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Relationship Between Foot Pressures and Alterations of Horizontal Velocities of the Center of Mass While Hurdling

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ABSTRACT

This study analyzed the landing phase of hurdle clearance to investigate how the vertical displacement in the hurdler's center of mass and foot pressures at ground contact lead to a change in the hurdler's overall horizontal velocity of the center of mass. This study examined four male collegiate high hurdlers as they performed three trials of clearing one 42 inch high hurdle. The subjects were filmed during the three trials using three Panasonic cameras (60 Hz) and one JVC video camera (60 Hz), which was later used to provide video images in order to digitize each frame using the APAS software. The subjects' foot pressure mapping data was also recorded at a sampling rate of 400 Hz during the three trials using the Tekscan high resolution (HR) Fscan hardware and software. The Tekscan HR Fscan hardware and software allowed for pressure measurements of the subjects' forefoot, heel, and total foot pressure measured in pounds per square inch. The data collected from the APAS software and the Tekscan software was then calculated using the statistical software package SPSS. Multiple Pearson product correlations were analyzed between the kinematic and kinetic variables with one of these correlations resulting in a moderate relationship. The correlation between the change in the center of mass horizontal velocity and the heel pressure psi during the landing phase resulted in a moderate relationship with a correlation coefficient of $r = .612$, $p = .034$. The relationship between these two variables indicates that when a hurdler heel taps during the transitioning from flight phase to landing phase there is a decrease in their horizontal velocity.

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CHAPTER 1

Introduction

The 110 meter high hurdles race is one of the most exciting races in the sport of track and field. In the men's 110 meter high hurdles there are 10 hurdles alienated down the backstretch of the track where the sprints take place, each standing 42 inches high and set 9.14 meters apart. The first hurdle is located 13.72 meters from the starting line and the last hurdle is situated 14.02 meters before the finish line. The goal for the hurdler is to sprint as fast as he can and get to the finish line in the least amount of time as possible, remembering that "they are sprinters first and hurdlers second" (Bowerman, 1991). Since there are 10 hurdles, the hurdler needs to stay low and glide over each hurdle. If the hurdler elevates to high over the hurdle he will slow down because his center of mass will raise and not allow his foot to make ground contact for acceleration. Instead, the hurdler must keep his center of mass as close to the hurdle as possible without touching it. Once the lead leg has passed the hurdle then it is brought back to the ground as soon as possible. Speed is gained or maintained through the propulsive action of the foot as it is in contact with the ground (Ward-Smith, 1997).

Hurdle clearance can be delineated into three phases: the take-off phase, flight phase, and the landing phase (Tidow, 1989). The *take-off phase* is when the hurdler approaches the hurdle and drives his lead leg forward and upward while plantar flexing his trail leg's foot against the ground. The hurdler should remain in a tall upright position while bringing the arm on the same side of the trail leg forward and pulling the lead leg arm backward. The hurdler then enters into the *flight phase* where his legs scissor with his lead leg straightening out. The hurdler has a slight forward lean of his upper body to lead him over the hurdle. The trail leg is behind the body but is brought up rapidly at an angle perpendicular to the lead leg (flexed at the knee). As the hips cross the hurdle there is a smooth clearance, instead of having both legs clear the hurdle at the same time causing the need for a much higher elevation of the body's center of mass.

As the trail leg clears the hurdle, the hurdler is then transitioning into the *landing phase*. His lead leg remains extended and coming down toward the ground in a pawing action to continue accelerating by converting into his proper sprinting form. Foot contact is where the hurdler will interact with ground reaction forces as the incoming vectors cause an opposite and equal reaction causing a braking action. Many non-elite hurdlers experience difficulties during the transitioning from their sprinting form from their landing phase. Typically these hurdlers do not have the strength in their lead leg's calf muscle to keep their foot plantar flexed or in their knee extensor muscles to keep the knee properly extended during landing. Their weight is then shifted backwards and they tap their heel on the ground or produce a hollowing out effect which decreases the height of the center of mass. This then requires a repositioning of the foot to a plantar flexed position for proper sprinting technique (Figure 1.1). Despite the dilemma, minimal research has been done to study what the effect of these variables can have on the overall horizontal velocity of the hurdler.

Purpose of the Study

The purpose of this study was to examine the landing phase of hurdle clearance to find how the vertical displacement in the hurdler's center of mass and foot pressures at ground contact, lead to a change in the hurdler's overall horizontal velocity of the center of mass. The variables observed in this evaluation were the measure of distance and velocity from when the hurdler first makes foot contact with the ground to when he begins to accelerate forward at toe-off. The peak pressures of the forefoot and the heel of the foot were measured during the landing phase.

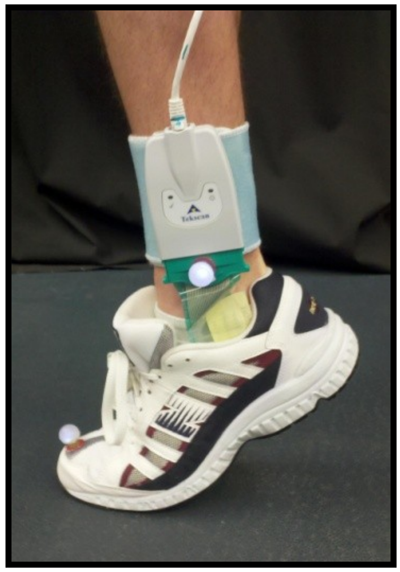

Figure 1.1

Plantar flexion (proper foot contact during landing phase & sprinting)

Statement of the Problem

The problem of the study was to determine whether a vertical change in the hurdler's center of mass correlates with an increase in the pressure per square inch (psi) of the forefoot's pressure producing a greater ground reaction force or braking action. An increased braking action could result in the overall horizontal velocity of the hurdler's center of mass to decelerate.

Operational Definitions

1. Lead leg -- The leg of the hurdler that is straightened out and clears the hurdle first. It is also the first leg to make contact with the ground at landing.

2. Trail leg -- The leg that the hurdler uses at takeoff to clear the hurdle and is the last leg/body part to clear the hurdle. It is then the second foot to make contact with the ground during the landing phase.
3. Ground reaction force (GRF) -- The force that is exerted from the ground to the body. Newton's third law of motion applies to GRF, which indicates that with any force the body applies to the ground there is an equal and opposite reaction applied by the ground to the body. The GRF selected for examination in this study will be along the Z plane that represents the vertical forces of the foot.
4. Velocity -- The rate of the change in the position of an object.
5. APAS -- Ariel Performance Analysis System software used to analyze human movement. The APAS model used in this study is version 12.1.0.14 and last updated in 2010.
6. Tekscan -- Software and hardware used for pressure mapping of the foot. This study used the Research version 6.3x, high resolution innersoles (25 sensels/in), and it was last updated in 2010.
7. Pawing action -- Explosive downward and backward movement of the leg and foot performed by sprinters to reduce the amount of time the foot is in contact with the ground.
8. Hollowing out -- The center of mass of the hurdler decreasing during landing phase due to not being able to keep lead leg extended.
9. Toe-off -- The hurdler's forefoot presses against the ground to accelerate forward during the transition from landing phase to sprinting form.
10. Toe-box -- The area of the foot that encompasses all of the toes.

11. Pounds per square inch (psi) -- A unit of pressure that is used in this study to measure foot pressures at landing.
12. SPSS (Statistical Package for the Social Sciences) -- A statistical software program used to analyze statistical data. SPSS version 16.0.2 (April 2008) was used to calculate the Person Product Correlations.

Delimitations

1. There were four male subjects.
2. Subjects were between the ages of 18-22 years old.
3. Subjects were currently active and competing in high hurdles at the collegiate level.
4. All subjects had completed one season of competition in the collegiate high hurdles prior to participating in the study.
5. All subjects were required to wear a pair of spandex shorts and a spandex shirt for proper positioning of active data markers and Tekscan hardware.
6. All subjects were required to perform three hurdle trials at competition effort.
7. The subjects had an approach of 13.72 meters, which represents the official distance from the start to the first hurdle, to clear one single hurdle set at the height of 42 inches.
8. Subjects' 13.72 meter run out was videotaped with three Panasonic PV-GS65 video cameras at 60 fields per second which provided a head on view from the left and right, and a side view with a 20 meter field of view.
9. The subject's foot contact and landing interaction was recorded by a JVC 9800 video camera operating at 240 frames per second and was placed perpendicular to the movement plane.

Limitations

1. A 50 ft tethered LAN cable was used for the Tekscan hardware because a wireless Tekscan was not available.

Assumptions

1. Subjects performed the hurdle clearance and provided competitive effort for each trial.
2. Every trial was performed by each individual subject's best effort, yielding similar results.
3. Active light emitting diode (LED) data markers of 1" or ½" inch diameter were placed on the subject in the exact spot as every other subject.
4. Active data markers remained on the subject's joint site during the execution of the skill.
5. All equipment used produced accurate measurement units for every subject and every trial.
6. The researcher performed proper equipment calibration and record the data.
7. Tekscan equipment did not alter the subjects' performance of the skill.
8. Subjects clearing one hurdle with indicated approach length demonstrated the same hurdling technique as a race.

