CHAPTER II

LITERATURE REVIEWS

Regulation of Hurdle race

The standard sprint hurdle race is 110 m for male. In male sprint hurdle race, the first hurdle is 13.72 m from the starting line, the last hurdle is 14.02 m to the finish line, 9.14 m between the hurdles, and the hurdle height is 1.07 m. (1).

Hurdle techniques

The objective of achieving better hurdling skill is to be able to attain optimal speed along with to minimize deceleration while running over the barriers (8). Hurdling coaches suggested that sprint hurdlers go over the hurdles using the same lead leg each time, taking 7-8 strides to the first hurdle and 3 strides between the hurdles comprises of hurdle step (HS), and three interhurdle steps which are landing step, recovery step, and preparatory step (2, 12). The HS can be divided into three phases including takeoff phase, clearance phase, and landing phase (6).

Prior to the takeoff phase, hurdlers should build their speed up to approach the hurdle by rapidly decelerated the trail foot in preparation for ground contact approximately 2.0 m before the hurdle, and then reaccelerate in a backward and downward direction for force application to leave to ground. After the lead leg leaves the ground, it is immediately driven up to the hurdle with knee and hip flexion, the trunk is in a slightly “forward position” (trunk flexion), and the shoulders are slightly ahead of the hips (6). The lead arm which opposes to the lead leg is flexed and internal rotated at the shoulder, and the elbow is flexed. The trail arm is flexed at the elbow and the shoulder is extended.

In clearance phase, the trunk needs to be leaned more forward together with lead leg hip flexion and knee extension in order to keep the CM closer to hurdle (5). As the lead knee is driven up above the hurdle rail, momentum is then transferred to make the knee extension by relaxing hamstring muscles (13). After the trail leg leaves the ground, it is pulled tightly to the body by knee flexed, hip abducted and internal rotated, and ankle dorsiflexed. As the hurdle is passed, the trail leg thigh is lifted to be in front of the body, and the lead arm is extended backward and downward to balance the trail leg.

At landing, the lead foot lands approximately 1 m from the hurdle and the lead leg should be in the "hips tall position" (straighten all leg joint angles), in order to land safely and loss velocity as less as possible (12). The trail leg knee is accelerated downward to the ground to reaccelerate the body for the next interhurdle step. The trunk is in a slightly forward and the shoulders ahead off the hips (6).

The movements of trunk and lead leg are associated with movements of trail leg. The forward angular momentum of the trail leg in the early part of the hurdle step was transferred later to the lead leg, which resulted in rapid downward motion of the lead leg in the final part of the hurdle step (14). McDonald et al. (14) determined angular momentum of the whole body and its distribution among the legs, arms and head-trunk of sprint hurdlers competing at the 1988 United States Olympic Trials. Twenty-three males and nine female hurdlers were filmed using three-dimensional video techniques. The clearances of the men' fifth hurdle and the women' fourth hurdle were filmed with Two Locam motion picture cameras set at frame rate of 50 frames per second. They reported that the combined angular momentum of the arms and the forward lean of the head-trunk were approximately equal and opposite to the angular momentum of the upward swing of the lead leg. Considering this rotation action-reaction mechanism, they concluded that the angular momentum of the trail leg played an important role in the distribution of the forward rotation component of the angular momentum of the body in the early part of hurdle step. During landing phase of hurdle step, the downward motion of the lead leg was produced mainly by transfer of angular momentum from the trail leg. If the hurdler had a small amount of forward angular momentum at takeoff, and if the lead leg were pulled down rapidly after passing the hurdle, the rest of the body would rotate backward, producing a marked backward leaning position, which would lead to a loss of horizontal velocity in the next interhurdle step. However, if the hurdler did not bring the lead leg down rapidly, the foot would land farther ahead of the CM, and the instant of landing would be delayed, which consequently lead to a loss of horizontal velocity in the next interhurdle step. Therefore, the hurdlers would generate a large amount of forward angular momentum during takeoff in order to achieve optimum landing position.

Kinematic analysis of sprint hurdles

Hurdling is a specialized form of sprinting that requires the clearance of a series of hurdles. Generally, during the training sessions, most hurdlers spend much of their times in body mechanics drills and speed training. Several researches concerning with kinematic analysis of sprint hurdles have been done in an international competition level. Several kinematic variables including linear and angular displacement, linear and angular velocity, and temporal variables were used to examine athletes' performance (3, 4, 5, 7).

