimal foot placement at touchdown. Touching down too far forward will cause horizontal braking, while touching down too far back may cause stumbling into a shortened stride (Dyson, 1967). A final factor concerning horizontal braking is knee flexion at touchdown. Touching down the foot with a straight leg causes additional braking as the center of mass continues to descend through the recovery step (Mero and Luhtanen, 1984). In order to avoid this, it has been suggested that the athlete touch down with the knee slightly flexed (Alford, 1980; Mann and Herman, 1985).

A final kinematic variable pertaining to hurdling technique is that of trunk angle during the hurdle step. Trunk angle is formed from the shoulders to the hip joint, relative to vertical. A strong argument has been established for the need for a large trunk angle (forward lean) during hurdle clearance (Alford, 1980; Harvey, 1985; Mann and Herman, 1985; McDonald and Dapena, 1991b; Benson, 1993). Having a strong forward lean prevents the hurdler from rising too high and leaping over the hurdle. It has been proposed that a shortened penultimate stride can help to promote this forward lean (Dyson, 1967). When combined with a strong scissor kick, the forward lean keeps the hurdler's center of mass low to the ground and promotes a flat hurdle clearance. This enables maintenance of horizontal velocity as well as a quick return to running. Whether a large trunk angle is necessary in longer hurdle events has yet to be established.

Some technique differences exist between genders as well as different hurdling events. In sprint hurdling, women have been shown to exhibit larger lead leg hip angles (Salo, 1997). In other words, women have a tendency to not raise their lead leg as high as men. It is very likely that this could be a contributing factor to women having a tendency to clear the hurdle with a greater margin than men. Whether these same trends occur in longer hurdle events is uncertain. Different hurdle heights between events has been shown to influence hip flexion, hip extension, and forward lean over a hurdle. Higher hurdles, found in sprint hurdling, require more forward lean as well as a stronger scissor kick (Brown, 1988). Doing so helps to aid in keeping the center of mass close to horizontal.

A large reason for technique differences between events has to do with the concern for running economy and energy expenditure. This is especially true in the steeplechase where runners not only have to negotiate 35 barriers, but do it over a distance of 3000 m. Ideal hurdling technique in the steeplechase is supposed to be similar to the intermediate hurdles, but slower speeds, and a need to conserve energy will cause slight alterations in mechanics (Alford, 1980). Pacing and conservation of energy becomes a major concern as the length of each hurdle event grows. Generally speaking, as economy becomes more of a factor, we see less of a pronounced layout over the hurdle (Griak, 1982; Brown, 1988). For example, in the steeplechase the trail leg has a tendency to remain more under the body, while in the intermediate hurdles is extends behind the body (Hislop, 1985). It is likely that similar differences exist with other direct performance variables and body kinematics (Adams, 1979).

In an attempt to fully understand these hurdling differences, more research needs to be done on technique in hurdle events of longer distances. As a result, this study has been designed to investigate the kinematic differences between men and women intermediate hurdlers and steeplechasers. In discussing what we expect to find through our research, we feel that several gender differences and event differences will be discovered. It is believed that with this new found information, steps can be made to improve longer distance hurdling mechanics, and with that, a continual improvement in overall performance.

In order to determine the ideal hurdle and barrier clearance to analyze, it is necessary to discuss differences in hurdle technique throughout a race. Study shows a gradual increase in hurdle flight times throughout the men's intermediate hurdles, with the greatest increase in time coming during the sixth hurdle (Pendergast, 1991). These increases in flight time are due to gradual decreases in horizontal velocity at takeoff. Hurdle times tend to stay relatively low until hurdle six, where they begin to gradually increase. This indicates the onset of fatigue occurring somewhere between hurdles five and six. In order to avoid analyzing a hurdler in a state a fatigue, filming should take place on a hurdle prior to hurdle number five. Although similar data is not found on the women's intermediate hurdles, one can assume similar trends in the onset of fatigue. In order to coincide with the filming of a mid-race hurdle in the intermediate hurdles, lap 4 of the steeplechase was chosen as a mid-race lap from which filming and analysis should occur. It has been previously established that there is no difference in hurdle clearance between the four non-water jump hurdles found on each lap (Hunter and Bushnell, 2006). Therefore, for convenience of camera placement as well as optimal view of the hurdler, barrier 3 appears to be appropriate for filming and analyzing.

