RELATIONSHIP BETWEEN FOOT PRESSURES AND HORIZONTAL VELOCITIES ALTERATIONS WHILE HURDLING

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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. Four male collegiate high hurdlers were videotaped from three camera views as they performed three trials of clearing the first 42 inch high hurdle during a start time trial. Also, simultaneous in-shoe foot pressures were collected at 400 Hz using a Tekscan Fscan with a 50 ft cable tether. A significant correlation of r=.612 (p=.034) was found between the center of mass (CM) horizontal velocity and the heel pressure (Pa) during the landing phase. Greater heel pressure at landing contributed to a decrease in the hurdlers' horizontal velocity.

KEY WORDS: Tekscan in-shoe foot pressures, hurdling kinematics, horizontal velocities.

INTRODUCTION: Hurdling is a modified form of sprinting that requires the negotiation of a series of hurdles. Since the objective of sprinting is to cover the distance in the shortest time possible, it may be concluded that an athlete's success in the event may be influenced by their ability to produce the greatest horizontal velocity with the smallest variations during the hurdle clearance. In order to accomplish this objective, one must produce high horizontal velocities as it is necessary to produce large amounts of horizontal force while in contact with the ground. Forces which are applied vertically during foot-contact ground interaction would tend to be nonproductive in generating the necessary horizontal ground reactive forces needed to propel the hurdler down the track. The application of greater horizontal forces would be indicated by shorter ground contact times and those horizontal forces may only be generated when the hurdler is contact on the ground. Large vertical displacements of the hurdler's center of mass (CM) during hurdle clearance would reflect the hurdler jumping over the hurdle rather than striding over the hurdle which would be shown in a long flight time and a vertical parabolic trajectory during the hurdle clearance. A vertical trajectory of the center of mass would be reflective of large vertical ground reactive forces at foot contact rather than the high horizontal forces that would be generated during the pawing action of the foot at contact (Coh, 2003). Indicators of improper striding would be decelerations in the hurdler's CM during the foot contact prior to take-off and during landing after hurdle clearance. This study's objective is to examine the relationship of the foot pressures at landing to alterations in the hurdler's horizontal velocities during the foot/ground interaction phase of hurdling.

METHODS: Four collegiate hurdlers in the middle of their outdoor season volunteered from a midwest college, read and signed an informed consent before they performed three maximal 30 m hurdle starts from a standard block. The subjects' mean age, height, and weight were 19.3 ±1.9 y, 1.87 ±.05 m, and 80.7 ±4.4 kg. The subjects' mean personal record time in the 110 m hurdle was 17.1 ±1.5 s and their average US shoe size was 11.8 ± 0.8. Prior to testing, subjects jogged 400 m, and then performed their regular sprinter stretches. All hurdle starts were recorded at 60 Hz with a .001 s shutter from a sagittal, right rear, and frontal views, 18 body active markers were identified, and a calibration cube was placed at location of the first hurdle in the field of view. Markers were digitized, transformed using the 3D direct linear transformation (DLT), and digitally filtered at 10 Hz using the Ariel APAS 2011 software. Kinematic variables of total body CM horizontal velocity at takeoff, and landing phases, and the velocity change between phases, the CM vertical displacement occurring between takeoff and hurdle clearance are shown in Figure 1. Subjects then put on their competition spikes that held the Tekscan high resolution insole shoe inserts utilizing 10 sensels per square centimeter which are shown in Figure 2. An elastic belt was placed around their waist, thighs, and shank in order to secure the LAN cables from their shoes to the computer.

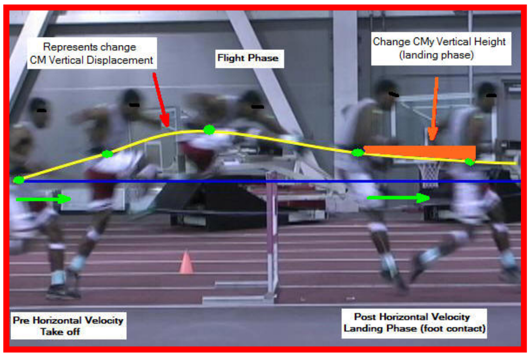

Figure 1: Hurdle kinematic variables

Figure 2: Active markers with Tekscan hardware.

