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Better water jump clearances were differentiated by longer landing distances in the 2017 IAAF World Championship 3000 m steeplechase finals

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ABSTRACT

The aim of this novel study was to analyse key kinematic variables during the water jump clearance amongst world-class 3,000 m steeplechasers. Thirteen men and 13 women were recorded as they negotiated the last water jump in the 2017 IAAF World Championship finals. Video footage (100 Hz) was recorded using three high-definition camcorders to derive spatiotemporal data; spatial data were normalised to athletes' statures. The time to cover the distance from 4.5 m before the water jump barrier to 4.5 m after ("9 m time") was used to describe overall clearance success. Although men had longer approach and exit step lengths, there were no differences when the data were normalised; by contrast, men's landing distances were greater in both absolute and relative terms. Women's shorter landing distances meant negotiating deeper water when exiting, with those athletes with longer landing distances running faster 9 m times (r = –0.87). Obtaining a high position on the barrier (clearance height) was correlated with longer landing distances (men: r = 0.75, women: r = 0.71) and could indicate better technique. Coaches should note that although technical proficiency in all aspects of the clearance is imperative, optimising the athlete's landing distance is paramount.

Keywords: elite-standard athletes, endurance, performance, track and field, videography

INTRODUCTION

The 3,000 m steeplechase is one of the distance races held within the athletics programme at all global championships, including the Olympic Games and International Association of Athletics Federations (IAAF) World Championships. It differs from all other distance races as competitors must negotiate 35 barriers, which include seven water jumps. The barriers are 0.914 m high in men’s competitions and 0.762 m high in women’s competitions, the same heights used in 400 m hurdling (IAAF, 2017). The sturdiness of the barriers means that athletes who collide with them are likely to lose considerable speed and could fall, and thus an effective technique to cross the barriers is crucial. The top of the barriers is 0.127 m wide (IAAF, 2017), enabling two techniques to cross them: a hurdling technique, similar to 400 m hurdling but with a clearance that is approximately between 5 and 10 cm higher (Chortiatinos, Panoutsakopoulos, & Kollias, 2010); and a step-on technique, where the athlete places one foot on the barrier and pushes off with it. The hurdle technique is more effective in maintaining velocity across the 28 regular barriers (Earl, Hunter, Mack, & Seeley, 2015) because of how the whole body centre of mass (CM) rises less (Dyson, 1986). However, the step-on technique is the most common method of navigating the water jump as, in theory, it allows for a greater clearance distance. The water pit is 3.66 m long and 3.66 m wide, and slopes at 12° upwards from a depth of 0.70 m until it is flush with the track surface (Kipp, Taboga, & Kram, 2017). However, how world-class athletes negotiate the water jump during major competitions has not been studied with regard to kinematic and spatiotemporal variables (e.g., step length, clearance time), and thus information from elite-standard competition will improve coaches’ understanding of optimum clearance mechanics among elite-standard steeplechasers.

Apart from the scarcity of research, there is also little coaching advice published that deals directly with how best to navigate the steeplechase water jump, with more attention paid to the technique used to cross the regular barriers (e.g., Ebbets, 1987; Martin & Coe, 1997; Popov, 1983). By contrast, Benson (1993) and Schmolinsky (2000) did provide some coaching recommendations with regard to the water jump: a take-off distance before the barrier of approximately 1.5 m (with consideration to be taken of the athlete's height and approach speed) that should not be much longer than the previous step; a low position of the CM above the barrier; and a landing position about 0.30 m from the end of the water pit (i.e., approximately 3.36 m from the barrier). However, this coaching advice for male steeplechasers predates the inclusion of the women's event at the IAAF World Championships in 2005, and overall there is a paucity of empirically based recommendations for coaches of athletes of either sex. Regarding biomechanical research on the water jump, previous studies by Hunter, Lindsay, & Andersen (2008) and Ogueta-Alday, Muñoz Molleda, & García-López (2014) found that men took off farther before the barrier than women, and also landed farther from it. Hunter et al. (2008) found that men and women experienced similar changes in running speed between the approach step before the barrier and the exit step out of the water. However, women slowed more than men as a proportion of approach velocity, and this was attributed by both Hunter et al. (2008) and Ogueta-Alday et al. (2014) to the fact that because the water jump distance is the same (3.66 m) for both sexes, women land farther down the slope and in deeper water, requiring them to "climb" out of the pit more. The studies by Hunter et al. (2008) and Ogueta-Alday et al. (2014) were of the US National Championships / Cardinal Invitational races and the XVII Meeting of the City of Mataró, respectively, with no previous research conducted of the world's best athletes in direct competition; furthermore, although these races did include some elite-standard athletes, the competitive structure of the World Championships (with heats two days before the final) means that championship-specific factors like fatigue can affect performance. New research on both men and women in elite-standard championship racing is therefore vital to provide coaches with research-based evidence from the world's best steeplechasers for their practices.