Over the years, there has been two predominate methods used in examining hurdling technique. The most common of which, two-dimensional (2-D) video analysis, is usually done by placing a video camera perpendicular to the hurdle and obtaining a sagittal view of the hurdler as they clear the obstacle (Mero and Luhtanen, 1984; Mann and Herman, 1985; Hunter and Bushnell, 2006). Video is then analyzed using some form of video analysis computer software. The x- and y-coordinates or 21 points defining a 14-segment model of the human body are recorded for each picture analyzed (Chow, 1993). Segment masses and center of mass locations are then computed using data from Zatsiorsky *et al.* (1990), as modified by deLeva (1996). Computer software is then used to assess any number of kinematic variables, such as distance, time, or velocity. When research demands require more accurate information on both rotational and translational variables than 2-D analysis can provide, three dimensional (3-D) studies can be done (McDonald and Dapena, 1991a; McDonald and Dapena, 1991b; Salo, 1997). These studies require two cameras set at approximately 90° to each other. Multiple cameras allow for a point in space to be tracked in three dimensions when imported into a 3-D analysis computer program. This form of motion analysis is more time consuming and labor intensive, but it is often considered the most accurate. The demands of this study allow for 2-D motion analysis.

Chapter 3

Methods

Design

This study is designed to compare the differences in hurdling kinematics between four groups: elite men intermediate hurdlers, elite women intermediate hurdlers, elite men steeplechasers, and elite women steeplechasers. A 2 x 2 factorial design will be used to detect differences between events (intermediate hurdles and steeplechase) and gender (male and female). Dependent variables will include several areas of hurdling kinematics (Appendix A-1).

Subjects

Twenty steeplechasers and twenty intermediate hurdlers will be filmed at the 2006 USA Outdoor Track and Field National Championships. In order to maintain an even distribution of gender, 10 men and 10 women will be filmed from each event. The 40 athletes to be used for analysis will be the top ten finishers from each event. Thus, the group of subjects will represent elite level athletes. This study was pre-approved by the university institutional review board and determined to be exempt from a need for informed consent since the video is considered public domain.

There are times when athletes may be blocked by officials or other competitors. Additional subjects will be filmed from each event in case film from any of the top performers cannot be used.

Instrumentation and Data Collection

A Canon Digital Video Camcorder (Lake Success, NY), running at 60 Hz, will be placed perpendicular to each hurdle/barrier in question, and be mounted on tripods (Manfrotto, Venice, Italy) extended to 1 m. Each camera will be placed approximately 80 m from the hurdle in order to decrease parallax error. It will be positioned to produce a field of view sufficient to capture the airborne portion of the penultimate step, the entire hurdle step, and the airborne portion of the recovery step of the hurdler in the lane for which it is set up. The sagittal plane around each hurdle will be calibrated using hurdle height as the scaling rod. In an attempt to compare similar phases of each event, filming of the athletes will take place at the approximate mid-point of each race. For the steeplechase, this has been chosen as barrier three on the fourth lap. For the intermediate hurdles, hurdle number four has been chosen as an appropriate mid-race hurdle to be analyzed.

A 2-D analysis will be performed using the Peak Motus Version 8.2 (Vicon Peak, Colorado Springs, CO), with sampling conducted at 60 Hz. A 21-point spatial model will be used to evaluate all variables involving center of mass measurements. Angular and distance measurements will be evaluated by digitizing the points relative to each variable (Appendix A-1).

Variables

The following variables will be evaluated between events and between genders: Loss of horizontal velocity over the hurdle, peak center of mass relative to hurdle height, horizontal position at peak center of mass, deviation angle at takeoff, length of hurdle step, length of both the takeoff distance and landing distance, minimum lead leg hip angle, minimum trail leg hip angle, maximum trunk angle, landing angle, and finally, the ratio of the recovery step to the penultimate step.