Reliability of kinematics variables

The intratester reliability for kinematic variables of sprint hurdling was reported by Salo et al. (15) who investigated seven British National level athletes using three-dimensional video analysis techniques. Four female and three male athletes were videotaped during their training sessions on an outdoor track. Two video camera recorders were located 20.5 m in front of the third hurdle and symmetrically 20.5 m to both sides away from the midpoint of the running lane. The cameras were genlocked for simultaneous exposure. The operating rate was 25 frames per second. The shutter speed was set to 1/1000 s to ensure sharp images of quick movements.

Salo et al. (15) found that the reliability values of kinematic variables across the eight trials ranged from 0.54 to 1.00 for females and from 0.00 to 0.99 for males. The highest reliability for both genders included the variables of maximum knee angle of lead leg and lead foot lateral movement. The lowest reliability was reported for the variables of time for maximal angular velocity of the lead leg hip for females and deviation angle at takeoff for males. The results showed 24 and 15 variables with over 0.90 values for female and male athletes, respectively. The authors explained that the number of variables with reliability over 0.90 was lower in males probably due to the height of the hurdle. The higher hurdle's height for male event enforced the more demanding on clearance, which can lead to the increased variation within the subjects in different trials and thus lowering the reliability levels. Moreover, the higher hurdles might be resulted in inaccuracies in digitizing obstructed landmarks since the male athletes leaned more forward and the trunk obstructed more body parts from the other camera view.

Linear displacement

Linear displacement during the hurdle step can be classified as horizontal and vertical displacement. Takeoff and landing distances and horizontal displacement of peak of CM parabola path to the hurdle have been used to determine horizontal displacement of CM (3, 4, 5). CM lift and clearance height have been used to determine vertical displacement of CM (4, 5).

Horizontal displacement

Finch et al. (3) determined hurdling performance of the four finalists' elite hurdlers in male sprint hurdle race during 2000 United States Olympic Trials using three dimensional video analyses. Video records were taken at 60 Hz from three camera views; two front right and sagittal perspectives of the third hurdle step. They found that takeoff distance for elite hurdlers was 2.25 ± 0.25 m and landing distance was 1.44 ± 0.35 m.

Salo et al. (4) determined hurdling performance of sprint hurdlers at different competitive levels. Four different competition sessions were examined using three-dimensional video analyses. Two video camera recorders operating at the rate of 25 Hz were positioned on the front and the rear side of the third hurdle. A total of twenty-eight trials were analyzed yielding fourteen clearances each for males and females. The male and female hurdlers were divided into two groups by race time: county and club levels for males and international and county levels for females.

They found that the takeoff distance was 2.15 ± 0.14 m for males and 2.12 ± 0.22 m for females. The landing distance was 1.49 ± 0.14 m for males and 1.19 ± 0.23 m for females.

McDonald et al. (5) determined hurdling performance of sprint hurdlers competing at the 1988 United States Olympic Trials. Twenty-three males and nine female hurdlers were filmed using three-dimensional video techniques. The clearances of the men' fifth hurdle and the women' fourth hurdle were filmed with two Locam motion picture cameras set at frame rate of 50 frames per second. They found that the takeoff and landing distances were 2.12 ± 0.14 m and 1.50 ± 0.15 m for males, and 2.09 ± 0.14m and 1.10 ± 0.17 m for females.

Results from previous studies were in agreement with techniques recommended by professional coaching that the takeoff and landing distances should be approximately 2.0 m and 1.0 m from the hurdle. The takeoff distance was considered to be the factor that influence CM parabola path. The longer takeoff distance will allow the hurdlers more distance to approach the hurdle horizontally and reach the peak of CM parabola path in front of the hurdle (2, 3).