As an endurance event, success in the steeplechase depends largely on physiological determinants such as maximal oxygen uptake, running economy and lactate threshold (Midgley, McNaughton, & Jones, 2007). However, Earl et al. (2015) found that running economy was not associated with hurdling technique over the regular barriers (variables measured were approach velocity, clearance height, take-off distance and lead knee extension), and successful steeplechasing relies greatly on better running speed between the barriers, rather than purely because of better hurdling ability. Nonetheless, technically poor water jump clearances (i.e., those that lead to considerable loss of velocity) can have a strongly negative effect on the race result (Schmolinsky, 2000), with time losses of approximately 1 s per jump during high-quality men's competition (compared with having no water jump) (Popov, 1983). Kipp et al. (2017) found in laboratory tests that athletes decelerated during the take-off phase before the barriers as they altered their body position to push upwards and onto the barrier (i.e., they reduced horizontal velocity and increased vertical velocity), and that the athletes subsequently accelerated upon landing. Given that Kipp et al. (2017) were unable to measure real water landings in their laboratory, as although the pit used was of the correct dimensions, it was not filled with water, an analysis of athletes in a World Championship final gives not only great ecological validity to the findings, but also allows for an evaluation and sex-based comparison of the key determinants in successfully negotiating the water jump. Therefore, in this study that was the first of its kind at an international competition, the aim was to analyse key spatiotemporal variables in determining success during the last water jump clearance in IAAF World Championship men's and women's 3,000 m steeplechase finals, with the purpose of providing scientific information to coaches to aid athlete performances during elite-standard steeplechasing.

METHODS

Participants

Data were collected as part of the London 2017 World Championships Biomechanics Project (Hanley, Bissas, & Merlino, 2018a; Hanley, Bissas, & Merlino, 2018b), and the use of those data for this study was approved by the IAAF, who control the data, and locally through the institution's research ethics procedures. Participants' dates of birth were obtained from the IAAF (2019), whereas their statures were obtained from Matthews (2017). Two men's statures were not available from this source and were calculated from the video footage using the analysis software. Thirteen men (age 25 ± 6 years; height 1.78 ± 0.07 m) and 13 women (age 24 ± 3 years; height 1.65 ± 0.05 m) were analysed as they crossed the water jump barrier on the last lap in their respective races (the last water jump clearance was the only one feasible given how close together the athletes were on other laps). The winner of the men's race could not be analysed as he was obscured by other competitors, and one other man and one woman were not analysed as both were disqualified under IAAF Rule 163.3(b) for infringement of the inside border (IAAF, 2019). Finishing times were obtained from the open-access IAAF website (IAAF, 2019) for competitors in both races.

Data collection

Three stationary Sony RX10 M3 full high definition digital cameras (Sony, Tokyo, Japan) were placed in three locations at the end of the stadium where the water jump was situated. One camera was positioned on the broadcasting balcony along the home straight (near the 100 m start line), one was positioned in the stand to the rear of the water jump (near the 200 m start line) and the third was positioned in the stand to the right of the athletes as they crossed the water jump barrier. The sampling rate for each camera was 100 Hz, the shutter speed was 1/1250 s, and the ISO was 1600. The resolution of each camera was 1920 x 1080 px. A rigid cuboid calibration frame (length: 4.56 m, width: 4.56 m, height: 3.04 m) was positioned twice on the running track (before and after the water jump barrier) to ensure an accurate definition of a volume within which the athletes ran and jumped. The base of the calibration frame was large enough to span the water pit entirely. Markings on the frame produced 36 non-coplanar control points per individual calibrated volume (72 points in total) and facilitated the construction of a global coordinate system.