Kinematic Research Hypotheses

1. Subjects with the greatest change vertically in their center of mass position during foot contact from hollowing out, knee buckling, or heel tapping will have the greatest decrease in horizontal velocity during the foot contact.

Kinetic Research Hypotheses

2. Subjects with higher average heel pressure (psi) during landing will have the greatest amount of deceleration in their center of mass horizontal velocity.

3. Subjects with higher levels of average forefoot pressure (psi) will have the greatest amounts of deceleration in horizontal velocity which in turn will lead to increased amounts of speed reduction.
4. The greater the subject's center of mass changes vertically during landing phase, the greater the amount of total foot pressure pounds per square inch (heel and forefoot pressures).

CHAPTER 2

Review of Literature

The review of literature for this study is an examination of proper hurdling technique and biomechanics of the hurdling phases in which this study will investigate.

Hurdling Technique

The 110 meter high hurdles do not leave any room for mistakes, "Hurdlers are usually agile people with quick reactions" (Bowerman, 1991). Most hurdlers make their mistakes at the hurdle clearance. Elite and collegiate hurdlers typically have great foot speed. It is the athletes that can take their sprint speed and be the most efficient in transitioning from hurdle clearance back to sprinting between the hurdles that excel in the sport. The landing phase of hurdle clearance is one of the most important elements in hurdling and has the largest reserve potential for improving the overall race time (Coh, 2003). Reserve potential will allow the hurdler to perfect their technique in order to decrease their overall speed. Two main elements that come into play with proper technique during the landing phase of hurdle clearance are center of mass height and foot pressures of the lead leg. By having a proper landing phase, a hurdler can I time greatly. Most top level coaches in track and field indicate that the hurdlers should land on the ball of their foot during the landing phase, but few realize why their athletes should perform this technique. Limited research has been conducted of the influence of what changes in the hurdlers center of mass and lead leg foot pressures can have on a hurdler's overall horizontal velocity.

Therefore, this study investigated how these variables correlate to the hurdlers horizontal velocity.

Biomechanical Phases

A study conducted by Coh (2003), took an in-depth look at the biomechanics of all the phases of hurdling and the role they played in the 110 meter world record. Coh's study analyzed the performance technique of one time World record holder Colin Jackson of the United Kingdom. Coh examined Jackson's foot contact time and found it to only last 0.08 of a second. Coh's research illustrated that as the hurdler's lead leg lands he maintains a high center of mass position of 1.15m due to the full extension of his hips, knee, and plantar flexion of his foot. This technique is key for a successful transition into sprinting mechanics. Proper biomechanics of sprinting has the foot plantar flexed and the athlete running on the balls of their feet. If the hurdler is not strong enough in the leg's posterior compartment musculature (gastrocnemius, soleus, achillies tendon), then they cannot produce enough strength to keep their foot in a plantar flexed position. Lack of strength causes their body weight to shift backwards instead of the proper forward body lean, resulting in a hollowing out or a decrease of the center of mass and a heel tap. A heel tap causes an increase in the time the foot is in contact with the ground, a decrease in the hurdler's center of mass, and unwanted ground reaction forces. Unwanted ground reaction forces cause the hurdler to decelerate. This ground reaction force has a negative effect or braking action when the vectors of the foot enter the landing phase and a positive effect or acceleration when exiting the landing phase. When examining the technique of the hurdler, the researcher was able to determine if the hurdler hollows out their center of mass by either over striding during landing phase or by buckling the knee. This causes the foot to have narrow downward facing vectors into the ground. This will result in a greater braking action caused by the ground reaction force vectors pushing in a backward manor. To combat these breaking vectors, the hurdler much keep their foot plantar flexed and strike the ground with a pawing action to eliminate as much of the negative vectors or braking action as possible. This effect is at its peak when the hurdler taps their heel by either landing on their heel or heel tapping. At this point the heel is positioned into the ground at an angle that causes a breaking action to occur, the vectors are going in the opposite direction of the hurdler. If the foot is properly plantar flexed at contact, the ground reaction force vectors will be channeled into a forward direction and not slow the hurdler down to the same degree as a heel tap.

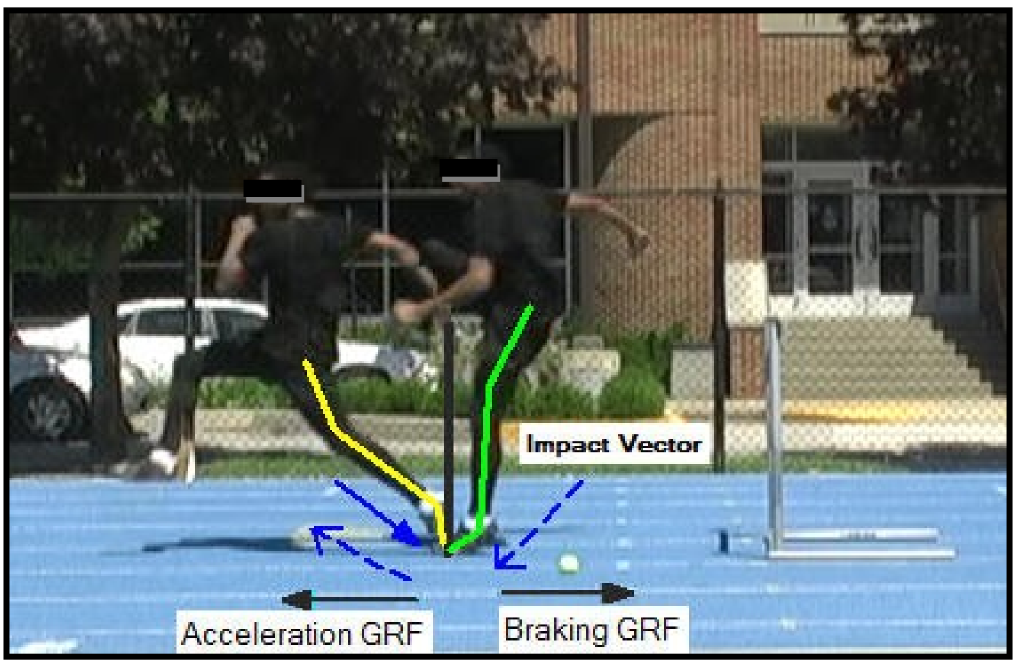

Figure 2.1

Foot vectors (braking & acceleration) in and out of landing phase

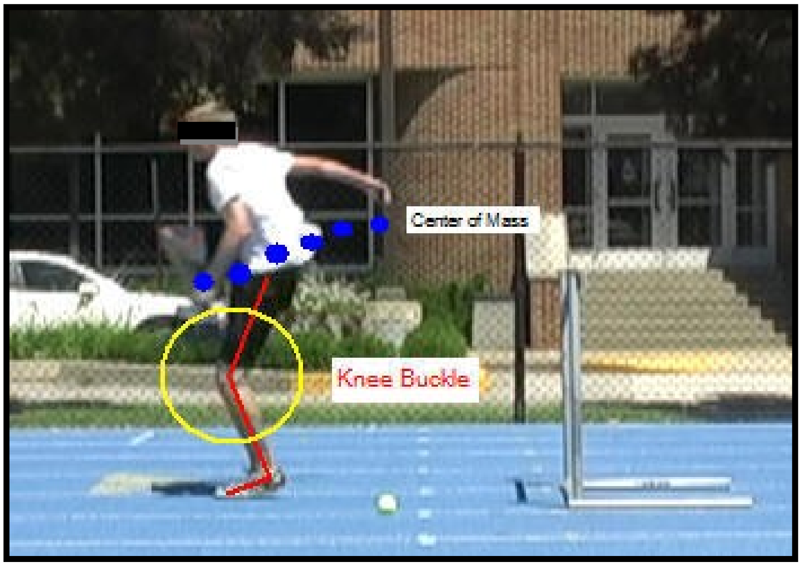

Figure 2.2

Buckling of the knee leading to hollowing out of center of mass

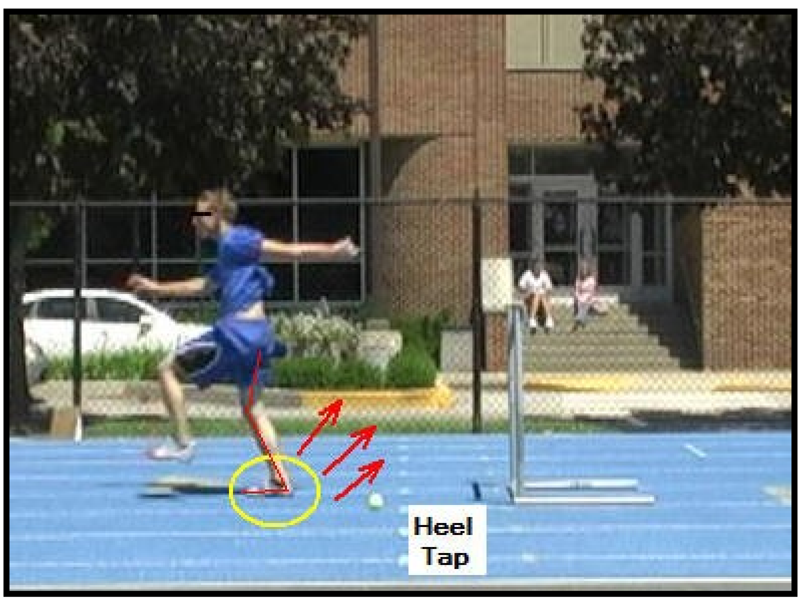

Figure 2.3

Heel tap during landing phase

Coh reported the ground reaction forces to be between the range of 2400N – 3300N; this variable is the overall force of the hurdler's foot pressure that the researcher in this study measured with the Tekscan system software and hardware. The hurdler must also withstand this large ground reaction force without buckling the knee. If the knee is buckled then there is a chance for the foot contact time to increase. This relationship was also investigated by the researcher in this study. The hurdler must have strong legs to be able to withstand these high forces and provide necessary leg stiffness (McMahon & Cheng, 1990). The leg musculature can be thought of as tunable springs that can absorb these forces. The stronger the leg musculature of the hurdler, the more force the hurdler can effectively withstand due to knee and leg stiffness. Also the greater their chance becomes of not buckling the knee, keeping the foot plantar flexed during the landing phase. Coh found that Jackson's change in his center of mass horizontal velocity was only 0.34 meters per second. Minimal change allowed him to be extremely efficient during the hurdle clearance phase. The researcher reported the data that was found from this study and compares it to what Coh reported for Jackson's performance techniques.