Appendix A-1 describes the methods for determining the angular and distance measurements within this study(see Appendix A-2, Figure 1, 2, 3, for visual description). Methods for determining the remaining variables are as follows:

Loss of horizontal velocity – the difference between recovery and penultimate step velocities. Velocities are determined by digitizing the hip joint during the airborne phase of each step. Displacement is divided by time to determine velocity.

Peak center of mass relative to the hurdle – the difference between peak center of mass and the height of the hurdle. A 21-point spatial model will be used to determine peak center of mass (Appendix A-2, Figure 4).

Horizontal position at peak center of mass – the horizontal coordinate of peak center of mass will be compared with the horizontal coordinate of the front edge of the hurdle (Appendix A-2, Figure 4).

In order to determine whether variable differences are due to gender or event, rather than velocity, all variables will be normalized by velocity through the hurdle. The velocities of the penultimate step, hurdle step, and recovery step will be averaged to determine the velocity through the hurdle. Variables will be normalized by dividing by this estimate of velocity.

Statistical Analysis

Differences in the dependent variables between genders and events will be tested using a 2 x 2 ANOVA. A second group of ANOVAs will also be calculated with all variables normalized by velocity through the hurdle. Alpha level will be set at 0.05 for all calculations.

References

Adams, W. C. (1979). Steeplechasing. *Track and Field Quarterly Review, 79*, 50-52.

Alford, J. (1980). Basic steeplechasing. *Modern Athlete and Coach, 18*, 29-32.

Benson, T. (1993). Steeplechasing - The art of interrupted running (Reprint). *Track and Field Quarterly Review, 93*, 27-29.

Brown, G. (1998). Clearance technique differences in the high and 400 m hurdles. *Modern Athlete and Coach, 26*, 39-41.

Chow, J. W. (1993). A panning videographic technique to obtain selected kinematic characteristics of the strides in sprint hurdling. *Journal of Applied Biomechanics, 9*, 149-159.

DeLeva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*, 1223-1230.

Dyson, G. H. G. (1967). Hurdling and steeplechasing. In *The Mechanics of Athletics* (4th Ed.), London: University of London Press LTD. 125-134.

Fisher, B. (1982). The steeplechase (Reprint). *Track and Field Quarterly Review, 82*, 39-40.

Griak, R. (1982). Steeplechase points to remember. *Track and Field Quarterly Review, 82*, 41.

Harvey, H. (1985). Steeplechase is an endurance event. *Athletics Coach, 19*, 3-4.

Hay, J. G., Canterna, R. W., and Miller, J. A. (1986). The techniques of elite male long jumpers. *Journal of Biomechanics, 19*, 855-866.

Hislop, C. (1985). Steeplechase technique. *Track and Field Quarterly Review, 85*, 18-22.

Hunter, I. and Bushnell, T. D. (2006). Steeplechase barriers affect women less than men. *Journal of Sports Science and Medicine, 5*, 318-322.

Mann, R. (1983). The elite athlete project - sprints and hurdles. *Track Technique, 84*, 2672-2675.

Mann, R. and Herman, J. (1985). Kinematic analysis of Olympic hurdle performance: women's 100 meters. *International Journal of Sport Biomechanics, 1*, 163-173.

McDonald, C. and Dapena, J. (1991a). Linear kinematics of the men's 110 m and women's 100 m hurdles races. *Medicine and Science in Sports Exercise, 23*, 1382-1391.

McDonald, C. and Dapena, J. (1991b). Angular momentum in the men's 100 m and women's 100 m hurdles races. *Medicine and Science in Sports Exercise, 23,* 1392-1402.

McInnis, A. (1978). Applying sprint sense to hurdling. *Track Technique, 74,* 2348-2350.

Mero, A. and Luhtanen, P. (1984). A biomechanical analysis of top hurdling. *Modern Athlete and Coach, 22,* 3-6.