Data analysis

The video files were imported into SIMI Motion (SIMI Motion version 9.2.2, Simi Reality Motion Systems GmbH, Germany) and manually digitised by a single experienced operator to obtain spatiotemporal data. An event synchronisation technique (synchronisation of four critical instants) was applied to synchronise the two-dimensional coordinates from each camera involved in the recording. Digitising started 15 frames before the beginning of the approach step and completed 15 frames after the exit step to provide padding during filtering (Smith, 1989). Each file was first digitised frame by frame and, upon completion, adjustments were made as necessary using the points over frame method (Bahamonde & Stevens, 2006), where each point was tracked through the entire sequence. The magnification tool in SIMI Motion was set at 400% to aid identification of body landmarks. The Direct Linear Transformation (DLT) algorithm (Abdel-Aziz & Karara, 1971) was used to reconstruct the three-dimensional coordinates from each camera's x- and y-image coordinates. Seventeen segment endpoints were digitised for each participant and de Leva's (1996) body segment parameter models used to obtain data for the CM and for various body segments of interest. Occasionally, dropout occurred where joint positions were not visible, and estimations were made by the operator. A recursive second-order, low-pass Butterworth digital filter (zero phase-lag) was employed to filter the calculations of displacement and the first derivatives. The cut-off frequencies were calculated using residual analysis (Winter, 2009) and ranged between 8.9 and 11.9 Hz.

The time to cover the distance from 4.5 m before the water jump barrier to 4.5 m after was calculated and described as the “9 m time”. Approach velocity was calculated as the mean horizontal velocity of the CM during the last step before take-off, with approach step length being defined as the distance covered from toe-off of one foot to toe-off of the contralateral foot (i.e., the take-off foot) (Figure 1). Take-off velocity was calculated as the resultant velocity of the CM at take-off; take-off angle was calculated using the horizontal and vertical components of take-off velocity. Take-off distance was the distance from the foot tip of the take-off foot to the water jump barrier (halfway between its edges, i.e., 63 mm from the near edge). Similarly, landing distance was the distance from the foot tip of the landing foot (first contact with the water) to the centre of the water jump barrier. Clearance time was the total time from take-off before the barrier until the first contact made with the water, with clearance height defined as the height of the CM above the barrier when it was directly above its centre. Exit velocity was calculated as the mean horizontal speed of the CM during the first step exiting the water after landing, with exit step length being calculated as the distance covered from the position of the landing foot into the water to first contact with the ground by the contralateral foot when leaving the water jump. The change in velocity between the approach step and the exit step has also been presented. The spatial variables (i.e., step lengths, take-off and landing distances) have also been expressed as a percentage of the participants’ statures and referred to as ratios. The amount of variation within a variable (per group of men or women) was measured using coefficient of variation (CV) and calculated as a percentage using the mean and standard deviation (SD) values for each variable.

Statistical analysis

Results are reported as mean ± one SD. Pearson's product moment correlation coefficient (r) was used to find associations separately within each sample of men and women, and considered to be small ($r = 0.10 – 0.29$), moderate ($r = 0.30 – 0.49$), large ($r = 0.50 – 0.69$) or very large ($r \geq 0.70$) (Hopkins, Marshall, Batterham, & Hanin, 2009). To help reduce the chances of a type I error, only those correlations greater than or equal to 0.70 (i.e., very large) were considered to be significant. Spatiotemporal, kinematic and anthropometric variables for men and women were compared using independent t-tests. An alpha level of 5% was set for all tests. Where differences were found within the sex-based comparisons, effect sizes were calculated using Cohen's d (Cohen, 1988) and considered to be either trivial ($d \leq 0.20$), small (0.21 – 0.60), moderate (0.61 – 1.20), large (1.21 – 2.00), or very large (2.01 – 4.00) (Hopkins et al., 2009).

RESULTS

The mean finishing time (min:s) for those athletes analysed in this study in the men's race was 8:25.47 (± 9.48), whereas it was 9:17.44 (± 9.68) for finishers in the women's race. Men had faster velocities at take-off and during the approach and exit steps, but there was no difference in how much each group slowed between the approach and exit steps (Table 1). Men's approach and exit step lengths were longer than women when measured in absolute terms, but not when expressed as a ratio of stature. Men's landing distances into the water were also longer, regardless of whether they were expressed in absolute or ratio terms.