When investigating the biomechanics of hurdling it can be delineated into phases: the approach phase, hurdle clearance, and run between hurdles. Significant research was conducted in this study on the hurdle clearance section. Hurdle clearance will be broken down into the take-off phase, flight phase, and landing phase (Tidow, 1989) shown in Figures 2.4 and 2.5. In this review article Tidow, described his model of technique for the high hurdles. Tidow supported the technique that the hurdler must come down to the ground with the lead leg extended and that it must not yield to the landing pressure to which it is applied to upon contact with the ground.

Figure 2.4

From hurdle clearance to landing preparation

In his research Tidow (1989), found that most hurdlers had ground contact approximately 1.30m to 1.40m beyond the hurdle. When examining the ground reaction forces and strength needed by the hurdler to withstand the impact, Tidow stated that for the continuation of acceleration after contact it is important to have the lead leg pre-tensed to provide the necessary leg stiffness while continuing to straighten the hip joint and the foot plantar flexed. Tidow also emphasized about how if the trail leg, while flexed, is lifted as high as possible then it can be brought into the proper running form in the direction in which the hurdler is going. The only way the hurdler can decrease the braking ground reaction force and limit foot contact time is by keeping the trail leg high. Tidow found this to prevent the hurdlers from elevating their center of mass more than 11 cm during the landing phase allowing them to continue sprinting at a high level.

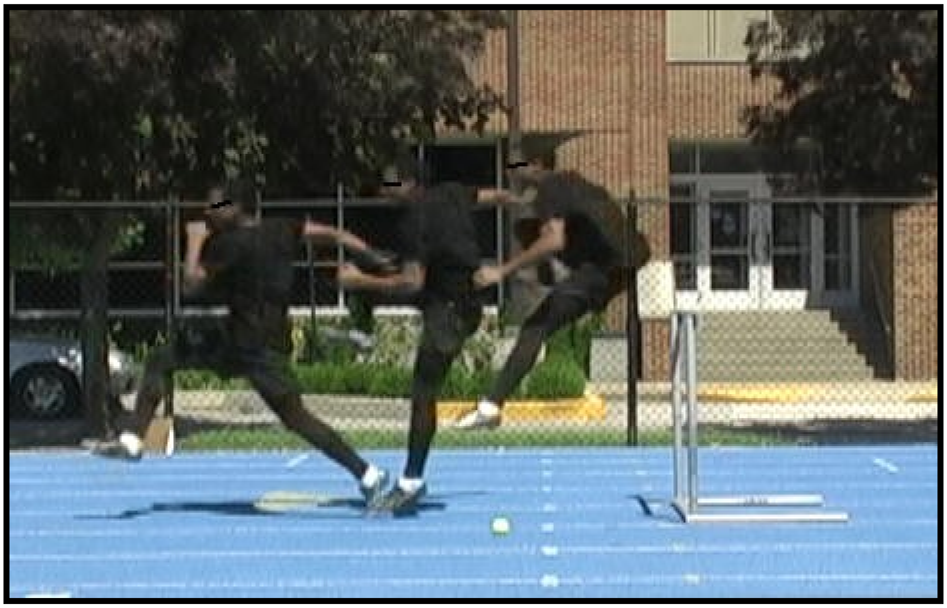

Figure 2.5

Landing phase to sprinting form

A study conducted by Salo, Grimsha, and Viltasalo (1997) examined the technical performance of hurdling in order to help athletes and coaches better understand the biomechanics behind it. The study was performed on one 20 year old female and two male athletes. The first male was 23 years old and had a personal best 110 m hurdle time of 14.86s and the second male was 23 years old and had a personal best 110 hurdle time of 14.83s. There were a total of eight trials (two sets of four trials) over four hurdles, starting out of the blocks. The recovery times were approximately four to fifteen minutes between trials and set, respectively. Four cameras from different views were used to film each trial. They then used the APAS software to transform the data into a three dimensional figure. Each subject's trial was digitized using the 14-segment body constructed model. They found that the horizontal velocity became an important variable when it comes to the overall performance of the athlete. In this present study the researcher used an experimental design similar to the methods described by Salo, Grimshaw & Viltasalo (1997).

Even though there has not been a large amount of research performed on foot pressure of the lead leg with change in the center of mass location and how that correlates to a change in horizontal velocity. There is still a need for this information to help athletes and coaches better understand what is happening during this foot/ground interaction phase of hurdling. Accordingly, this study investigated these variables in order to examine their relationship to a change in horizontal velocity during the hurdling phases.

CHAPTER 3

Methodology

The methodology is divided into the following subheadings: 1) subject selection and preparation; 2) testing procedures; 3) video graphic techniques; 4) data reduction; and 5) statistical analysis.

Subject Selection and Preparation

There were four volunteers from a Division III Midwest College participating in this study. All subjects in this study were males between the ages of 18 and 24 years, who were currently active and competing in high hurdles and had at least one season of competition at the collegiate level of track and field. Subjects were asked to perform three trials of hurdling one 42 inch hurdle. All subjects participated in this study by their own free will and were not required to participate by a coach. The coach's consent was necessary for the researcher to be allowed to recruit athlete to participate in the study. Subject's height was measured by a stadiometer in inches and mass was determined by a Tanita Digital Physician Scale (BLUB-800) to the nearest .01 kg. Shoe size along with the hurdler's top three career best times in the 110 meter high hurdles were recorded for this study. The hard copies of this information were stored in a locked file cabinet in the biomechanics lab, Arena C-63. All subjects were required to read and acknowledge their understanding of the study and any questions that they might of had were answered at that time. They then gave written consent of participation by signing an informed consent form (Appendix A). If a subject chose to withdraw from the study at anytime, they were able to do so without any consequences from the researcher.

Testing Procedures

A total of four male collegiate hurdlers were asked to perform three trials of hurdling a 42 inch hurdle. The subjects were required to wear spandex shorts or tights on their legs, spandex shirt or tank top, and their competition racing spikes. Each subject warmed up by jogging 400 meters, performing basic stretches, and performing hurdle warm up drills (Appendix B). Subjects then had a total of 18 active data markers affixed to their skin and clothing with non-allergenic adhesive tape. These active data markers were placed on the forefoot of their shoes, heel of their shoes, both ankles, knees, hips, shoulders, elbows, wrists, and one marker on their forehead and one on their chin using the protocol discussed in Plagenhoef (1971).

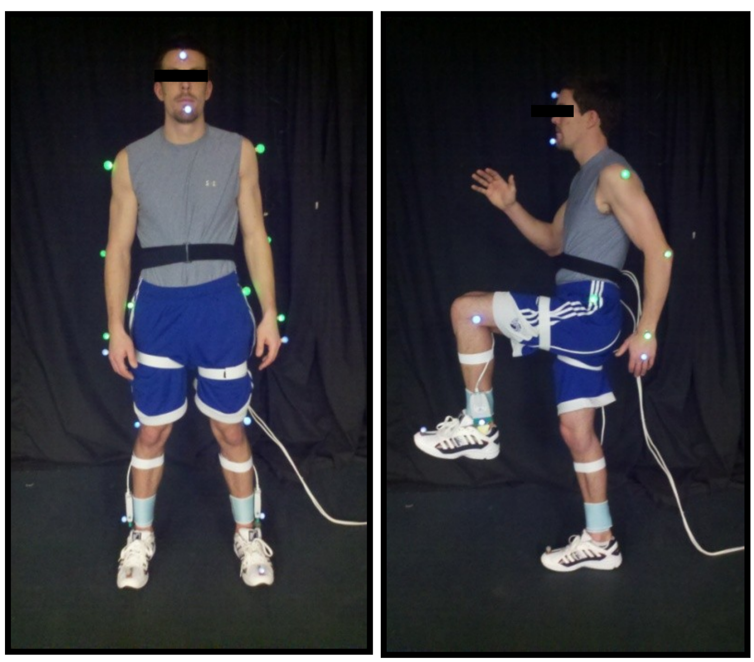

Figure 3.1

Active data markers with Tekscan hardware

Subjects then put on their competition spikes that held the insole shoe inserts from the Tekscan. An elastic belt was placed around their waist, thighs, and shins in order to secure the LAN cables from their shoes to the computer. The subject then performed the step calibration test to acclimate the Tekscan software and hardware to each subject's body weight (Appendix C). This allowed the software to properly differentiate 13 discrete pressure levels with corresponding colors to identify the foot pressures being applied during the movement (Figure 3.3).

