

Research article

Gender differences and biomechanics in the 3000m steeplechase water jump

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Abstract

Since 1996, women have been competing in the 3000m steeplechase race internationally. Whenever women and men both compete in similar events with different equipment (the barriers are lower for women) consideration should be given as to how techniques should be coached differently. This study investigated the differences in water-jump technique between men and women after accounting for differences in running speed and which techniques led to maintenance of race pace through the water-jump. Eighteen men and 18 women were filmed at two major track and field meets during the 2004 season. Peak Motus 8.2 was used to digitize all seven jumps from each athlete. Various characteristics of water-jump technique were measured or calculated and compared using two multiple linear regressions (one for men and one for women) to determine which characteristics led to maintaining race pace speeds through the water jump obstacle. Repeated measures ANOVA was used to determine any differences between men and women in the measured characteristics of technique. Velocity through the jump divided by race pace was predicted very well by approach velocity and landing distance for men and women. Other characteristics of the movement were non-significant. Differences between genders were found in: approach velocity, take-off distance, landing distance, push-off angle, velocity through jump, and exit velocity. Men and women steeplechasers must focus on approach velocity and landing distance to complete the water-jump close to their race pace. Coaches need to consider many characteristics of technique that differ between men and women.

Key words: Track and field, athletics, hurdling, running, biomechanics.

Introduction

The steeplechase requires a unique combination of endurance, power, and technique. In comparison with an open 3000 m race without water-jumps or barriers, runners are

typically 30 s slower in a 3000 m steeplechase race (Popov, 1983). Steeplechase athletes must jump barriers 35 times during the 3000 m race. Seven of the barriers are followed by a 3.66 m water pit which gradually slopes upwards until it is even with the track surface from a depth of 0.70 m (Figure 1). The slower times in the 3000 m steeplechase compared with the open 3000 m race show the effect the barriers have on performance. While conditioning and physiological parameters are the main determinants of performance in steeplechasing (Kenney and Hodgson, 1985), certain adjustments in technique over the water-jump may benefit performance as has been shown in steeplechase and sprint hurdling (Hunter and Bushnell, 2006; McDonald and Dapena, 1991).

The barrier heights in the steeplechase are equal to the hurdle heights used in the 400m race (0.762 m and 0.914 m for women and men respectively). The differences in barrier height, body height, and approach velocity between men and women lead to differences in step lengths and body positioning in hurdling (Hunter, 2006; McDonald and Dapena, 1991). Although a different movement pattern is required for the water-jump compared with hurdling, some gender differences were expected in the water-jump for the same reasons described above with hurdling.

This study investigated the characteristics of technique that lead to maintaining velocity through the water-jump, and differences between men and women in various aspects of technique.

Methods

Eighteen men and 18 women were filmed from four different views during all seven water-jumps during two 3000 m steeplechase races (2006 USATF National Championships and 2006 Cardinal Invitational at

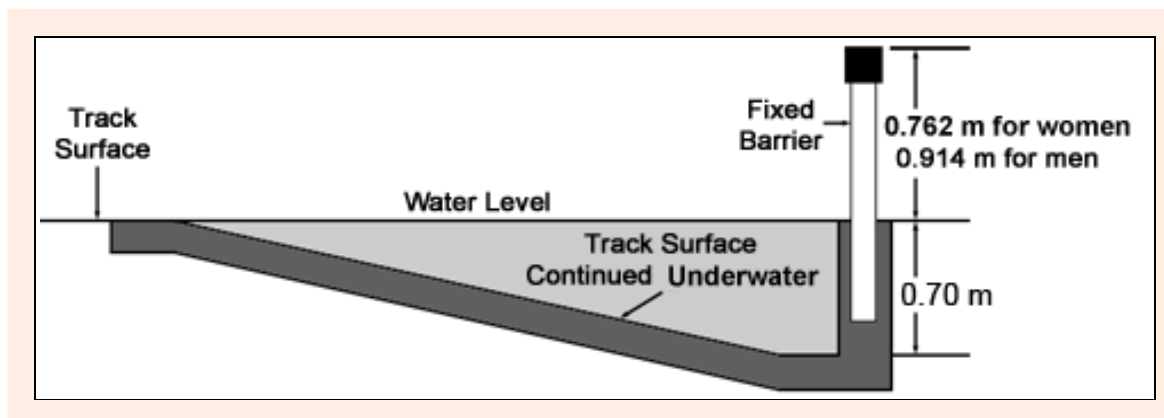


Figure 1. The dimensions of the water jump.

