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Steeplechase Hurdle Economy, Mechanics, and Performance

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ABSTRACT

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Research surrounding the steeplechase is scarce, with most research focusing primarily on how biomechanical factors relate to maintaining running speed while crossing barriers. One area that has not been well explored is the relationship between biomechanical factors and hurdling economy. The purpose of this study was to investigate how performance times and biomechanical variables relate to hurdling economy during the steeplechase. This was accomplished by measuring running economy of collegiate and professional steeplechasers while running with and without hurdles. Biomechanical measures of approach velocity, take-off distance, clearance height, and lead knee extension while hurdling, as well as steeplechase performance times were correlated to a ratio of running economy with and without hurdles. Results indicated no correlation between steeplechase performance time and the ratio of running economy during the hurdle and non-hurdle laps. Results also indicated no correlation between the aforementioned biomechanical variables and ratio of running economy during the hurdle and non-hurdle laps. Increasing approach velocity did not negatively affect running economy. Steeplechasers may continue to increase approach velocity without hurting their economy or performance times.

Keywords: steeplechase, running economy, hurdle economy, biomechanics

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Introduction

In the quest to run faster, jump higher, and throw further, track and field events are continually being researched. One such event, the steeplechase, is filled with questions to be answered. Although it has been contested for over 150 years, it wasn't until 2005 that the women's steeplechase was introduced to the World Championships. In 2008 it was first contested in the Olympic Games. With the introduction of the women's steeplechase to world contests, interest in the race has increased (Hunter and Bushnell 2006; Hunter, Anderson, and Lindsay, 2008).

The steeplechase is 3000 meters (m) long with four barriers and one water pit jump per lap (Figure 1). The water pit jump is a barrier followed by a 3.66 m long water pit, typically about 0.7 m at the deepest point (Figure 2). A steeplechaser encounters a total of 28 barriers and seven water pit jumps during the race. The barrier heights are set at 0.914 m for men and 0.762 m for women (Figure 3). There are no lane assignments, therefore steeplechasers often have to navigate the obstacles (barriers and water pit jump) surrounded by their competitors. With varying distance between barriers there is no set stride pattern as seen in the hurdle races of shorter distances; therefore adjustments to running stride are made before each approach to the barrier. Just like running technique influences running economy (Williams and Cavanagh, 1987), hurdle and water jump technique should influence the economy of steeplechase running. As coaches and athletes begin to understand the techniques needed to improve hurdling economy during the steeplechase, the athletes will have more energy to improve their running speed between obstacles and run faster race times.

To improve race performance, steeplechase runners must examine their distance running economy as well as their hurdling economy. Economy of distance running has been extensively researched (Williams and Cavanagh, 1987; Conley and Krahenbuhl, 1980; Daniels and Daniels, 1992), and many biomechanical factors related to steeplechase hurdling have been examined (Hunter and Bushnell 2006; Griak, 1982; Gartland and Henson, 1984; Popov, 1983); however, economy of hurdling in distance running has not been studied.

Better economy leads to better distance running performance. In highly trained runners with similar ability and VO_2max, running economy accounted for a significant amount of variation in 10,000m race performances (Conley and Krahenbuhl, 1980). Running economy is measured by oxygen uptake at a given submaximal speed (Cavanagh and Williams, 1982). Trained runners are more economical at their specific race pace than at the other paces (Daniels and Daniels, 1992). Much time in the steeplechase is spent between barriers therefore good distance running economy will benefit the athlete.

In addition to high distance running economy, successful steeplechasers need a good understanding of hurdle and water jump technique. There are two ways to clear the non-water pit barriers in a steeplechase race. The first is the hurdle technique in which the athlete keeps the lead leg knee slightly flexed and pulls the trail leg through after the lead leg clears the barrier. The second is the step-on technique where the athlete puts one foot on top of the barrier as they go over it, thus taking off and landing on the same foot. From a biomechanical viewpoint the hurdle technique is more economical (Popov, 1983; Hunter and Bushnell, 2006).