Paschke, D. G. (2004) A biomechanical analysis of steeplechase barrier clearance techniques: hurdle and step-on. *Kinesiology Abstracts, 17(1).*

Pendergast, K. (1991). Some aspects of the 400 m hurdles. *Modern Athlete and Coach, 29*, 32-35.

Popov, T. (1983). Hurdling in the steeplechase. *Modern Athlete and Coach, 21*, 17-18.

Salo, A. (1997). 3-D biomechanical analysis of sprint hurdles at different competitive levels. *Medicine and Science in Sports Exercise, 29*, 231-237.

Scholich, M. (1985). Steeplechase technique. *Modern Athlete and Coach, 23*, 20-21.

Stolley, S. (1996). Coaching the steeplechase. *Track and Field Coaches Review, 96,* 38-39.

Zatsiorsky, V. M., Chugunova, L. G., and Seluyanov, V.N. (1990). Methods of determining mass-inertial characteristics of human body segments. In Chernyi, G. G., Regirer, S. A. (eds.), *Contemporary Problems of Biomechanics,* USA: CRC Press. 272-291.

Appendix A-1

Tables

Table 1: Methods for determining angular measurements and distance measurements

Variable	Points Digitized
Deviation angle at takeoff	Hip joint, toe at takeoff, horizontal axis from the takeoff toe
Landing angle	Hip joint, toe at touch-down, horizontal axis from the takeoff toe
Lead-leg hip angle	Lead leg knee joint, hip joint, and shoulder joint
Trail-leg hip angle	Trail leg knee joint, hip joint, and shoulder joint
Trunk angle	Shoulder joint, hip joint, horizontal axis from the hip joint
Hurdle step	Horizontal coordinate of toes at takeoff, horizontal coordinate of toes at touch down
Takeoff distance	Horizontal coordinate of toes at takeoff, horizontal coordinate of the front edge of the hurdle
Landing distance	Horizontal coordinate of the front edge of the hurdle, horizontal coordinate of the toes at touch down
Penultimate step	Horizontal coordinate of the toes at takeoff of the penultimate step, horizontal coordinate of toes at touch down of the penultimate step
Recovery step	Horizontal coordinate of the toes at takeoff of the recovery step, horizontal coordinate of toes at touch down of the recovery step

Appendix A-2

Figures

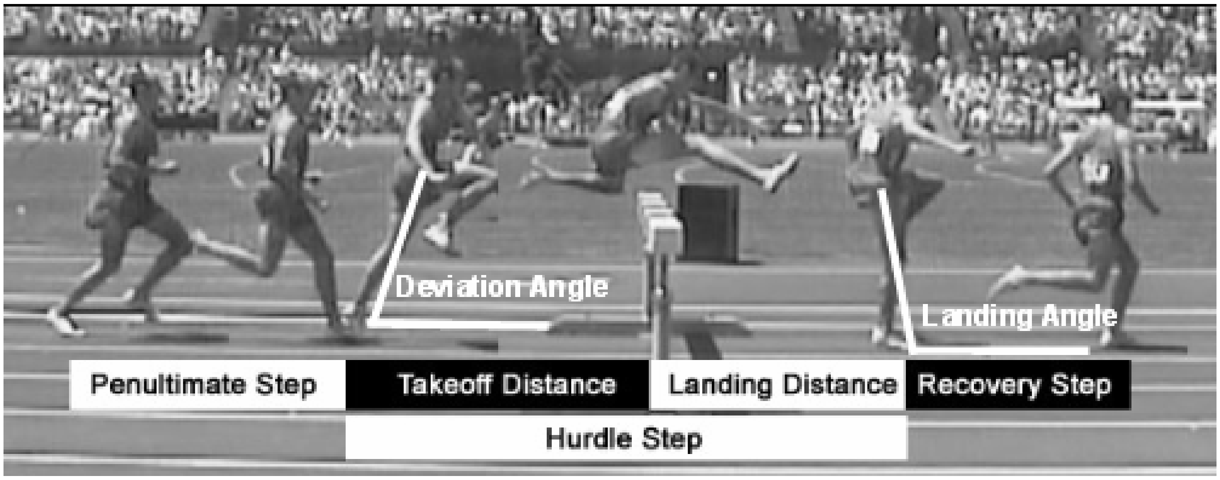

Figure 1: Visual description of step lengths, takeoff distance, landing distance, deviation angle and landing angle