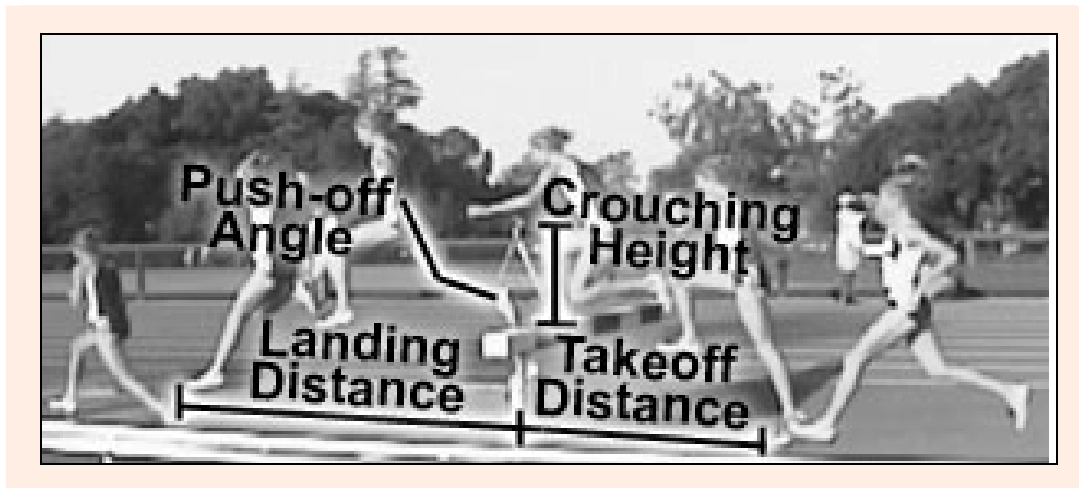


Figure 2. Some of the measured characteristics.

Stanford University) with digital video cameras running at 60Hz with a shutter speed of 1/250 s (Canon Elura 60, Lake Success, NY). The cameras were placed 20-30 m from the water jump at four locations diagonal to the water jump. For each jump, two perpendicular camera views were chosen from the four camera positions. The two views were chosen based upon lighting and positioning of other athletes. The cameras were zoomed to include 6 m prior to and 4 m past the water jump. Athletes were digitized throughout this range once their entire body was completely in the field of view.

Prior to data collection, a survey pole calibration was performed using four 2.43 m poles with 36 locations digitized. The poles were positioned in a rectangle enclosing the area the athletes would be analyzed in. A theodolite was used to determine the location of each pole.

Athletes had an average finish time of $8:38 \pm 0:16$ for men and $10:01 \pm 0:09$ for women. The University Institutional Review Board approved the study and waived the need for informed consent since the race was deemed a public event.

All jumps from all athletes were digitized using Peak Motus 8.2 (Colorado Springs, CO) using a 20-point spatial model. Since markers could not be placed upon the athletes, joint centers and endpoints of segments were determined by the researchers. Center of mass calculations were completed using body segment parameters

adjusted from Winter (1990). Following the application of the Direct Linear Transformation (Abdel-Aziz and Karara, 1971), three-dimensional coordinates were low-pass filtered at 6 Hz as determined optimal by the Peak Motus 8.2 program. Then the following variables were calculated (Figures 2 and 3):

- Take-off distance-Horizontal distance from the front edge of the barrier to the take-off toe
- Crouching height-The vertical distance from the top of the barrier to the center of mass when the center of mass is directly above the barrier
- Push-off angle-Knee angle of the push-off leg as the athlete leaves the barrier.
- Landing distance-Horizontal distance from the front edge of the barrier to the landing toe at touchdown
- Velocity through jump divided by average race pace (v/p)-Average velocity from 5 m prior to the barrier to 2.5 m past the water pit divided by average race velocity
- Approach velocity-Average velocity from 5 m prior to the barrier to 2.5 m prior to the barrier
- Exit velocity-Average velocity from the far edge of the water pit to 2.5 m past the water pit

Two stepwise multiple linear regressions were completed (one for men and one for women) with v/p as the dependent variable and all the variables listed above other than exit velocity as the independent variables.



Figure 3. Velocity Calculations. Approach velocity was calculated from 5 m prior to the barrier until 2.5 m prior to the barrier (first gray region). Exit velocity was calculated from the end of the water-pit until 2.5 m past the water-pit (second gray region). Velocity through the jump was calculated from 5 m prior to the barrier until 2.5 m past the water-pit.

Table 1. Results of stepwise linear regressions. Approach velocity and landing distance were the only variables left in the model for predicting velocity through the jump divided by race pace. R^2 values were 0.84 and 0.82 for women and men respectively.