Faster overall speeds come from having a steady pace in distance running (Billat, Slawinski, Daniel, and Koralsztein, 2001); therefore, one of the most important considerations in successful steeplechase hurdling is maintenance of horizontal velocity. Biomechanical measures that have previously been used to describe steeplechase hurdling include horizontal velocity into, over, and exiting the hurdle and water jump; take off distance; landing distance; crouch height;

clearance height; push-off angle; hip, trunk and knee angles during flight; and takeoff and landing step lengths. An understanding of how these biomechanical characteristics relate to maintaining running speed while crossing the barriers already exists for men and women (Hunter, Anderson, and Lindsay, 2008). However, the relationship between these characteristics and the economy of steeplechase hurdling is unknown.

We have chosen to measure approach velocity, clearance height, takeoff distance, and lead knee extension as they all contribute to the maintenance of horizontal velocity (Hunter, Anderson, and Lindsay, 2008). Measuring these biomechanical factors while also measuring running economy (oxygen uptake at a given submaximal speed) will allow a comparison of steeplechasers technique as it relates to running economy. This information will better help us understand how biomechanical variables that have been associated with increased steeplechase performance are related to hurdling economy during the steeplechase.

The purpose of this study is to answer the following research questions in an attempt to learn more about how energy expenditure and kinematics are related to steeplechase performance.

1. Is steeplechase performance time related to the ratio of running economy with and without steeplechase barriers?
2. Are any biomechanical factors (approach velocity, clearance height, takeoff distance, and lead knee extension) related to the ratio of running economy with and without steeplechase barriers?

Related to these purposes, we hypothesized that runners with faster 3000 m steeplechase times will have a smaller ratio of hurdle lap running economy to non-hurdle lap running economy. We also expect that runners with a higher approach velocity, lower clearance height, greater takeoff distance, and greater lead knee extension will have a smaller ratio of hurdle lap running economy to non-hurdle lap running economy.

Methods

Participants

Ten female steeplechasers participated in this study (Table 1). Each participant was either a Division 1 NCAA or professional steeplechase athlete. Participants were contacted in person or by phone and asked to participate in the study. All procedures were approved by the appropriate institutional review board. Written informed consent was obtained from subjects prior to participation in the study.

Design

The oxygen cost of running with and without steeplechase barriers at a fixed pace was examined in a counter balanced cross over design.

Procedures

The participants' height, weight, age, and personal best and season best steeplechase time was recorded prior to beginning testing. All running took place at the Brigham Young University outdoor track. While wearing a portable metabolic system (Cosmed K4 telemetry system), participants completed their typical warm up followed by one 800 m interval (two laps around the outdoor track). Participants then ran four, 800 m intervals (from a standing start) with three minutes rest between intervals. Two of the intervals were over steeplechase barriers and two were without barriers. Intervals alternated between running with and without the barriers. Steeplechase barriers were set at 0.762 m (30 in). There were five barriers per 400 m lap spaced evenly around the track (providing a total of 10 barriers) in each hurdling interval. Participants ran all intervals at their individual season best steeplechase race pace. Order of intervals was counter balanced as each subject served as their own control. Five subjects started with a non-hurdle interval and five started with a hurdle interval. Oxygen uptake was measured using the Cosmed K4 telemetry system. It has been shown to be an accurate and reliable method of measuring oxygen uptake (Hausswirth, Bigard, and LeChevalier; 1997). Running economy was determined by the participants' oxygen uptake divided by their running speed in meters per second expressed as ml min^{-1} kg^{-1}. Running economy during the steeplechase intervals was compared to running economy of the flat track intervals. Running speed was confirmed with a stopwatch. Any interval that was more than 1.5% different in time from the average interval time was eliminated from the analysis.

Two of the barriers were on the straight sections of the track. A video camera running at 120 Hz (Casio Exilim FH-25) was placed to film the athlete's hurdling the barriers from a sagittal view at each of these barriers. A two-dimensional analysis was completed using Vicon Motus 9.2 (Vicon Corp, Colorado Springs, CO). Measures of approach velocity (average velocity of the front of the torso, from 5 m before barrier to 2.5 m before barrier), clearance height (the vertical distance between the joint center of the lead leg hip and the top of the hurdle at the high point of the jump), takeoff distance (the horizontal distance from the takeoff toe and the front edge of the barrier), and lead knee extension (the greatest angle of extension of the lead knee until the lead foot is past the barrier) were calculated using Vicon Motus 9.2.