Figure 3.2

Tekscan shoe innersoles insert and innersole handles

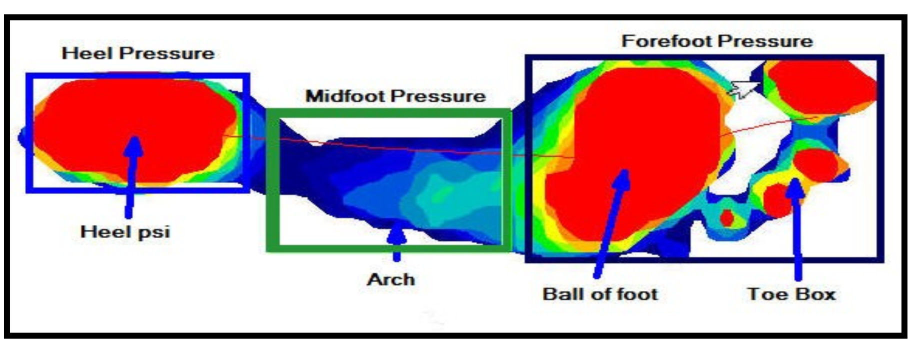

Figure 3.3

Pressure mapping image from Tekscan

The subjects perform the three trials; starting from a standing start and having an approach of 13.72 meters to the hurdle which is the distance from starting blocks to first hurdle in a 110m hurdle race. Subjects then had a landing/deceleration phase of 45 feet because of the 50 foot LAN cable used by the Tekscan. If the subject needed additional distance for proper deceleration, the quick release mechanism of the LAN cables from the Tekscan occurred providing an appropriate runway. This provided a total range of 90 feet for the hurdle clearance execution when LAN cables are attached to the Tekscan hardware. The researcher held the excess LAN cable during the movement so that it did not obstruct the hurdler during the hurdle clearance. There were approximately five minutes between each trial for data collection. During this time the subjects had access to water and were performing active rest. After all three trials were completed, the subjects were required to perform a cool down by jog 400 meters around the track and perform basic stretches.

Video Graphic Techniques

The subjects were videotaped with three Panasonic 3CCD cameras that filmed at a speed of 60 fields per second with a shutter speed of .001s. These cameras were streamed to the computers using the Cap DV function of the APAS software. The first camera was placed perpendicular to the hurdler, set up in a straight line with the hurdle, at a height of three feet above the ground, and 32 feet away from the hurdle. The second and third camera, were placed in front of the hurdle to the right and left, respectively. They were set at three feet in height from the ground, 35 feet away from the hurdle, with at least 20 degree angle to the right and left of the runway to create a 40 degree angle between the two cameras. A fourth camera, JVC 9800, was placed 4 feet in front of the hurdle and 22 feet perpendicular to the hurdle and running plane. (Figure 3.4) The fourth camera was one foot above the ground and filmed at 240 images per second with a shutter speed of 1/250s. Camera four focused strictly on the foot contact at landing after hurdle clearance. A calibration cube and fixed point were placed in the view of each camera for later analysis of the video collected. Tekscan innersole shoe inserts were placed in both of the subject's shoes and delivered pressure cell information to the computer for foot pressure data analysis.

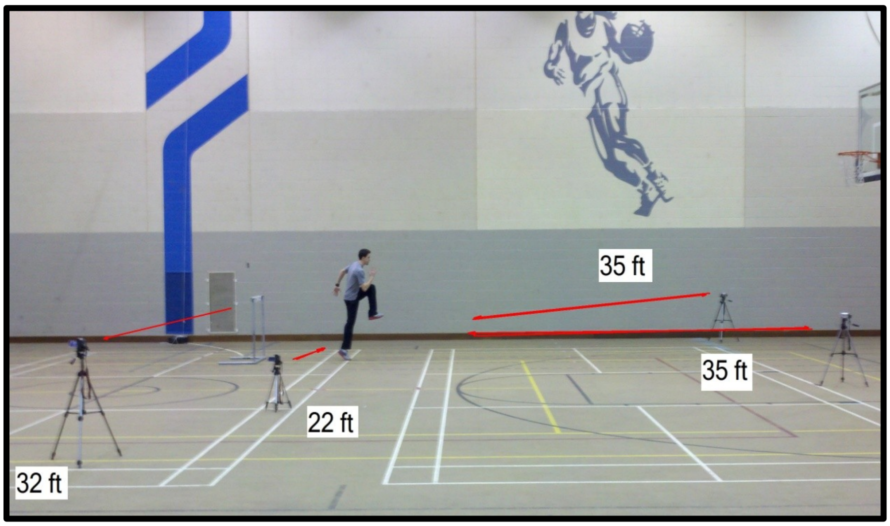

Figure 3.4

Camera set up with camera distances

Data Reduction

After the data had been collected, each trial was analyzed using the APSA software (Ariel Performance Analysis System). Each trial was then digitized from camera angles one, two, and three and transformed into a three dimensional model using the direct linear transformation (DLT) and calibration cube information. All of the digitized points were smoothed using a Butterworth second order recursive low-pass digital filter with a frequency cut-off at 10 hertz (Hz). Numerical data was collected from the display menu in the APASview section of the software. Included in this data was the hurdler's horizontal velocity of the center of mass and vertical changes in the center of mass from contact to acceleration. The Tekscan software was used to analyze the foot pressures of the hurdler during the landing phase of hurdle clearance. The peak pressures were measured in the forefoot (toe box, ball of the foot, arch) and the heel (Figure 3.3). With this data the researcher was able to examine the pressure of the foot used in the technique of the hurdler's foot contact. When performed correctly the hurdler's forefoot was the only pressure measured at foot contact.

The researcher used these five variables from the data collected to investigate the hypotheses. The following kinematic and kinetic variables were defined and calculated as follows:

Kinematic Variables

1. Change in Horizontal Velocity during Hurdling
    - The difference between the pre-hurdle clearance (take-off phase) center of mass horizontal velocities and the post-clearance (landing phase) center of mass horizontal velocities, horizontal velocity is defined as the speed at which the hurdler is running parallel to the ground.
2. Change in Vertical Height of Hurdlers Center of Mass
    - The subject's vertical height of their center of mass at touchdown subtracted from the center of mass vertical height at the lowest point during the hollowing out period. The hurdlers' center of mass vertical height is the measure of the hurdler's center of mass perpendicular to the ground.

Table 3.1

Kinematic variable data collection sheet

	Trial	CM V_x Post	CM V_x Pre	Δ CM V_x	CM_y Contact	CM_y Hollow	Δ CMy Con-Hol
Subject 1	1	--	--	--	--	--	--
	2	--	--	--	--	--	--
	3	--	--	--	--	--	--
Subject 2	1	--	--	--	--	--	--
	2	--	--	--	--	--	--
	3	--	--	--	--	--	--
Subject 3	1	--	--	--	--	--	--
	2	--	--	--	--	--	--
	3	--	--	--	--	--	--
Subject 4	1	--	--	--	--	--	--
	2	--	--	--	--	--	--
	3	--	--	--	--	--	--

Note: CM represents Center of Mass
Δ CM V_x represents Change in Center of Mass Horizontal Velocity (X axis)
CM_y Contact represents Center of Mass Vertical Height at foot contact
CM_y Hollow Center of Mass Vertical Height during knee flexion or hollowing of knee
Δ CMy Con-Hol represents Change in Center of Mass Vertical Height at contact minus hollowing out

Kinetic Variables

3. Peak Heel Pressure Data

- The peak heel pressures (normalized by the subject's body weight calculation) recorded at contact from the three trials divided by the subject's body weight.
- The heel pressure (psi) was determined by using the Tekscan software. The Tekscan software and hardware records at a sampling rate of 400/s and was then be divided by the change in time.

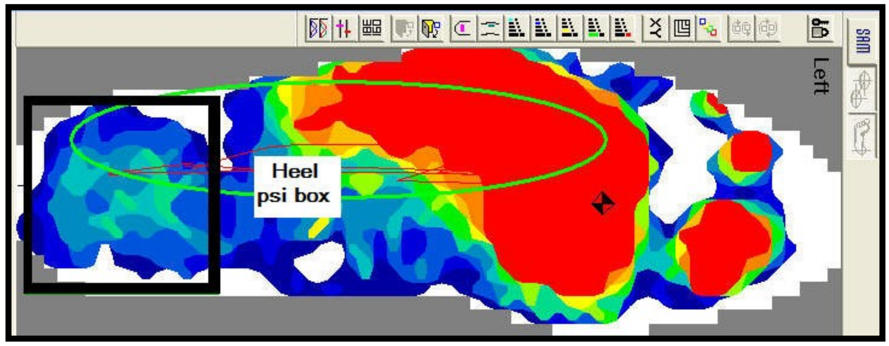

Figure 3.5

Heel pressure mapping indicator

4. Peak Forefoot Pressure Data
    - The peak forefoot pressures from the three trials were normalized for the subject's body weight.