	Women			Men		
	β	<i>p</i> -value	SEE	β	<i>p</i> -value	SEE
Intercept	-0.002	0.991	0.156	0.496	0.006	0.134
Approach Velocity (m/s)	0.115	0.007	0.035	0.051	0.001	0.031
Landing Distance (m)	0.118	<0.001	0.027	0.050	0.001	0.029

Velocity divided by race pace was chosen as the dependent variable since runners have to return to race pace following the water jump. If they can keep from slowing too much during the water jump, there will be less acceleration required as they exit the water pit. However, coaches and athletes should realize that increasing this variable indefinitely is not advisable. Since seven jumps were measured for each athlete, the average value for each variable was input into the regression model. A repeated measure ANOVA was performed to determine differences between genders in all the variables listed above. Finally, the repeated measures ANOVA was performed again after normalizing the variables (other than crouching height and push-off angle) for race pace. This allowed us to determine whether any differences between genders could be accounted for by differences in race pace.

Results

Velocity through the jump divided by race pace (v/p) was predicted very well by approach velocity and landing distance for men and women (Table 1). All other variables were removed as they did not make significant contributions to increasing multiple R^2 values.

The relationships of v/p with all parameters showed linear trends throughout the range of measured values. However, only three variables were found significantly different after normalizing by race pace. Variables that appear to be due to gender alone rather than just different race paces include: Push-off angle (greater for women), exit velocity (smaller for women), and loss of velocity (greater for women) (Table 2).

Discussion

Women and men both showed linear trends in the v/p regression model throughout the range of measured values. There was no apparent local maximum in the relationships between v/p and approach velocity or landing distance. Thus, increasing approach velocity or landing distance through the ranges of these athletes should increase v/p further. However, it is important to keep in mind that a higher v/p value is not necessarily advantageous, because economy of movement must be considered in the steeplechase. None of the athletes in this study approached the water-jump barrier at their maximum velocity or attempted to maximize their landing distance. If they had, the current regression model predicts a higher v/p . While this may seem desirable at first, the large fluctuation in effort would likely result in a much greater energy cost (Billat et al., 2001).

While only seven water-jumps occur in a 3000 m steeplechase race, the obstacle must have some effect on running time since it takes athletes away from their normal running stride. The most important factor in steeplechase performance is physical conditioning (Kenney and Hodgson, 1985). With the water-jump making up only about 1% of the total race distance, even a weak correlation between v/p and race pace encourages us to believe that v/p is an appropriate variable to consider in steeplechase performance. This correlation was observed and was very small ($R^2 = 0.02$, $F = 4.04$, $p = 0.046$).

In order to complete a water-jump obstacle close to race pace (v/p close to 1.00), one must obtain relatively high approach velocity. Average approach velocities were 5.32 m/s (5:02 minutes/mi) and 6.16 m/s (4:21

Table 2. Gender differences. “/Pace” represents the variables after dividing by race pace. Data are means (\pm SD).

Variables	Women	Men	<i>p</i> -value
Takeoff Dist (m)*	1.41 (.17)	1.66 (.19)	< .001
Takeoff Dist/Pace	.28 (.03)	.28 (.03)	.397
Crouching Height (m)	.59 (.07)	.58 (.05)	.110
Pushoff Angle (deg)*	124 (26)	111 (26)	< .001
Landing Dist (m)*	2.54 (.43)	2.85 (.34)	< .001
Landing Dist/Pace	.51 (.09)	.49 (.06)	.057
Velocity Through Jump (m/s)*	4.62 (.53)	5.44 (.45)	< .001
Velocity through jump/Pace	.92 (.10)	.93 (.06)	.257
Approach Velocity (m/s)*	5.32 (.49)	6.16 (.43)	< .001
Approach Velocity/Pace	1.06 (.09)	1.05 (.06)	.569
Exit Velocity (m/s)*	4.26 (.59)	5.13 (.61)	< .001
Exit Velocity/Pace*	.85 (.11)	.88 (.09)	.027
Loss of Velocity (m/s)	1.06 (.37)	1.02 (.45)	.504
Loss of Velocity/Pace*	.21 (.07)	.18 (.08)	< .001
Avg Race Speed	4.99 (.16)	5.79 (.26)	< .001

Significantly different variables represented by “*”.

minutes/mi) for women and men respectively. While many may think an increased v/p is desirable, an approach velocity could become too high. Since economy is so important in the steeplechase, it is possible to go too high above race pace. Another important factor to consider is landing distance. The athletes that are more successful at the water-jump land relatively close to the end of the water-pit. These athletes typically get only one foot wet with each jump (the second foot plant is beyond the water-pit). This matches with the average landing distance values found in this study (2.54 m and 2.85 m for women and men respectively, $p < 0.001$). Since the pit is 3.66 m long, those with a lower v/p are landing deeper and typically getting both feet wet before exiting the water pit.