Data Analysis

To answer the first research question, a linear regression was used to determine the correlation between the ratio of hurdle lap running economy to non-hurdle lap running economy to an athlete's current 3000 m steeplechase time. Running economy was found by dividing the participants' oxygen uptake by their running speed for both the hurdle and non-hurdle intervals. We expected that athletes with a faster 3000 m steeplechase time would have a smaller ratio.

To answer the second research question, a stepwise multiple linear regression was used to determine the correlation between the ratio of hurdle lap running economy to non-hurdle lap running economy to approach velocity, clearance height, takeoff distance, and lead knee extension. We expected that athletes with a smaller economy ratio would have a greater approach velocity, lower clearance height, greater takeoff distance, and greater lead knee extension.

Results

There was no correlation between steeplechase performance time and the ratio of hurdle lap running economy to non-hurdle lap running economy ($F=0.742$, $p=0.414$). Figure 4 contains a scatterplot of these findings. Oxygen uptake accounting for body mass in the intervals with hurdles (51.9 ± 4.0 ml min^{-1} kg^{-1}) and the intervals without hurdles (50.6 ± 4.9 ml min^{-1} kg^{-1}) was significantly different ($t=-2.761$, $p=0.011$). Average running speed for the hurdle intervals was 4.43 m s^{-1} and for the non-hurdle intervals was 4.41 m s^{-1}. Running economy in the intervals with hurdles (0.1319 ± 0.0241 ml m^{-1} kg^{-1}) was significantly different from running economy in the intervals without hurdles (0.1362 ± 0.0252 ml m^{-1} kg^{-1}; $t=2.941$, $p=0.016$; Table 2).

No correlation was found in the stepwise linear regression model that related the measured hurdle biomechanics to the ratio of hurdle lap running economy to non-hurdle lap running economy (Table 3, Figures 4-8). Average approach velocity (4.26 ± 0.54 m s^{-1}), take-off distance (1.22 ± 0.32 m), clearance height (0.36 ± 0.07 m), lead knee extension (139 ± 22 degrees) along with individual measurements are found in Table 4.

Discussion

The purpose of this study was to determine how steeplechase performance time relates to a ratio of running economy during running with and without steeplechase barriers as well as which biomechanical factors (approach velocity, clearance height, takeoff distance, and lead knee extension) are most closely related to running economy during running with steeplechase barriers. The ratio of hurdle lap running economy to non-hurdle lap running economy was not related to the subjects' steeplechase time. Faster steeplechasers did not have a smaller ratio than slower steeplechasers. There are many factors that contribute to race times: temperature, wind, precipitation, elevation, experience, pacing abilities, and various physiological characteristics. More economical runners may not have run a race in ideal conditions; therefore they may have a slower season best time. In addition, some of the subjects may be better at hurdling but not as good at the water jump, while some may be better at the water jump than hurdling. We do not know how this affects race times but the water jump may have a greater effect on race time than hurdling does so a more efficient hurdler would not necessarily have a better personal best time. We suspect that the added variability due to these factors may have masked any correlations that do exist. Even though the running economy ratio was not connected to performance time, there may be other factors such as strength, power, or ability to change pace during a race that could be related to performance time.

A 3000 m steeplechase race on average takes 30 seconds longer than a flat 3000 m race (Popov, 1983). This is about a 5% difference in time. However, we found only a 2.7% difference in energy cost. One reason for the small difference could be that we only measured 800m of hurdling at a time, whereas the steeplechase is 3000 m long race. 3000 m of continuous hurdling could lead to greater fatigue and therefore an increase in energy cost and race times. Another reason for the small difference could again be attributed to the fact that we only measured runners while hurdling and not during the water pit jump. We did this to isolate the effect that hurdle technique had on running economy, but the water jump may be a larger contributor to the increased energy cost and slower times that come with a steeplechase race.