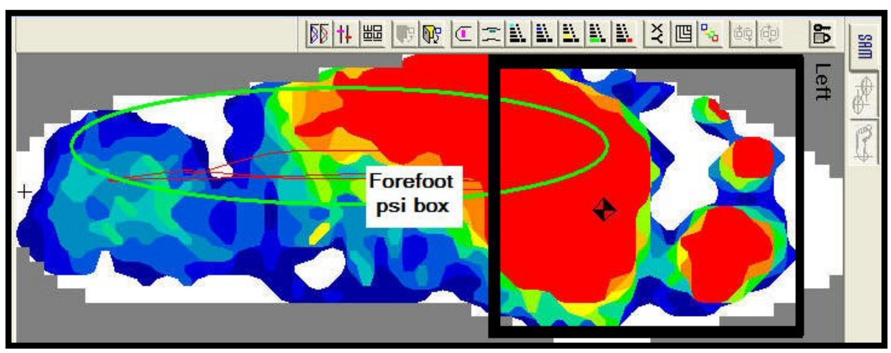

Figure 3.6

Forefoot pressure mapping indicator

5. Peak Average Pressure of Foot (heel + midfoot + forefoot)
    - The Tekscan whole foot pressure's peaks added together in order to create a common number then normalized by the subject's body weight (Figure 3.3).

- Where the addition of the heel, midfoot, and forefoot pressures added together and divided by the subjects' body weight to create a total foot pressure which allowed for comparison between the subjects.

Table 3.2

Kinetic variable data collection sheet

	Trial	Δ CM Horz. Vel_x	Heel PSI	Forefoot PSI	Total Foot PSI
Subject 1	1	--	--	--	--
	2	--	--	--	--
	3	--	--	--	--
Subject 2	1	--	--	--	--
	2	--	--	--	--
	3	--	--	--	--
Subject 3	1	--	--	--	--
	2	--	--	--	--
	3	--	--	--	--
Subject 4	1	--	--	--	--
	2	--	--	--	--
	3	--	--	--	--

Note: Δ CM Horz. Vel_x represents the change in horizontal velocity of the center of mass
Heel, Forefoot, and Total Foot psi were normalized by body weight

Statistical Analysis

A statistical analysis was performed using four separate Pearson Product correlations using the SPSS software program (SPSS Inc., 2007). The data used in the statistical analysis from the variables was from each subject's three trials. All tests of significant statistical data were performed at the .05 level of significance.

Correlation Variables

1. Determine the relationship between variable 1 (Change in Horizontal Velocity) versus variable 4 (Change in Center of Mass Vertical Height)
2. Determine the relationship between variable 1 (Change in Horizontal Velocity) with variable 2 (Peak Heel Pressures)
3. Determine the relationship between variable 1 (Change in Horizontal Velocity) versus variable 3 (Peak Forefoot Pressures)
4. Determine the relationship between variable 4 (Change in Center of Mass Vertical Height) versus variable 5 (Foot Average Peak Pressure)

Table 3.3

Correlation comparisons

Δ CM V_x vs Δ CM_y Vertical Height
Δ CM V_x vs Heel psi
Δ CM V_x vs Forefoot psi
Δ CM V_x vs Total Foot psi (heel + forefoot)

Note: Δ CM V_x represents change in horizontal velocity of the center of mass
Δ CM_y represents change in vertical height of the center of mass

Table 3.4

Kinematic and kinetic variable acronym legend

Variable Acronym	Variable Title
CM	Center of Mass
V_x	Horizontal Velocity
V_y	Vertical Velocity
Δ	Delta is a change in a variable between phases
Δ CM V_x	Change in Center of Mass Horizontal Velocity (X axis)
CM_y Contact	Center of Mass Vertical Height at foot contact
CM_y Hollow	Center of Mass Vertical Height during flexion of the knee or hollowing of knee
Δ CMy Con-Hol	Change in Center of Mass Vertical Height at contact minus hollowing out
Δ CM Horizontal Vel_x	Change in Center of Mass Horizontal Velocity (X axis)
Heel Avg. PSI	Average Heel Pounds Per Square Inch
Forefoot Avg. PSI	Average Forefoot Pounds Per Square Inch

CHAPTER 4

Results and Discussion

The results and discussion section have been divided into the following subheadings: 1) subject characteristics; 2) results of hurdling kinematic variables; 3) discussion of hurdling kinematic variables; 4) results of hurdling kinetic variables; and 5) discussion of hurdling kinetic variables.

Subject Characteristics

The subjects in this study were four male high hurdlers from a Division III Midwest College that were currently participating on the track and field team. These four subjects had career best times in the 110 meter high hurdles ranging from 15.8s – 19.1s with the mean average being 17.1 seconds. The heights of the subjects were measured using a stadiometer and body mass of the subjects were measured using a digital scale before the testing session began. The mean age of the subjects that participated in this study was 19.3 years of age, the mean height of the subjects was 73.5 inches, and the mean body mass of the subjects was 177.5 lbs. The subjects' physical characteristics can be seen in Table 4.1.

Table 4.1

Subjects' physical characteristics

Subjects	Body Mass (lbs)	Height (inches)	Age (years)	PR 110m Hurdle (sec)	Shoe Size (US)
1	185.0	73.0	22	15.8	12.0
2	185.0	75.0	19	16.2	13.0
3	165.0	71.0	18	19.1	11.0
4	175.0	75.0	18	17.1	11.0
Mean	**177.5**	**73.5**	**19.3**	**17.1**	**11.8**
SD	**9.6**	**1.9**	**1.9**	**1.5**	**0.8**

Note: PR indicates personal record in the 110 meter high hurdles

Results of Hurdling Kinematic Variables

The changes in the subjects' center of mass horizontal velocities and changes in the center of mass vertical displacements during the 12 trials were analyzed using the APAS software. The researcher recorded the horizontal velocity of each subjects' center of mass before flight phase at take-off (pre), then at foot contact during the landing phase (post). The researcher then subtracted the (pre) flight phase from the (post) landing phase to determine the change in horizontal velocity. The results from the statistical analysis indicate that there was a significant relationship in the subjects' horizontal velocities during landing phase when correlated with the heel pressure pounds per square inch (r =.612 and *p*= .034).

In order to analyze the change in center of mass vertical height, the researcher recorded the center of mass height during the landing phase at foot contact while the subjects' foot was in the plantar flexed position. Then the researcher recorded the center of mass at the lowest point during the hollowing out period of the center of mass, whether that consisted of a heel tap (when the heel touches the ground during landing phase), flexion of the knee or both. The result from the statistical analysis indicates that there were no significant relationships when a vertical change occurs in the subjects' center of mass correlated with a change in horizontal velocity during the landing phase (p= -.198 and r =.538).

Table 4.2

Diagram of kinematic variable calculations

1. Δ **Vel_x** = CM Horz. Vel_x post – CM Horz. Vel_x pre
2. Δ **CM Vertical Ht**. = avg. CM Vertical Ht. at touchdown – avg. CM Vertical Ht. at the beginning of the acceleration phase

Note: Δ Vel_x represents the change in horizontal velocity
Δ CM Vertical Ht**.** represents the change in vertical height of the center of mass
CM Horz. Vel_x (pre-post) represents horizontal velocity of center of mass at take off (pre) and at foot contact during landing (post)

Table 4.3

Kinematic variable acronym legend

Variable Acronym	**Variable Title**
Δ Vel_x	Change in Horizontal Velocity (X axis)
CM Horz. Vel_x pre	Center of Mass Horizontal Velocity pre (x axis)
CM Horz. Vel_x post	Center of Mass Horizontal Velocity post (X axis)
Δ CM Vertical Ht.	Change in Center of Mass Vertical Height
avg. CM Vertical Ht.	Average Center of Mass Vertical Height