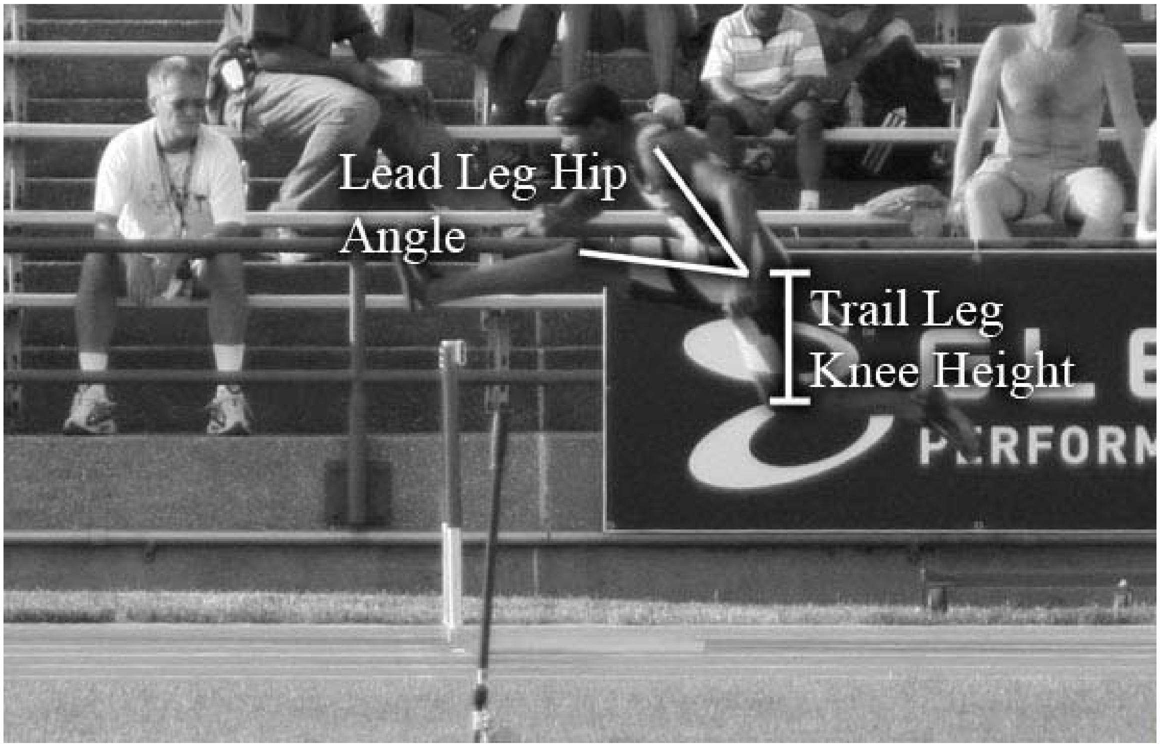

Figure 2: Visual description of hip angle and knee height

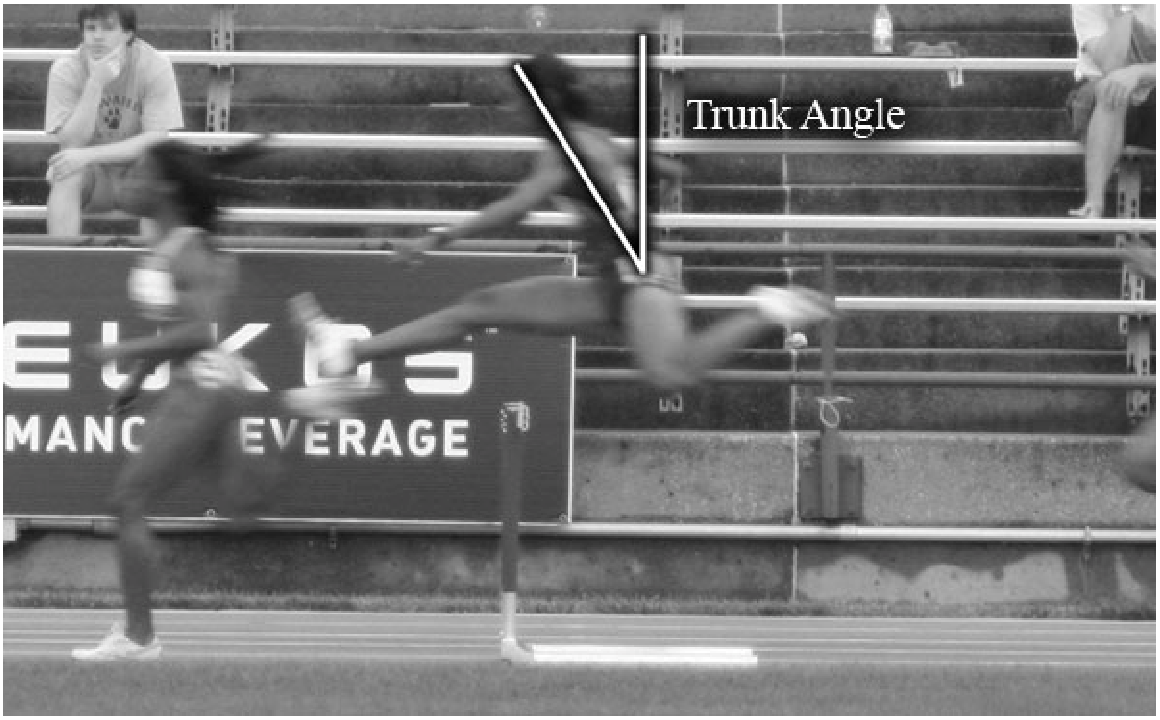

Figure 3: Visual description of trunk angle

Figure 4: Visual description of peak center of mass and horizontal position at peak center of mass

Appendix B

Additional Results

Category 1: Men's Intermediate Hurdlers

	Bennett	Clement	Jackson	Garrett	Tinsley	Carter	Green	Williams	Sharpe	Thornton
Deviation Angle (°)	65.30	62.55	64.70	60.50	67.40	64.65	56.70	63.65	58.85	71.20
Landing Angle (°)	111.15	110.40	101.50	109.85	102.60	108.40	107.90	106.90	112.25	100.40
Lead-leg Hip Angle (°)	66.60	74.20	46.40	57.00	56.70	77.40	66.50	59.20	76.20	77.60
Peak Height (m)	0.42	0.50	0.33	0.41	0.41	0.46	0.44	0.42	0.33	0.50
Horizontal Position of PH (m)	-0.22	0.13	-0.15	-0.23	-0.20	-0.11	-0.31	-0.48	-0.16	-0.10