There was no correlation between hurdle economy and technique for any of the variables measured (approach velocity, take off distance, clearance height, lead knee extension). The measurements of clearance height, take off distance, lead knee extension were similar to those found in other studies (Hunter and Bushnell, 2008). Approach velocity was slower than the Olympic caliber athletes measured in other studies (Hunter and Bushnell, 2008). A limited number of subjects may have prevented us from finding a connection. With a high variability in hurdle technique, a greater number of subjects could potentially demonstrate which aspects of technique most affect hurdle economy. Not only is there inter-individual variability, but also intra-individual variability (Table 4). Technique can vary depending on which lead leg is used and how well the subject judges their approach to the hurdle and the take-off. More jumps with each leg as a lead leg could help to identify which aspects of technique most affect economy. As a race progresses, there may also be changes in technique that could affect hurdle economy as the runner fatigues. In addition, there is likely a non-linear correlation between hurdle economy and the measured biomechanical factors. We did not have a large enough range of data to determine such a connection. Future research should be conducted to elucidate these ideas.

Previous studies have found that increasing approach velocity helps to maintain horizontal velocity through the hurdle (Hunter and Bushnell, 2006; Hunter, Anderson, and Lindsay, 2008). We found that increasing approach velocity did not affect hurdle economy. Therefore steeplechasers can accelerate into the hurdles to maintain horizontal velocity without causing a significant increase in energy expenditure. A steady pace in distance running leads to faster overall speeds (Billat, Slawinski, Daniel, and Koralsztein, 2001) and maintaining horizontal velocity through the hurdle allows for a steadier pace.

We had a wide range of abilities in our subjects. Steeplechase times ranged from 625 seconds to 720 seconds. Having such a large range of athletes increased our ability to find a correlation between hurdle mechanics and running economy. However, we were unable to find a correlation.

While the specific techniques of steeplechase hurdling were not connected to performance times, there are other training methods steeplechasers could consider to improve their performance. Plyometric training has been shown to improve running economy in distance runners likely through mechanisms residing in the muscles (Saunders, Teleford, Pyne, Peltola, Cunningham, Gore, and Hawley, 2006; Spurrs, Murphy, and Watsford, 2003). The addition of a plyometric training plan to a steeplechasers training may aid in preventing muscular fatigue which would allow the runner to have better running economy throughout the race. This may even help prevent potential changes in hurdle technique as a result of fatigue, allowing the runner to be more efficient over hurdles in the later stages of the race. Future research could examine the relationship between plyometric training and improving hurdle economy and steeplechase performance times.

Conclusion

In conclusion, steeplechase performance time was not related to the ratio of running economy with hurdles compared to running economy without hurdles. Running with hurdles does have a greater metabolic cost than running without hurdles. Hurdle technique was not correlated with economy; however future studies with greater subject numbers may be able to determine a connection. Accelerating into the hurdle did not cause a significant increase in running economy. Accelerating into the hurdle allows the athlete to maintain horizontal velocity through the hurdle and athletes may continue to do so without hurting their economy.

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Table 1. Subject characteristics

Subject #	Age (yrs)	Height (m)	Mass (kg)	Steeplechase season best time (s)
1	20	1.65	56.8	656
2	20	1.70	60.5	648
3	22	1.70	56.8	625
4	23	1.68	60.0	705
5	19	1.72	63.6	671
6	29	1.78	61.4	695
7	22	1.57	51.8	678
8	32	1.75	61.4	720
9	33	1.68	50.0	663
10	25	1.72	62.7	701
Average	25 ± 5	1.70 ± 0.05	58.6 ± 4.5	677 ± 29