Finch et al. (3) found that elite level hurdlers' mean horizontal displacement of peak of CM parabola path was 0.03 m before the hurdle. Similar to McDonald et al. (5) who reported that male hurdlers reached the peak of CM parabola path at 0.03 ± 0.15 m before the hurdle, while female hurdlers had longer distance of their peak of CM parabola (0.30 ± 0.16 m) prior to the hurdle. The authors concluded that the male hurdlers did not need to move the peak of parabola as far from the hurdle as the female hurdlers. The short distance of the male hurdlers' peak of CM parabola path had no effect on the hurdle clearance.

<u>Vertical displacement</u>

Salo et al. (4) found that female hurdlers' average CM lift was less than that of male hurdlers (0.23 ± 0.03 m for female and 0.30 ± 0.05 m for male). Besides, the female hurdlers elevated their CM higher than the male hurdlers while passing over the hurdle. These results indicated that the female hurdlers had larger margin over the hurdle than the male hurdlers.

Similar to McDonald et al (5) found that the Olympic level male hurdlers cleared the hurdle successfully with CM parabola 0.28 ± 0.02 m higher than the hurdle, while the CM of the female hurdlers reached a maximum height 0.35 ± 0.3 m higher than the hurdle. To produce CM parabola path with the same margin over the hurdle as that of the male hurdlers, the female hurdlers should decrease their vertical velocity at takeoff, which would reduce the flight time of hurdle step. The short duration of the flight phase together with the wide motions required for the limbs in the hurdle clearance would make it difficult or impossible to complete the preparation for landing.

In conclusion, according to the takeoff distance, the longer distance allowed the hurdler more distance to approach the hurdle, which resulted in 1) a small displacement of CM from the takeoff point to the highest point of the CM parabola path, and 2) an attainment of the peak of CM parabola path in front of the hurdle. Therefore, the hurdlers were able to cross the hurdle with lower CM parabola path (4, 5). The lower CM parabola path is beneficial for hurdlers, since it required a smaller change in the vertical velocity during takeoff, and allowed the hurdler to cross the hurdle with more mean horizontal velocity (4). These implied that the longer takeoff distance, the less of vertical CM displacement and having peak of CM parabola path substantially before the hurdle would be the proper technique of the hurdling.

Table 1 Takeoff distance, landing distance, CM lift, clearance height, and horizontal displacement of peak of CM parabola path to the hurdle of male and female hurdlers from the previous studies

Study	McDonald et al., 1991	Salo et al, 1997	Finch et al., 2000
Subject	23 Olympic level male hurdlers and 9 Olympic level female hurdlers	7 County and 7 club level male hurdlers 7 International and 7 county level female male hurdlers	4 Elite level male hurdlers
Takeoff distance	2.12 ± 0.14 m for males and 2.09 ± 0.14 m for females	2.15 ± 0.14 m for males and 2.12 ± 0.22 m females	2.25 ± 0.25 m
Landing distance	1.50 ± 0.15 m for males and 1.10 ± 0.17 m for females	1.49 ± 0.14 m for males and 1.19 ± 0.23 for females	1.44 ± 0.35 m.
CM lift		0.23 ± 0.03 m for males and 0.30 ± 0.05 m for females	
Clearance height	0.28 ± 0.02 m for males and 0.35 ± 0.3 m for females		
Horizontal displacement of peak of CM parabola path to hurdle	0.03 ± 0.15 m for males and 0.30 ± 0.16 m for females		0.03 ± 0.32 m

Angular displacement

For the angular displacement, there was only one study that examined minimum hip flexion angle of lead leg. Salo et al. (4) found that male hurdlers had minimum hip flexion angle of the lead leg less than female hurdlers (45 ± 7° for male and 61 ± 7° for female). These results indicated that the male hurdlers had greater trunk flexion and raised their lead leg more than female hurdlers, permitted the male hurdlers to lower their CM parabola path.

Angular velocity

There was only one study that examined angular velocity of the lower extremities. Salo et al. (4) found that the mean maximal angular velocity of the trail hip flexion were 748 ± 19°.s^{-1} for males and 638 ± 66°.s^{-1} for females. These showed that the male hurdlers were able to cross the hurdle faster than the female hurdlers.