Approach velocity and landing distance were expected to be correlated with v/p. Perhaps the more interesting finding of this study is the lack of significance of other variables. This may explain why many world-class steeplechasers appear awkward in their movements over the water jump. As long as their approach velocity is high and they obtain a relatively long landing distance, the other aspects of their technique do not relate to v/p.

The water-jump produces a greater disruption in running velocity in the women than in the men. Exit velocity was greater for men even after accounting for race pace while approach velocity was not. Demonstrating this idea further, loss of velocity was greater for women after accounting for differences in race pace. The lower exit velocities after accounting for race pace might be explained by the pit being the same length for men and women. Since women do not jump as far as men, they will be landing deeper in the water. They are also jumping from a lower height, which results in a decreased flight time compared with the men who jump from a greater height.

Women extend at the knee more than men as they push off the barrier. Pushing off the barrier through a greater extension may help women obtain a greater landing distance, partly overcoming their slower approach velocity and lower barrier height. Crouching height is no different even though body heights are typically different. Since women are taking off from a lower barrier height in the steeplechase water-jump, they may be crouching less to obtain a greater take-off height and increase flight time to get a longer jump.

One limitation to the current study is the lack of information about body height. Some of the gender differences may be due to body height rather than gender alone. Thus, the reason for some gender differences remains unknown.

While technique differences exist between men and women in the water-jump, the movement is similar. The same focus should be given to men and women in terms of what makes a successful water-jump. Increasing approach velocity leads to greater v/p. However, it should be realized that increasing v/p indefinitely is not desirable due to the required economy of a 3000 m race. Working towards an optimal v/p should be focus of steeplechasers. Coaches and athletes should realize that other small differences in technique occur between elite men and

women, but they have little impact on the overall performance of the water-jump.

Conclusion

Women may need to be coached differently than men in technique for the water jump. With the lower approach velocity for women, women take off closer to the barrier so that they can land on top of it in a good position. The lower approach velocity also appears to lead to a shorter jump and as a consequence, results in an uphill step out of the water pit following landing. Thus, women's race paces are affected more by the water-jump than those of the men, as was found in this study, with loss of velocity divided by race pace being greater for women than men.

Success in completing the water-jump of the 3000m steeplechase without dropping from race pace dramatically can be accomplished by accelerating during the approach to the barrier and accomplishing a relatively long landing distance. There are obviously limits to how much acceleration and how far of a jump off the barrier should be attempted. However, with the athletes analyzed in this study, the larger the approach velocity and the longer the jump into the water, the better the athletes were able to keep their water-jump horizontal velocity close to their race pace. Thus, training for the water jump should include surging along with any technical work.

Acknowledgments

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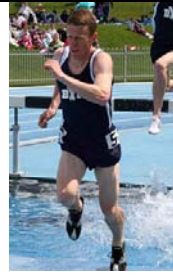
References

- Abdel-Aziz, Y. and Karara, H.M. (1971) Direct linear transformation from comparator coordinates into object space coordinates in close-range photogrammetry. In: *Proceedings of the ASE/UISymposium on Close-range Photogrammetry*. Urbana: University of Illinois Press. 1-18.
- Billat, V., Slawinski, J., Danel, M. and Koralsztein, J. (2001) Effect of free versus constant pace on performance and oxygen kinetics in running. *Medicine and Science in Sports and Exercise* **33**(12), 2082-2088.
- Hunter, I. and Bushnell, T. (2006) Steeplechase barriers affect women less than men. *Journal of Sports Science and Medicine* **5**(2), 318-322.
- Kenney, W. and Hodgson, J. (1985) Variables predictive of performance in elite middle-distance runners. *British Journal of Sports Medicine* **19**(4), 207-209.
- McDonald, C. and Dapena, J. (1991) Linear kinematics of the men's 110-m and women's 100-m hurdles races. *Medicine and Science in Sports and Exercise* **23**(12), 1382-1391.
- Popov, T. (1983) Hurdling in the steeplechase. *Modern Athlete and Coach* **21**(1), 17-18.
- Ward-Smith, A. (1997) A mathematical analysis of the bioenergetics of hurdling. *Journal of Sports Science* **15**(5), 517-526.
- Winter, D.A. (1990) *Biomechanics and motor control of human movement*. 2nd edition. John Wiley & Sons, Toronto.

Key points

- Women may need to be coached differently than men in the steeplechase water jump due to different techniques required.
- Men and women must focus on a high approach velocity to complete the steeplechase water jump successfully.
- Men and women must generate a relatively long landing distance to maintain velocity and keep from having to use extra energy exiting the water pit.
- Women's race paces were affected more than men's by the water jump in a negative way.

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