Table 2. Speed, oxygen uptake, running economy

	Without barriers			With barriers			
Subject number	Speed (m s^{-1})	VO2 (ml min^{-1} kg^{-1})	Running Economy (ml m^{-1} kg^{-1})	Speed (m s^{-1})	VO2 (ml min^{-1} kg^{-1})	Running Economy (ml m^{-1} kg^{-1})	Running economy ratio
1	4.46	48.8	0.1140	4.57	51.2	0.1167	1.0239
2	4.66	57.3	0.1280	4.61	57.4	0.1298	1.0137
3	4.73	55.4	0.1219	4.73	55.0	0.1212	0.9942
4	4.28	55.0	0.1340	4.22	55.4	0.1367	1.0201
5	4.46	53.4	0.1248	4.46	54.0	0.1259	1.0090
6	4.27	49.4	0.1206	4.18	54.8	0.1340	1.1108
7	4.44	41.5	0.1558	4.41	43.8	0.1655	1.0626
8	4.17	50.9	0.1271	4.15	51.4	0.1265	0.9953
9	4.53	45.3	0.1041	4.53	48.5	0.1115	1.0707
10	4.30	48.7	0.1888	4.26	49.7	0.1944	1.0301
Average	4.43 ± 0.18	50.6 ± 4.9	0.1319 ± 0.0241	4.41 ± 0.20	51.91 ± 4.0	0.1362 ± 0.0252	1.0330 ± 0.0372

Table 3. Stepwise linear regression correlation coefficients

	Unstandardized Coefficients	P Value
Approach Velocity	4.19	0.82
Take-off Distance	-18.61	0.64
Clearance Height	-13.92	0.88
Lead Knee Extension	-0.03	0.93

Table 4. Biomechanical measures

Subject	Approach velocity (m s^{-1})	Take-off distance (m)	Clearance height (m)	Lead knee extension (degrees)
1	4.36 ± 0.21	1.26 ± 0.08	0.33 ± 0.06	127 ± 22
2	4.34 ± 0.24	1.18 ± 0.17	0.45 ± 0.04	121 ± 19
3	5.62 ± 0.20	1.83 ± 0.16	0.34 ± 0.04	142 ± 9
4	3.87 ± 0.16	0.85 ± 0.08	0.42 ± 0.02	119 ± 10
5	4.11 ± 0.63	1.53 ± 0.21	0.21 ± 0.06	172 ± 21
6	3.79 ± 0.20	1.01 ± 0.10	0.37 ± 0.02	129 ± 7
7	4.34 ± 0.19	1.36 ± 0.17	0.29 ± 0.04	164 ± 8
8	3.74 ± 0.26	0.74 ± 0.11	0.43 ± 0.04	104 ± 10
9	4.36 ± 0.18	1.09 ± 0.07	0.37 ± 0.04	155 ± 7
10	4.10 ± 0.35	1.31 ± 0.04	0.41 ± 0.05	158 ± 6
Average	4.26 ± 0.54	1.22 ± 0.32	0.36 ± 0.07	139 ± 22