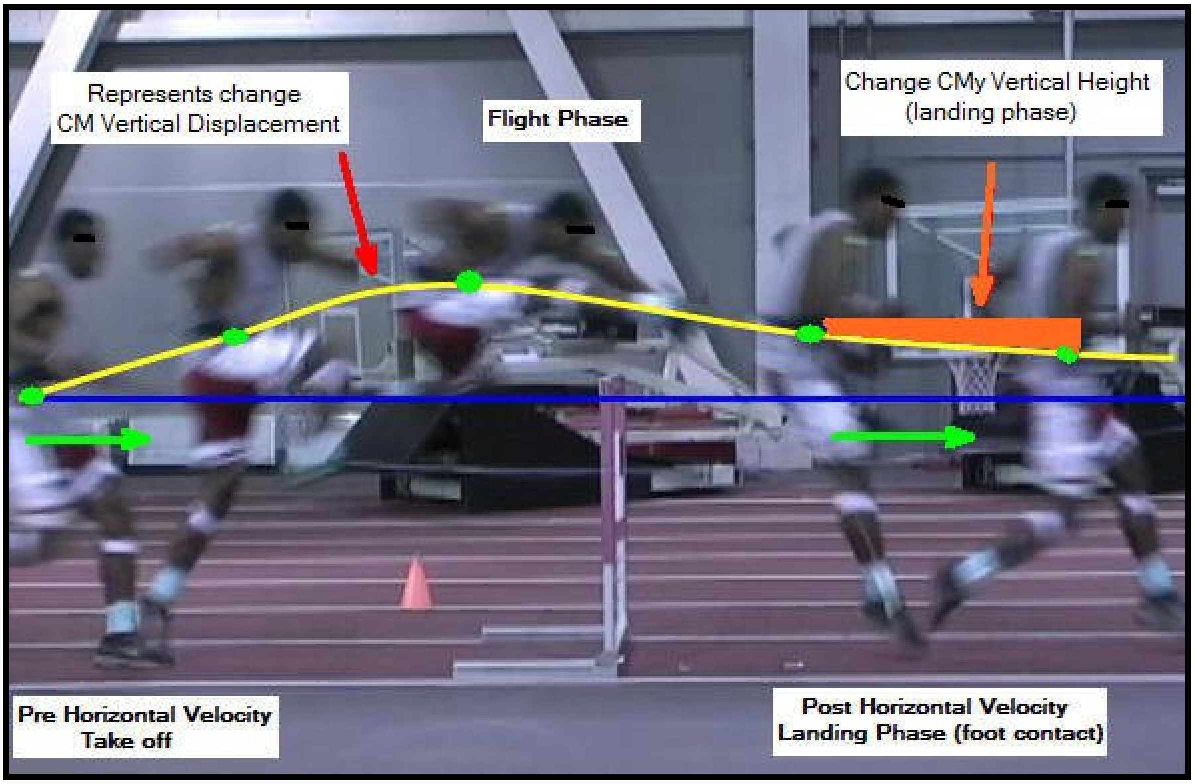

Figure 4.1

Strobe motion of kinetic variables

Discussion of Hurdling Kinematic Variables

The data collected in this study demonstrates that the subjects' mean velocity during hurdle clearance was 547.3 cm*s-1 and the mean change of their horizontal velocity from takeoff to landing phase was -79.55 cm*s^{-1}, which was presented in Table 4.5 and graphically illustrated in Figure 4.1. This would indicate that on average the subjects' speed was decreased by 14% at foot contact following the flight phase at landing. In addition, as the subjects transitioned from flight phase to landing phase the statistical analysis indicates that every subject decreased their center of mass height. The subjects' average height of their center of mass during hurdle clearance was 129.3 cm. The mean change in vertical displacement of the subjects' center of mass during foot contact during the landing phase was -9.04 cm, due to the hollowing of the knee or knee flexion. This would indicate that on average the subjects' center of mass vertical height changed by 7% during the landing phase of hurdle clearance. The results from the change in the center of mass and vertical displacements are presented in Table 4.4 and the alterations in center of mass horizontal velocity and center of mass vertical height are graphically presented in Figure 4.2.

Table 4.4

Change in the center of mass horizontal velocity

	Mean	SD	Range
Δ Horizontal Velocity	-79.6 cm*s^{-1}	38.2 cm*s^{-1}	-11.9 cm*s^{-1} to -148.1 cm*s^{-1}
Δ Vertical Height	-9.1 cm	-2.4 cm	-5.3 cm to -12.7 cm

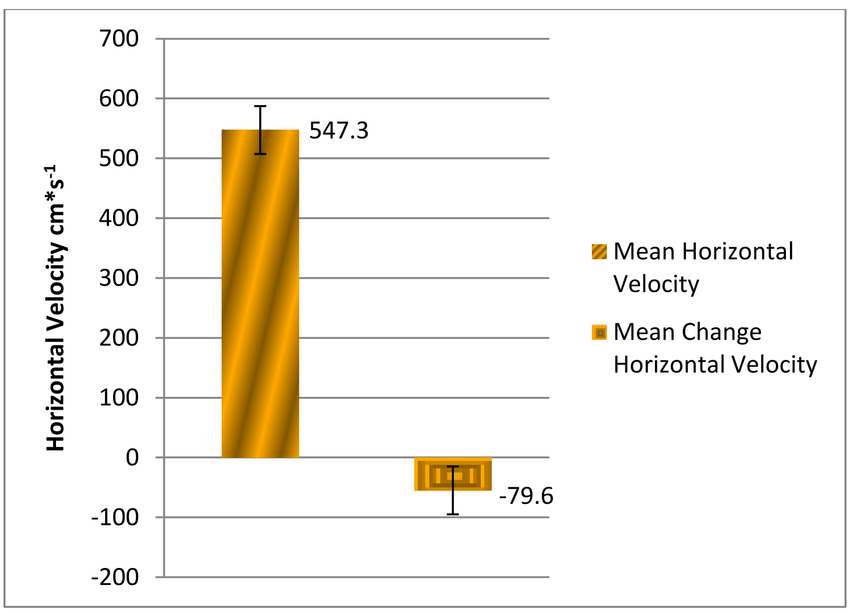

Figure 4.2

Mean horizontal velocity and mean Δ in horizontal velocity at landing

The correlation between the change in horizontal velocity of the center of mass and the vertical displacement of the center of mass indicate that there was a weak negative relationship at r =-.198. The 2-tailed t-test indicate that there was not a significant relationship at the *p*= .05 level, with the 2-tailed t-test representing the t probability of *p*= .538. The statistical analysis did not support the researcher's hypothesis which speculated that the subjects with the greatest amount of change vertically in their center of mass would result in the greatest decrease in their horizontal velocity at foot contact.

Table 4.5

Correlation between Δ horizontal velocity versus Δ vertical displacement

	Δ CM_x Horz. Vel.	**Pearson Correlation**	**Sig. (2-tailed)**	**N**
Δ CM_y Vertical Ht.	--	-0.198	0.538	12

Note: Δ CM_x Horz. Vel. represents the change in horizontal velocity of center of mass
Δ CM_y Vertical Ht. represents a change in vertical height of center of mass

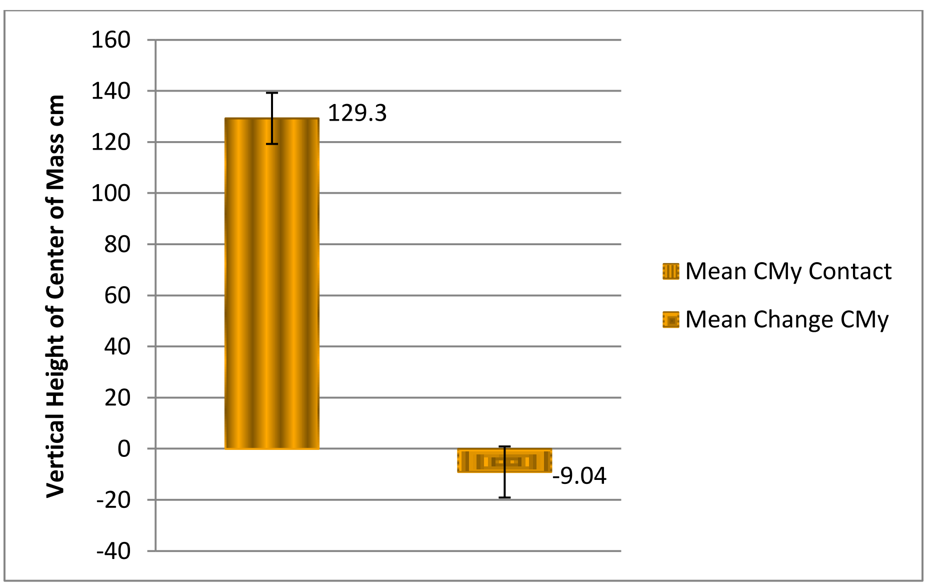

Figure 4.3

Mean vertical height and mean change in vertical displacement of CM

Results of Hurdling Kinetic Variables

The total area of the subjects' foot pressures was expressed in pounds per square inch and all 12 trials were recorded using the Tekscan high resolutions hardware sensors and software. The Tekscan software averaged together the subjects' foot pressures across sensels (that had a sensel resolution of 25 sensels per inch) during the contact of the lead leg during landing phase and the researcher recorded the data from the pressure zone boxes placed around the forefoot, midfoot, and heel. This data was then normalized by dividing the subjects' body weight for comparison between subjects. The results from the statistical analysis revealed that there was a significant relationship between the heel pressures (psi) and the subjects' change in center of mass horizontal velocity. The data also illustrated that there was not significant relationships when the horizontal velocity was correlated against the forefoot pounds per square inch, the midfoot pounds per square inch or with the total foot pounds per square inch.