Trail-leg Knee Height (m)	-0.24	-0.31	-0.27	-0.20	-0.25	-0.23	-0.24	-0.25	-0.21	-0.16
Trunk Angle (°)	38.55	29.35	43.55	39.60	41.45	41.85	35.85	40.20	29.75	27.95
Take-off Distance (m)	2.23	2.12	2.26	2.66	2.24	2.78	2.71	2.73	2.17	2.40
Landing Distance (m)	1.99	2.57	1.70	1.85	1.92	1.46	1.63	1.66	1.84	2.00
Hurdle Step Length (m)	4.22	4.69	3.96	4.51	4.16	4.24	4.34	4.39	4.01	4.40
Penultimate Step Length (m)	2.16	2.19	1.98	2.53	1.96	2.63	2.32	2.08	1.94	2.05
Recovery Step Length (m)	1.88	1.95	1.71	1.68	1.62	1.92	1.72	1.47	1.78	1.59
Step Length Ratio	0.87	0.89	0.86	0.66	0.83	0.73	0.74	0.71	0.92	0.78
Penultimate Horzontal Vel. (m/s)	9.34	8.87	8.93	9.42	8.58	9.56	8.35	8.93	8.46	8.38
Recovery Horizontal Vel. (m/s)	8.98	8.34	7.97	7.64	7.51	7.92	7.46	7.68	7.59	7.65
Loss of Horizontal Vel. (%)	3.85	5.98	10.75	18.90	12.42	17.11	10.66	14.00	10.28	8.77
Hurdle Velocity (m/s)	8.77	9.31	9.31	9.60	8.90	9.35	9.00	9.60	8.97	8.71