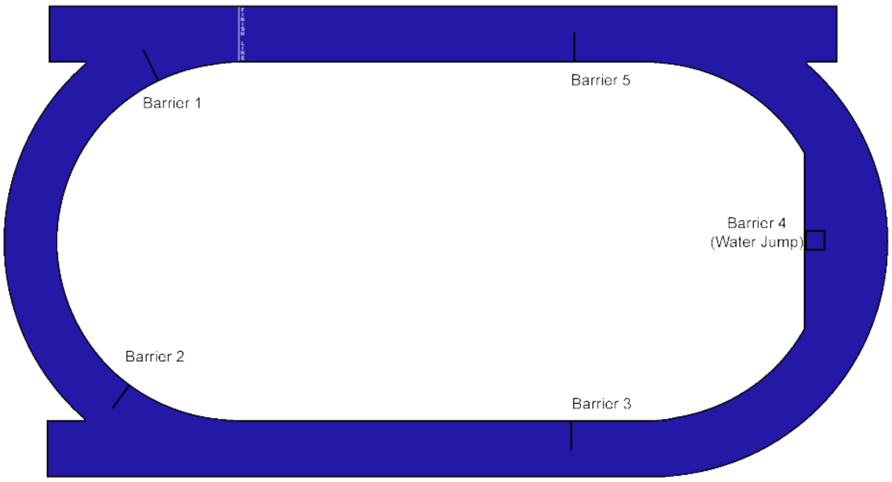

Figure 1. Overhead view of steeplechase obstacle placement on a track

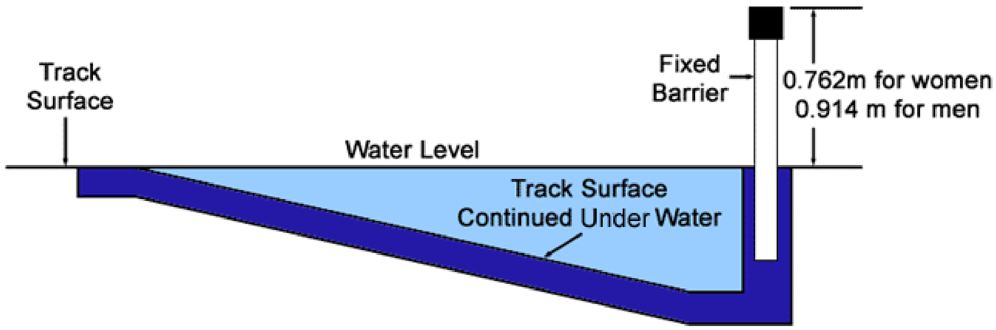

Figure 2. Steeplechase water pit

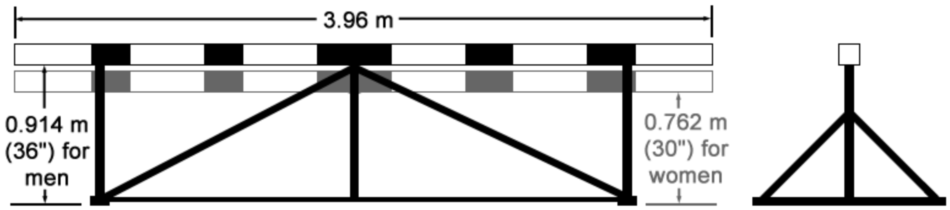

Figure 3. Steeplechase barrier

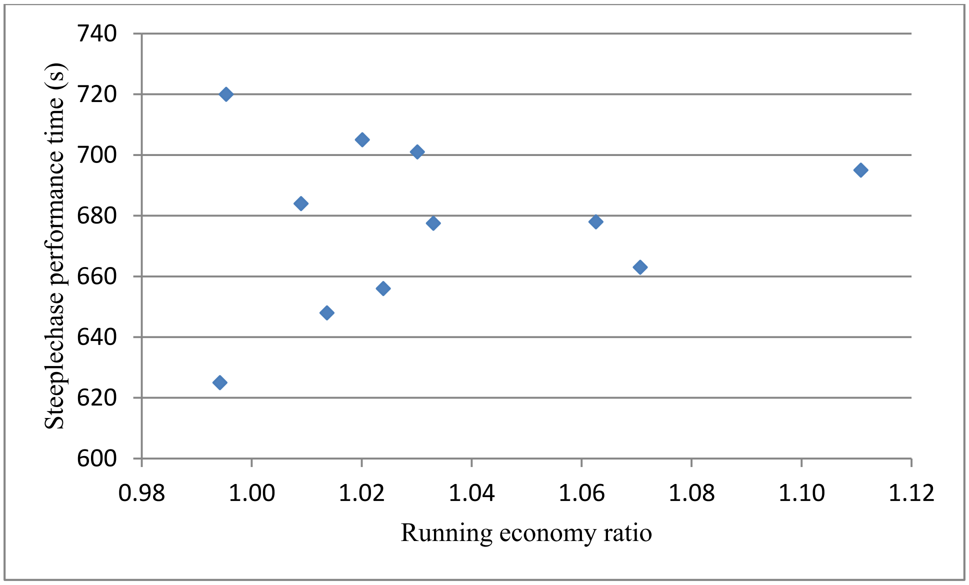

Figure 4. Steeplechase performance time versus running economy ratio (p=0.414).