Table 4.6

Equations for normalizing kinetic variable calculations

1. **Peak Heel Pressure Data** = average peak heel psi / subject's body weight
2. **Peak Forefoot Pressure Data** = average forefoot psi / subject's body weight
3. **Peak Average Foot psi** = (average heel + forefoot psi) / subject's body weight

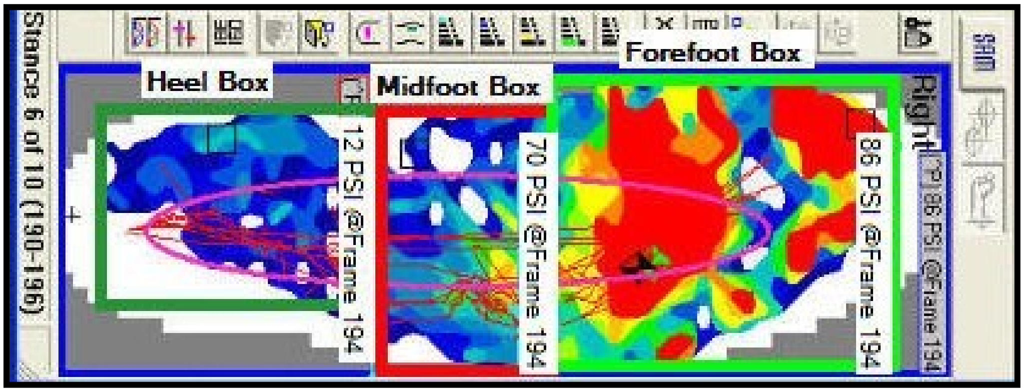

Figure 4.4

Picture of scanned foot pressure measurements

Discussion of Hurdling Kinetic Variables

The results of the kinetic variables during hurdling, specifically forefoot ground reaction forces, can be compared between this study and the study conducted by Coh, (2003). Coh conducted a study that investigated the ground reaction forces applied at foot contact during the landing phase of elite hurdler Colin Jackson. The researcher in this study also examined the forefoot pressures at foot contact during the landing phase of hurdling. After being divided by the subjects' body weight, the data resulted in the subjects' ground reaction forces to be between the ranges of 0.44 psi – 2.05 psi. The mean forefoot pressure of the subjects' data was 1.01 pounds per square inch of surface area. When examining the ground reaction forces of the midfoot pressures the results indicate a range of 0.09 psi – 0.38 psi with an overall mean of the subjects' midfoot pressure data of 0.16 pounds per square inch of surface area. When examining the heel pressure ground reaction forces, the data indicate that 3 of the 5 subjects recorded at least one heel pressure (psi). The data illustrated that 5 out of the 12 trials or 42% of the trials recorded a heel pressure during the landing phase of hurdle clearance. The range of the 5 trials of the recorded data was between 0.03 psi and 0.11 psi, resulting in an overall mean of the subjects' heel pressure data of 0.03 pounds per square inch of surface area. The data that was recorded from the forefoot, midfoot, and heel pressures established the overall mean of the total foot pressure to be 1.19 psi. The descriptive statistics from the forefoot, midfoot, heel, and total foot pressure psi can be found in Table 4.7.

Table 4.7

Foot pressure psi during the landing phase of hurdling

Foot Region	Mean psi / BW (lbs)	SD	Range (psi)	N
Forefoot	1.0	0.6	0.4 to 2.1	12
Midfoot	0.2	0.1	0.1 to 0.4	12
Heel	0.1	0.1	0.0 to 0.1	12
Total Foot	1.2	0.5	0.5 to 2.2	12

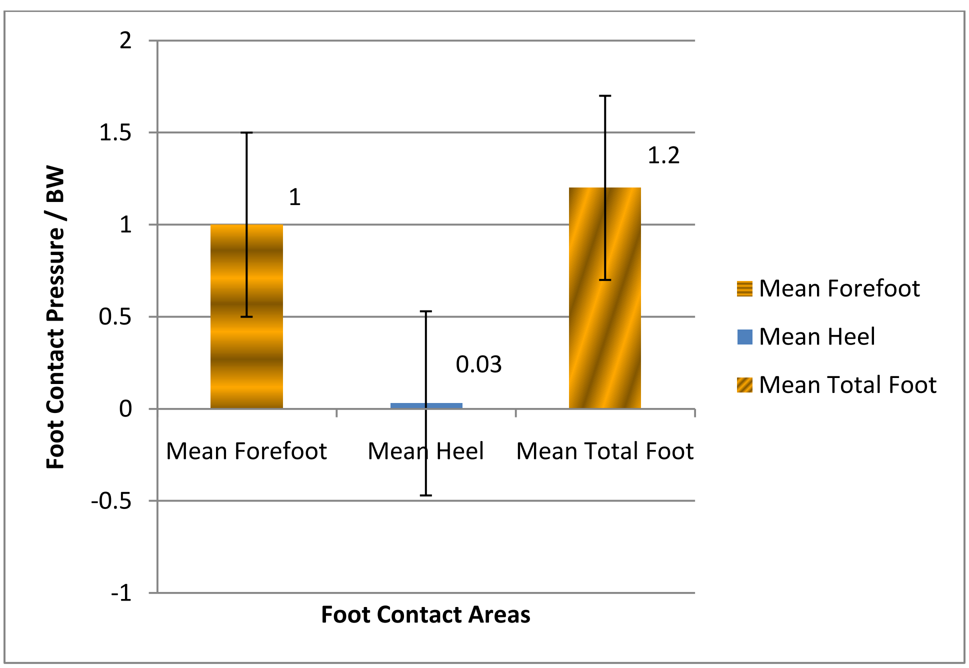

Figure 4.5

Mean forefoot, heel, and total foot pressure (psi)

When examining the correlation between the change in center of mass horizontal velocity and the heel pressure coefficient (psi), the data indicates that there is a moderate positive relationship of r =.612. This correlation is significant at the *p*= .05 level with a 2-tailed t-test value of *p*= .034. This indicates that when there is heel contact during the landing phase the subjects' overall speed decrease. These results are consistent with the researcher's hypothesis which stated that the subjects with higher average heel pressure psi during landing would have a deceleration in their center of mass horizontal velocity. The correlation between the change in center of mass horizontal velocity and forefoot pressure (psi) resulted in a weak non- significant relationship with a correlation coefficient of r =.026. The significance of the 2-tailed t-test also indicates that the relationship between the two variables were not significant with a *p*= .935. The total foot pressure (psi) was also found to have a weak relationship when correlated against the change in center of mass horizontal velocity, with a Pearson product correlation coefficient of r=.103. The 2-tailed t-test is also representative of a weak correlation with no significance at *p*=.750. This data indicate that when the subjects transitioned into the landing phase at foot contact, their total foot pressure (psi) does not have a strong relationship with the decrease in their horizontal velocity. The data from the kinetic variables correlation results can be seen in Table 4.8.

Table 4.8

Correlation-Δ CM horizontal velocity versus the foot (psi) during hurdling

Correlation	Pearson Correlation	Sig. (2-tailed)	N
Δ CM Horz. Velocity vs. Heel psi	.612**	.034*	12
Δ CM Horz. Velocity vs. Forefoot psi	.026	.935	12
Δ CM Horz. Velocity vs. Midfoot psi	.133	.679	12
Δ CM Horz. Velocity vs. Total Foot psi	.103	.750	12

Note: Δ CM Horz. Velocity represents change in horizontal velocity of the center of mass
*Indication of significance at $p \leq .05$ level
**Indication of moderate correlation

Chapter 5

Summary, Conclusions, and Recommendations

Summary

The purpose of this study was to examine the landing phase of hurdle clearance to investigate how the vertical displacement in the hurdler's center of mass and foot pressures at ground contact lead to a change in the hurdler's overall horizontal velocity of the center of mass. An examination of these variables was performed in order to find information that would further help the sport of track and field, specifically the high hurdles. The elite 110 meter high hurdler races usually last less than 14 seconds which makes it important to save as much time as possible during a race. The landing phase of hurdle clearance has the largest reserve potential for improving the overall race time (Coh, 2003). Therefore, this study examined the relationship of foot contact pressures and horizontal velocity change during hurdling.

During this study, four Division III Midwest College male track high hurdlers completed three trials of clearing one 42 inch high hurdle ran at maximum effort. The subjects' age and shoe size were recorded along with their height and weight measurements before the trials took place. The subjects were filmed during the three trials using three Panasonic cameras (60 Hz) and one JVC video camera (60 Hz), which was later used to provide video images at 60 Hz in order to digitize each frame using the APAS software. The subjects' foot pressure mapping data was also recorded at a sampling rate of 400 Hz during the three trials using the Tekscan HR Fscan hardware and software. The data collected from the APAS software and the Tekscan software was then analyzed using the statistical software package SPSS or Statistical Package for the Social Sciences (SPSS Inc., 2007). The data collected from the trials was broken down into separate variables; 1) change in the center of mass horizontal velocity, 2) change in the center of mass vertical height, 3) forefoot pressure (psi), 4) midfoot pressure (psi), 5) heel pressure (psi), and 6) total foot pressure (psi). Person product correlations were determined between the following variables: 1) change in the center of mass horizontal velocity; 2) change in the center of mass vertical height; 3) forefoot pressure (psi); 4) midfoot pressure (psi); 5) heel pressure (psi); and 6) total foot pressure (psi). The results indicated that there was a significant relationship between the change in the center of mass horizontal velocity and the heel pressure psi at landing. However, there were no significant differences between the change in the center of mass horizontal velocity and the other variables such as change in the center of mass vertical height, forefoot, and total foot pressure at landing.

Conclusion

During this study the subjects were analyzed for variables during the landing phase of high hurdling; change in the center of mass horizontal velocity, change in the center of mass vertical height, forefoot pressure, midfoot pressure, heel pressure, and total foot pressure. The results concluded that there was not a significant relationship between the change in the center of mass horizontal velocity and the variables of: change in the center of mass vertical height, forefoot pressure, midfoot pressure, and total foot pressure. The data did result in a significant relationship when correlating the change in the center of mass horizontal velocity with the heel pressure (psi) with a correlation coefficient of r =.612.