The subject then performed the step calibration test to acclimate the Tekscan software research version 6.3 and hardware to each subject's body weight. This allowed the software to properly differentiate 13 discrete pressure levels with corresponding colors to identify the foot pressures measured in pounds per square inch and later the pressures were converted to the units of pascals (Pa) being applied on the heel, midfoot, and forefoot during the movement shown in Figure 3.

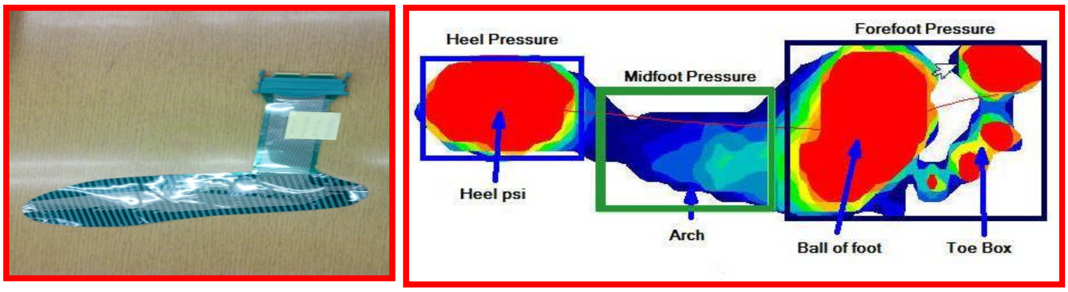

Figure 3: Tekscan shoe sensor and foot pressure mapping.

RESULTS: 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 changes in the subjects' CM horizontal velocities representing the differences between the flight phase at take-off (pre) and the foot contact during the landing phase (post) are presented in Table 1.

Table 1: Change in CM horizontal velocity and vertical displacement while hurdling.

Variable	Mean	±	SD
CM Hurdle Clearance Horizontal Velocity	5.47	±	.41 $m*s*^{-1}$
Δ Horizontal Velocity Takeoff-Land	-.80	±	.38 $m*s*^{-1}$
Vertical Height of CM at Clearance	129.30	±	.03 cm
Δ Vertical CM Displacement Takeoff-Land	-9.04	±	.02 cm

The hurdlers' CM position was decreased 9 cm during the foot contact during landing after hurdle clearance. Also, the hurdlers' CM horizontal velocity decreased 0.8 ($m*s^{*-1}$) at foot landing when compared to the CM velocity at take-off.
A Pearson's correlational analysis indicated that there was a significant relationship (r = .61, *p* = .034) between the subjects' the normalized heel pressure (Pa/kg) and the horizontal velocity changes during the landing phase. Non-significant correlational relationships were found between the horizontal velocity changes at landing and the foot pressure applied by the runners' midfoot and the forefoot shown in Table 2.

Table 2: Mean Table of Foot Region Foot Pressures Normalized by Body Weight (Pa/kg)

Foot Region	Normalized Mean Pa / %Body mass Kg	SD Pa/kg	Range Pa/kg	N (n x trials)
Forefoot	85.4	51.2	34.0 to 179.0	12 (4x3)
Midfoot	17.1	8.5	8.5 to 0.4	12 (4x3)
Heel	8.5	8.5	0.0 to 8.5	12 (4x3)
Total Foot	102.5	42.7	42.7 to 188.0	12 (4x3)