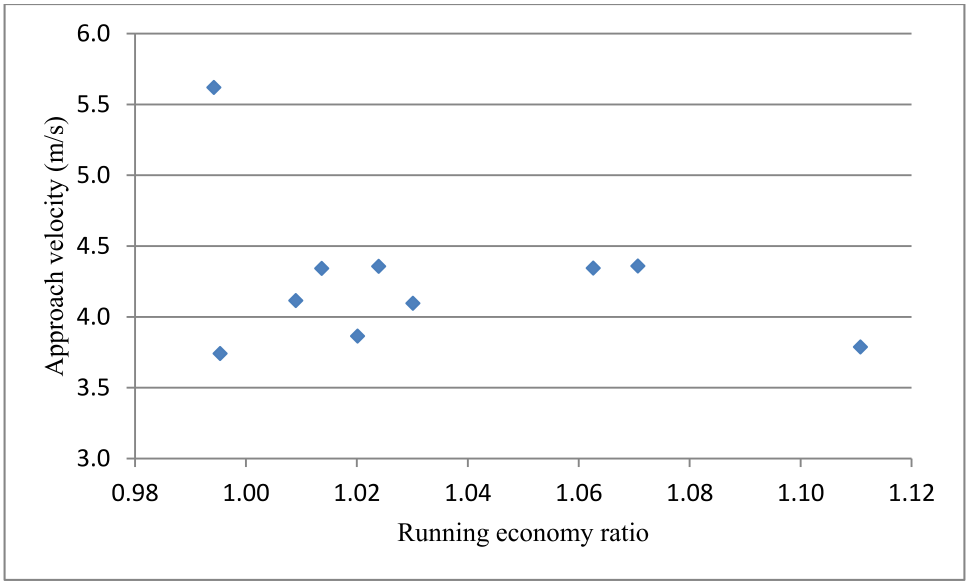

Figure 5. Approach velocity versus running economy ratio ($p=0.82$). Approach velocity measured as average velocity of the front of the torso, from 5m before barrier to 2.5m before barrier.

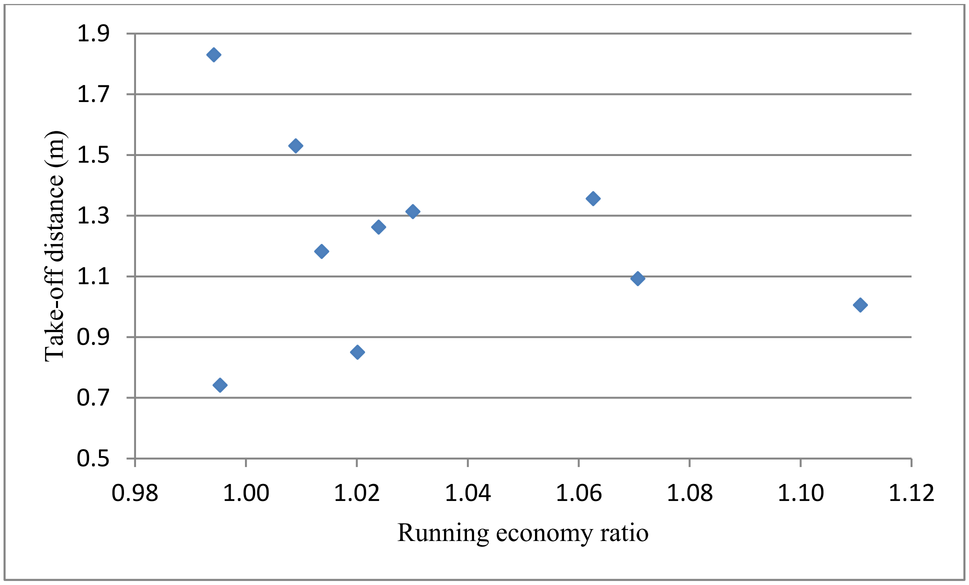

Figure 6. Take-off distance versus running economy ratio (p=0.64). Take-off distance measured as the horizontal distance from the takeoff toe and the front edge of the barrier.