Category 2: Women's Intermediate Hurdlers

	Martin	Demus	Johnson	Smith	Ross-Williams	Glover	Leach	Darden	James	Richardson
Deviation Angle (°)	63.75	62.60	64.35	67.30	65.60	62.20	66.15	64.60	66.40	61.75
Landing Angle (°)	105.30	114.85	111.10	110.70	112.65	108.10	110.45	113.20	101.90	105.15
Lead-leg Hip Angle (°)	73.40	76.90	80.70	78.80	66.50	92.80	80.30	98.90	74.80	57.70
Peak Height (m)	0.46	0.45	0.48	0.50	0.30	0.46	0.47	0.43	0.57	0.41
Horizontal Position of PH (m)	-0.14	0.01	0.23	-0.18	-0.30	-0.26	-0.04	0.29	-0.13	-0.32
Trail-leg Knee Height (m)	-0.28	-0.33	-0.30	-0.31	-0.27	-0.30	-0.30	-0.14	-0.28	-0.28
Trunk Angle (°)	36.10	33.40	20.20	30.65	24.90	22.84	19.65	13.55	21.35	33.05
Take-off Distance (m)	2.02	1.88	2.14	2.01	2.23	2.25	1.77	2.13	2.29	2.15
Landing Distance (m)	1.84	1.79	1.79	1.63	1.11	1.56	1.99	1.81	1.86	1.36
Hurdle Step Length (m)	3.86	3.67	3.93	3.64	3.34	3.81	3.76	3.94	4.15	3.51
Penultimate Step Length (m)	1.54	2.01	1.94	1.98	2.01	2.03	1.82	2.01	2.09	1.85
Recovery Step Length (m)	1.24	1.15	1.67	1.69	1.72	1.56	1.56	1.82	1.67	1.84
Step Length Ratio	0.81	0.57	0.86	0.85	0.86	0.77	0.86	0.91	0.80	0.99
Penultimate Horzontal Vel. (m/s)	7.13	7.85	7.78	7.63	7.65	7.50	7.56	7.96	7.65	7.08
Recovery Horizontal Vel. (m/s)	6.94	7.35	7.01	6.81	6.84	6.85	6.73	7.36	7.03	6.68
Loss of Horizontal Vel. (%)	2.66	6.37	9.96	10.81	10.59	8.67	10.98	7.54	8.10	5.65
Hurdle Velocity (m/s)	7.82	8.38	8.41	7.97	8.40	8.40	8.09	8.66	8.55	8.21