Linear velocity

Vertical and horizontal velocities were used to determined linear velocity. McDonald et al. (5) reported the vertical velocity at takeoff of 1.76 ± 0.13 m/s for male hurdlers and 1.49 ± 0.14 m/s for female hurdlers. The results were in agreement with Salo et al. (4) who reported the vertical velocity to be 1.7 ± 0.2 for county level hurdlers and 1.9 ± 0.2 for club level hurdlers. Salo et al. (4) concluded that the vertical velocity of 1.7 m/s was needed for the hurdlers to clear the hurdle successfully. During takeoff, an increase in vertical velocity resulted in less effective successful hurdle clearance. McDonald et al. (5) found that the changes in vertical velocity during takeoff affected the changes in the horizontal velocity. The increase in vertical velocity was associated with the loss of horizontal velocity, thus reduced in mean horizontal velocity during hurdle step. There is some similarity between the hurdle takeoff and triple jump takeoff. Bing et al. (16) determined the optimum phase ratio in the triple jump using three-dimensional video analysis. Two S-VHS video cameras were used to record the locations and orientations of the performance of the subjects at a frequency of 60 Hz. They found that during takeoff the gained in the vertical velocity was linearly correlated with the lost in the horizontal velocity.

Salo et al. (7) determined techniques in sprint hurdles within the athlete and found critical individual aspects, which influence performance. A typical training session of three Finnish National level athletes was videotaped in an indoor hall. For each athlete, eight trials during hurdle step were videotaped using four video camera recorders. The cameras operating at the rate of 25 frames per second were located symmetrically around and 29.0 m away from the midpoint of the third hurdle. The data were analyzed using a three-dimensional video analysis.

They found that the shortest hurdler had a tendency to come closer to the hurdle as the velocity increases. Although, he was quite comfortable on his approach to the hurdle at the intermediate running velocities, he needed to raise the CM from the lower position in a shorter distance than the taller hurdlers. With the lower horizontal velocities, the hurdlers also required more vertical lift, as the takeoff distance was longer. It was also found that for this shortest hurdler, he had a vertical lift that was positively related with higher horizontal velocity. However, this was generally not recommended for other hurdlers as the vertical lift wastes energy. Thus, it would be important to control the takeoff distance and horizontal velocity during approach to the hurdle.

McDonald et al. (5) found that horizontal velocity depended not only on the changes in the vertical velocity, but also on the initial value of a horizontal velocity. During approaching the hurdle, if the hurdler ran to takeoff at fast speed, the ground reaction force exerted on the hurdler with a large backward impulse, it was difficult to push backward on the ground. On the other hand, if the hurdler ran more slowly, it was easier to push backward on the ground, and thus increased in forward horizontal velocity (5).

During landing phase, McDonald et al (5) found that the hurdlers' vertical velocity continuously dropped until landed onto the ground, but failed to recover forward horizontal velocity because the trail leg landed with the unsupported leg in front of the body. The reduced of horizontal velocity during hurdle step should be facilitated the recovery in the interhurdle steps. They found that the horizontal velocity was recovered mainly in the second support phase after hurdle clearance.

Temporal variables

For temporal variables, foot contact time during support phase and flight time during hurdle clearance were examined. Finch et al. (3) found that the mean foot contact time which calculated from the step going to the hurdle of the elite hurdlers was 0.142 ± 0.01 s. They suggested that the application of greater horizontal forces would be indicated by shorter ground contact times. This meant that the shorter foot contact would result in greater mean horizontal velocity. They also found that the flight time was 0.317 ± 0.018 s for the elite level hurdlers. They suggested that the shorter flight time while clearing the hurdle would be beneficial in achieving fast hurdling times.

<u>Sacrum is the representative of the CM of the body</u>

Saini et al (17) measured the vertical displacement of the CM of the body during walking by comparing four methods of varying complexity to estimate the vertical displacement of the CM in 25 able-bodied, female subjects. The first method, the sacral marker method, utilized an external marker on the sacrum as representative of the CM of the body. The second method, the reconstructed pelvis method, which also utilized a marker over the sacrum, theoretically controlled for pelvic tilt motion. The third method, the segmental analysis method, involved measuring motion of the trunk and limb segments. The fourth method, the forceplate method, involved estimating the CM displacement from ground reaction force measurements. The results showed that there was no significant difference between the sacral marker and other methods. It can be concluded that the sacral marker was the simplest method which provided essentially the same estimate of the vertical displacement of the CM as the more complicated measures.