The moderate relationship between the change in the center of mass horizontal velocity and heel pressure (psi) indicates that when a high hurdler is transitioning from flight phase to landing phase and there is a tapping of the heel on the ground, the hurdler decreased in their overall horizontal velocity. This would mean that the hurdler lost speed after every landing phase during a race and there are ten hurdles on the track during a 110 meter high hurdle race. There are a number of reasons why a hurdler may tap their heel during the landing phase such as; inability to keep their foot plantar flexed due to the lack of strength in their gastrocnemius, flexion of the knee or buckling of the knee due to lack of strength in the quadriceps, or possibly a more vertical take off trajectory causing poor landing technique. Therefore a hurdler that is consistently heel tapping could work on the strength development of their leg musculature and landing technique and hopefully decrease their overall time during a 110 meter high hurdle race. The results from this study are helpful to further the knowledge of the landing phase during hurdle clearance in the 110 meter high hurdles and will hopefully enhance the level of competition.

Recommendations

Based on the results of this study, the following recommendations for future studies would include; an increased number of subjects, differences between genders, a higher skill level of the subjects participating in the study, and recommendations for future biomechanical research involving high hurdling.

This study used four collegiate track athletes to examine the landing phase of hurdle clearance. In future studies it may benefit the researcher to use a larger number of subjects with different levels of competition. This would allow for a greater sample size when conducting statistical analyzes to reduce the chances of random error and increase the power of the study. A greater sample size could result in a different statistical output that may reflect stronger relationships between the variables used in this study.

One may increase the number of subjects in the study by inviting both male and female hurdlers to participate in the study. Both male and female subjects would allow for a greater amount of statistical analyses between the two genders to determine whether there may be a moderate relationship between a change in velocity and heel pressure for females as well as males. However, incorporating both genders may raise further complications because of the differences in hurdle height, race distance, body size, and body composition.

A study examining a sport technique that is very challenging such as the landing phase during hurdling, may have better results if performed by subjects of the elite level. This study used four colligate high hurdles, if one were to use hurdlers whose times and landing technique were world class level the results may vary dramatically. Elite hurdlers tend to have superior technique during all the phases of hurdling. This superior technique could lead to a reduction of inter-trial variability and cause minor differences in their variables to result in a significant statistical difference.

Further recommendations for future biomechanical research studies involving high hurdling:

1. Investigation of adding additional hurdles for clearance during the trials.
2. Investigation of the relationship between the take off phase and landing phase.
3. Investigation of the relationship between the center of mass vertical height during pre hurdle clearance and landing phase.
4. Investigation of how a wireless Tekscan hardware system would compare to the tethered Tekscan Fscan hardware.
5. Investigation of how longer harness tabs, to permit greater ankle motion, may influence the hurdling data.

6. Investigation of the differences in knee flexion angles between trials.
7. Investigation of gender differences during landing phase.
8. Investigation of differences between leg strength measurements of the subjects.
9. Investigation of how a leg strength program could affect performance, pre versus post horizontal velocities.
10. Investigation of how take-off trajectory influences landing phase foot pressures.
11. Investigation of horizontal velocity alterations occurring at touchdown to toe-off during the landing phase.

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APPENDIX A

Subject Informed Consent

TITLE:

Relationship between Foot Pressures and Alterations of Horizontal Velocities Center of Mass While Hurdling

PURPOSE:

This study will be conducted by Braden Cole to fulfill the requirement of his master's thesis culminating experience for completion of masters of arts degree for the Department of Physical Education in the School of Nursing and Health and Human Performance at Indiana State University.

The purpose of this study is to analyze how a change in center of mass and lead leg foot pressures can correlate with the overall horizontal velocity of the hurdler during the landing phase of hurdle clearance.

PROCEDURES:

Participation in this study will take approximately one hour.

1. Subject's will be weighted with a digital scale and then have their height measured with a stadiometer.
2. Subject's will jog two warm up laps around the 200m indoor track and then perform 10 individual hurdle clearances to warm up and feel comfortable with the hurdle clearance maneuver.

3. Tekscan innersole shoe sensors will be placed in the subject's track spikes; these will be attached via two Tekscan handles connected to the subject's ankles which will have 50 ft of Cat5e LAN cable connecting it to the computer.
4. Active data markers will be attached to the subject's shoulders, elbows, wrists, hips, knees, heel, toe box, forehead, and chin for help during video analysis.
5. The subject will then perform the step calibration for the Tekscan software and hardware.
6. The subject will start their approach of 50 feet out of competition staring blocks, then hurdle one high hurdle set at 42 inches.
7. There will be a total of 3 trials. Each trial will be videotaped for analysis.

POTENTIAL RISKS AND DISCOMFORTS:

This study has no foreseeable risks to you as a participant. You will be asked to perform your normal hurdling technique that you use during practice and competition. If you are injured during the study, treatment will be available including first aid, emergency treatment, and follow-up care as needed. Payment for any such treatment must be provided by you or your health insurance.

POTENTAL BENEFITS TO SUBJECTS:

There are no direct benefits to the participants in this study.

CONFIDENTIALITY:

The records of this study will be confidential. Any published information will not include any information that will make it possible to identify you as a subject without your consent. Research records will be kept in a locked file, only the researcher will have access to these records.

WITHDRAWAL OF CONSENT:

Your decision whether or not to participate in this study will not affect your current or future relationship with Indiana State University, Physical Education Department, or your individual coaches. If you choose not to participate in the study, you may withdraw from the study at any time without affecting those relationships.

CONTACTS AND QUESTIONS:

The researcher conducting this study is Braden Cole. If you have questions concerning this study you may ask him, his advisor Dr. Alfred Finch, Dr. Thomas Sawyer Physical Education Department Chair (812-237-2645), Dr. Thomas Steiger Chair of Institutional Review Board (812-237-3426) at any time during the study by email or phone.

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afinch@indstate.edu

STATEMENT OF CONSENT:

I have read the above information and my questions have been answered. Therefore, I consent to participate in this study. I wish to have the video tape of my performance handled as follows:

Check those in which apply to you

I wish to have the video tape of my performance handled as follows:

_____ Video will be destroyed at the completion of the study after three years.

_____ Video may be used for future presentations.

_____ Video may be used for future research.

_____ Video may be used for research and/or teaching in future applications.

Subject code:______

____________________________ Date: ________

Participant Signature

____

Name (Printed)

____________________________ Date: ________

Signature of Investigator

APPENDIX B

Warm Up and Cool Down

Warm-Up

- Jog 400m
- Static Stretching (hold 20-30s)
    - Sit and reach right leg & switch to left leg
    - Butterflies with feet out and head between legs
    - Butterflies with feet in and elbows pushing down on knees
    - Right arm across the chest and hold (same with left)
    - Squat sit
- Dynamic Stretching
    - Walking stretch for 10m and accelerate for 20
        - Butt kickers
        - High knee pulls
        - Walking lunges
        - A-Skip
    - Hurdle Walkovers
    - Leg swings with hand against the wall (side to side & front to back)
- Lead Leg and Trail Leg on HH stretch

Cool-Down

- Jog 800m
- Static Stretching (hold 20-30s)
    - Sit and reach right leg & switch to left leg
    - Butterflies with feet out and head between legs
    - Butterflies with feet in and elbows pushing down on knees
    - Right arm across the chest and hold (same with left)
    - Squat sit

APPENDIX C

Tekscan Fscan Sensor Step Calibration

The subjects will first be weighted using a digital scale to find their exact body weight. To initiate step calibration, initially, the subject stands entirely on the foot to be off-loaded. The user presses the Start button, and a timer appears in the calibration window. After a second, the computer directs the subject to rapidly shift their weight onto the foot to be calibrated and keep their weight applied for five to ten seconds. It is important that the subject's weight be entirely borne through the foot being calibrated.

The computer derives two factors:

1. The fast response factor is a linear relation between raw counts and engineering units.
2. The slow response factor compensates for changes in output from the sensor over time.

For most research, step calibration is expected to be the most accurate technique. Because the computer analyzes the force from the calibration foot, step calibration reduces trial-to-trial variation compared to Point calibration. In other words, the computer is consistent compared to operator variability. Step calibration has both a factor for rapid dynamic changes and compensates for time related changes in sensor output. This makes it applicable to many different situations, such as a patient standing or performing a more athletic maneuver, such as jogging or running. (Tekscan Manual, 2007)

APPENDIX D

Subjects' horizontal velocity changes (pre – post)

	Pre Horizontal Velocity cm*s^{-1}	Post Horizontal Velocity cm*s^{-1}	Change in Horizontal Velocity cm*s^{-1}
Subject 1			
Trial 1	580.2	522.8	-57.4
Trial 2	579.2	509.9	-69.2
Trial 3	546.7	534.8	-11.9
Subject 2			
Trial 1	527.9	444.6	-83.3
Trial 2	487.3	421.2	-66.2
Trial 3	597.9	449.8	148.0
Subject 3			
Trial 1	510.4	394.3	-116.2
Trial 2	581.4	535.7	-45.7
Trial 3	515.5	422.5	-93.1
Subject 4			
Trial 1	484.4	435.1	-49.3
Trial 2	570.3	483.7	-86.6
Trial 3	586.2	458.4	-127.8
Mean	547.3	467.7	-54.9
Standard Deviation	40.7	48.4	71.2