DISCUSSION: The decrease in the hurdlers' CM position during the hollowing phase at foot contact was attributable to a heel tapping action where the athlete did not possess sufficient calf strength to maintain a plantar flexed ankle position thus resulting in the runner making full heel contact and this hollowing action also may be the result of the hurdler not having adequate knee extensor strength during weight acceptance and the knee tended to collapse at impact.
A non-significant correlation relationship of r = .54 (*p* = .20) was found between the CM vertical height decrease and the change in the CM horizontal velocity transitioning from takeoff to landing. The need for elite hurdlers to maintain leg stiffness during the landing phase was reported by Tidow (1989) to reduce the hollowing of the hurdler at contact and help maintain the hurdler's horizontal velocity.
The significant relationship found between the decrease in the CM horizontal velocity and the increased heel foot pressure would indicate that if a hurdler made substantial foot contact on the heel rather than the recommended forefoot landing then this would result in a larger deceleration of the hurdler at landing. A visual comparison between the foot pressure mappings of an ineffective heel contact landing is shown in Figure 4 and an effective forefoot contact landing is shown in Figure 5.

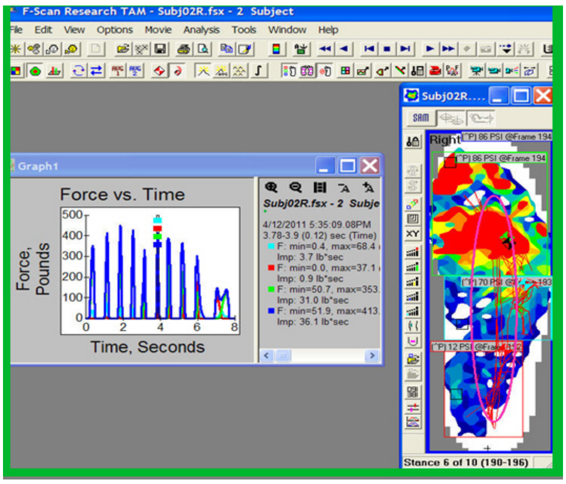

Figure 4: Heel strike foot pressures.

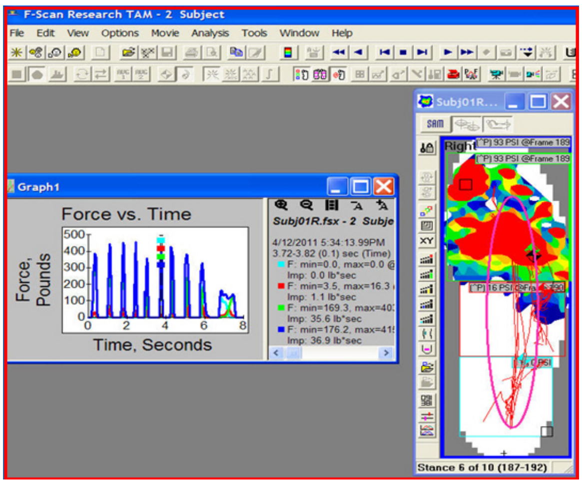

Figure 5: Forefoot contact foot pressures.

In a hurdling study conducted by Coh (2003) the ground reaction forces at foot contact measured by a force platform were reported to be between 2400N to 3300N. This was the only study which recorded the in-shoe foot pressures during actual hurdling technique in order to examine the foot/ground interaction at contact.

CONCLUSIONS: The findings of this study supported the hurdling technique used when coaching elite hurdlers where the athlete is typically told that they should land on their forefoot after hurdle clearance and not allow the heel to make contact or heel tap in order to help maintain their horizontal velocity. This required leg stiffness preventing the buckling of the lead leg at landing after hurdle clearance was reported by McMahon & Cheng (1990). An elongated stride which could lead to a heel contact was reported to hinder block clearance time in a study conducted by Stevenson (1997). The significant relationship between heel foot pressures and horizontal velocities may have implications for the strengthening programs of the hurdler's leg strength in order to maintain a plantar flexed foot contact position at landing. Such small technique alterations may be beneficial for coaches and athletes, in sprinting events where the margin of winning or losing is measured in milliseconds.

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