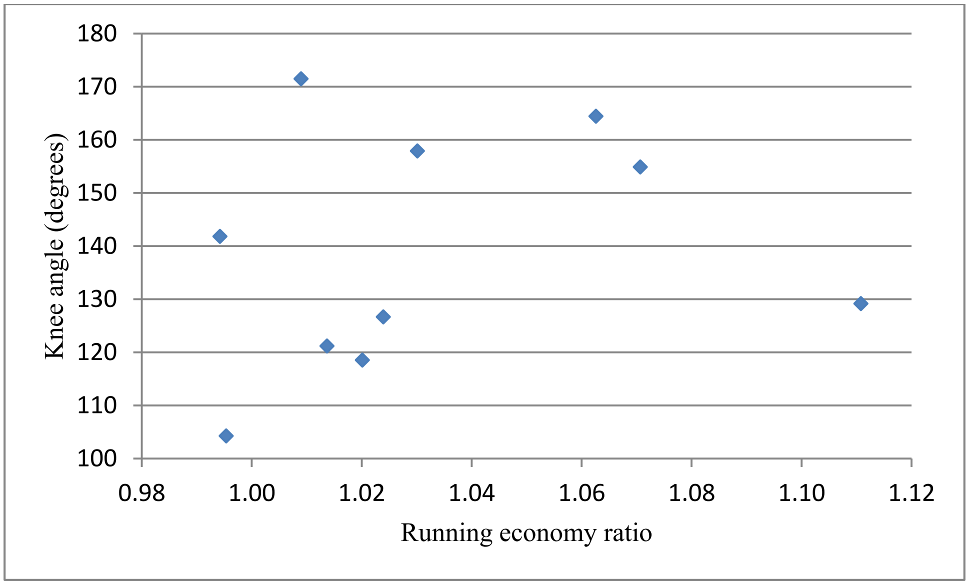

Figure 7. Knee angle versus running economy ratio (p=0.93). Knee angle measured as the greatest angle of extension of the lead knee until the lead foot is past the barrier.

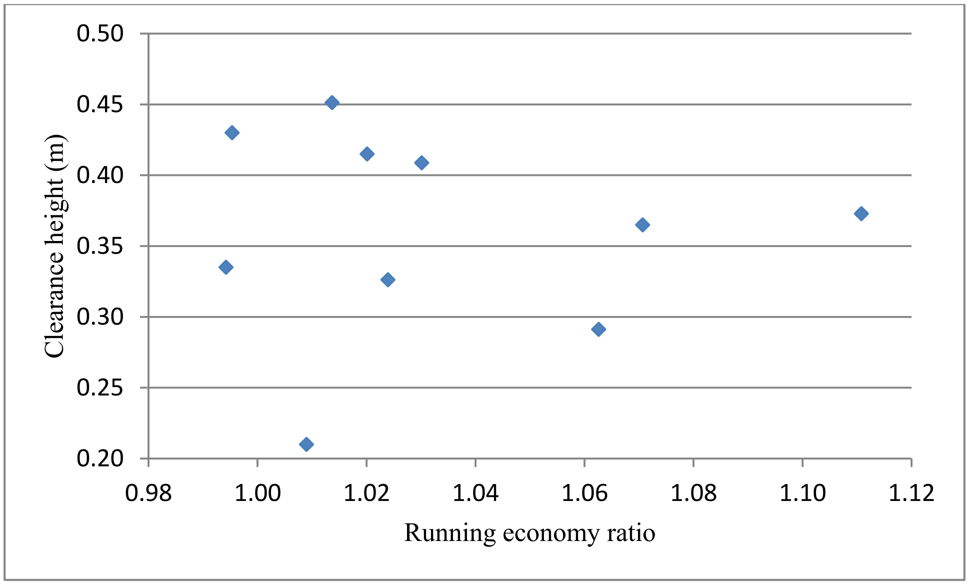

Figure 8. Clearance height versus running economy ratio (p=0.88). Clearance height measured as the vertical distance between the joint center of the lead leg hip and the top of the hurdle at the high point of the jump.