Category 3: Men's Steeplechasers

	Lincoln	Slattery	Huling	Sallberg	Brooks	Nicks	Spence	Watson	Olinger	McAdams
Deviation Angle (°)	71.65	74.25	71.00	74.35	71.90	72.30	71.00	77.45	81.15	70.20
Landing Angle (°)	98.65	101.65	107.40	100.15	98.60	96.60	108.00	100.65	98.30	101.10
Lead-leg Hip Angle (°)	57.90	79.40	90.70	70.80	72.10	44.10	53.30	69.70	86.60	79.30
Peak Height (m)	0.63	0.62	0.55	0.54	0.56	0.64	0.48	0.63	0.60	0.51
Horizontal Position of PH (m)	-0.08	-0.03	-0.26	-0.05	0.02	0.01	-0.06	0.00	-0.14	-0.08
Trail-leg Knee Height (m)	-0.24	-0.24	-0.35	-0.17	-0.29	-0.09	-0.23	-0.13	-0.25	-0.29
Trunk Angle (°)	29.10	17.30	17.20	26.30	27.25	49.30	34.00	30.30	21.60	33.60
Take-off Distance (m)	1.68	1.87	2.10	1.49	1.64	1.71	1.81	1.49	1.71	1.80
Landing Distance (m)	1.79	1.79	1.43	1.43	1.64	1.58	1.54	1.64	1.64	1.49
Hurdle Step Length (m)	3.47	3.66	3.53	2.92	3.28	3.29	3.35	3.13	3.35	3.29
Penultimate Step Length (m)	1.58	1.66	2.07	1.43	1.57	1.67	1.67	1.51	1.75	1.58
Recovery Step Length (m)	1.51	1.48	1.45	1.20	1.41	1.30	1.30	1.21	1.20	1.43
Step Length Ratio	0.96	0.89	0.70	0.84	0.90	0.78	0.78	0.80	0.69	0.91
Penultimate Horzontal Vel. (m/s)	5.59	5.72	5.76	5.20	5.63	5.40	5.62	5.12	5.74	5.40
Recovery Horizontal Vel. (m/s)	4.88	5.19	4.85	4.36	5.39	4.92	4.74	4.24	4.78	5.06
Loss of Horizontal Vel. (%)	12.79	9.27	15.89	16.25	4.27	8.90	15.75	17.19	16.72	6.30
Hurdle Velocity (m/s)	6.17	5.85	6.17	5.10	6.03	5.80	6.10	5.56	6.10	5.89

Category 4: Women's Steeplechasers

	Galaviz	Anderson	DiCrescenzo	Cox	Strong	Messner	Wort	Kuca	Rudkin	Chesser
Deviation Angle (°)	72.80	71.10	70.20	78.25	66.10	72.65	70.60	79.20	65.70	67.45
Landing Angle (°)	107.80	102.85	107.90	94.65	106.85	94.90	104.00	91.95	103.45	105.25
Lead-leg Hip Angle (°)	57.90	53.30	91.70	47.70	74.30	51.90	74.30	72.60	79.10	63.60
Peak Height (m)	0.52	0.54	0.54	0.64	0.53	0.59	0.56	0.66	0.53	0.49
Horizontal Position of PH (m)	-0.38	0.18	-0.14	0.05	-0.48	-0.07	-0.10	-0.05	-0.59	-0.28
Trail-leg Knee Height (m)	-0.28	-0.33	-0.34	-0.22	-0.36	-0.19	-0.27	-0.14	-0.35	-0.30
Trunk Angle (°)	33.55	37.50	20.80	49.10	27.70	40.85	27.35	34.95	23.70	38.85
Take-off Distance (m)	1.77	1.19	1.59	1.49	1.92	1.52	1.55	1.43	1.95	1.69
Landing Distance (m)	1.11	1.50	1.39	1.32	1.02	1.25	1.38	1.05	1.02	1.06
Hurdle Step Length (m)	2.88	2.69	2.98	2.81	2.94	2.77	2.93	2.48	2.97	2.75
Penultimate Step Length (m)	1.86	1.50	1.72	1.52	1.90	1.50	1.82	1.53	1.63	1.58
Recovery Step Length (m)	1.07	1.30	1.51	1.10	1.44	1.07	1.28	1.17	1.16	1.21
Step Length Ratio	0.58	0.87	0.88	0.72	0.76	0.71	0.70	0.76	0.71	0.77
Penultimate Horzontal Vel. (m/s)	5.38	4.78	5.14	5.20	5.54	5.27	5.67	4.57	5.55	4.98
Recovery Horizontal Vel. (m/s)	4.25	4.38	4.29	4.43	4.52	4.48	4.25	3.97	4.65	4.41
Loss of Horizontal Vel. (%)	21.00	8.37	16.63	14.81	18.41	14.99	25.04	13.03	16.22	11.55
Hurdle Velocity (m/s)	5.39	5.26	5.39	5.12	5.54	4.70	5.44	4.85	5.43	5.53