The men were taller than the women (*P* < 0.001, *d* = 2.09), and the barrier height for men (0.914 m) was greater as a proportion of men's statures (51.3 ± 2.1%) than the barrier height for women (0.762 m) was for them (46.1 ± 1.4%) (*P* < 0.001, *d* = 2.93). The CV for men's stature was 4.1%, whereas it was 3.0% for women. Thirteen of the 14 men and 13 of the 14 women analysed stepped onto the water jump barrier; by contrast, the athlete finishing 14th (last place) in the men's race, and the athlete finishing 10th in the women's race, did not step onto the barrier but hurdled it instead. Landing distance into the water was positively correlated with clearance time and clearance height in men and women, and with approach and exit velocities in women only (Tables 2 and 3). The 9 m time was negatively correlated with approach and exit velocities (men and women) and landing distance (women only). One other notable correlation that occurred in the women's event was that landing distance was correlated positively with take-off velocity (*r* = 0.70, *P* = 0.007).

DISCUSSION

The aim of this study was to analyse key spatiotemporal variables in determining success during the last water jump clearance in IAAF World Championships men's and women's 3,000 m steeplechase finals. In terms of establishing how well the athletes negotiated the water jump, the key variable was the 9 m time, as it took into account how well the athletes approached the barrier, cleared it, and exited from the water. In both races, athletes with faster approach velocities had faster take-off velocities, and both sexes lost approximately the same proportion (–18%) of velocity between the approach and exit phases. In theory, it is the landing phase into the water that predominantly slows the athletes down; indeed, it was shown in this study that those women with longer landing distances had shorter 9 m times, demonstrating how important it is to land relatively far from the barrier and into shallower water in elite-standard women's steeplechasing. The mean landing distance found for men

(2.71 ± 0.35 m) was much shorter than the 3.36 m distance recommended by Schmolinsky (2000) and could be used as a rough guide for male steeplechasers.

Given that the men were faster and taller than the women, and are required to clear a higher barrier, it was not surprising that their approach, take-off and exit velocities were greater, nor that their approach and exit step lengths and take-off and landing distances were longer. However, there were far fewer differences between the sexes when stature was considered. Interestingly, the only sex-based difference between the spatial variables when calculated as a proportion of stature was for landing distance ratio (i.e., the landing distance expressed as a proportion of athlete stature), and this highlighted a key performance difference between men and women's clearance techniques. As the water jump pit is 3.66 m long, the women landed with 1.60 m left to clear on average, compared with only 0.95 m for men, and the larger CV for women (23.9%) also showed that many women landed in considerably deeper water. Additionally, the men cleared the water during their exit step (ending with a mean distance of 3.86 m from the barrier), whereas the women typically took their exit step with both feet having been submerged in the water (mean distance of 3.10 m from the barrier). Men's longer landing distances might partly have been achieved by pushing off from a greater height (the additional 0.15 m height of the barrier), as clearance height was correlated with landing distance in both sexes, and greater barrier height was also probably a reason for men's slightly higher take-off angles when approaching the barrier. The correlations between clearance height and landing distance within both men and women also showed that achieving a high CM position whilst on the barrier is beneficial for propelling the body farther, and should be encouraged by coaches, particularly as nearly all athletes analysed stepped on the barrier rather than hurdling it.

By default, the greater height of the barrier for men provides them with a more optimal take-off position to achieve a longer range, as well as the opportunity to exert larger horizontal forces during push-off. Contrary to the findings of Hunter et al. (2008) in national championship racing, the lack of a difference between world-class men and women for change in velocity suggests that the decelerating effects of landing in deeper water for women were similar to the effects of crossing a higher barrier in men (which, amongst these athletes, was also higher as a proportion of men's statures than women's). However, this does not invalidate the recommendation for women to try to achieve longer landing distances, especially as longer distances were correlated with faster 9 m times in women. Ultimately, women are more likely to land in deeper water than men because of the lower barrier height, lower approach velocity, shorter statures, and less muscle strength to push from the barrier. Although this does not present a competitive disadvantage as women and men compete separately, the lower barrier that was introduced when women's steeplechasing became a championship event was not matched by a change in the depth or dimensions of the water jump pit. For women to experience similar foot-water and uphill resistances as men and improve performances and times more in line with the sex-based differences in flat races, a device that changes the pit's dimensions for women could be considered by the IAAF. Previous research conducted soon after the women's event was introduced at the World Championships indicated that the regular steeplechase barriers might slow women less than men (Hunter & Bushnell, 2006), and therefore a comprehensive study incorporating all regular barriers and water jumps throughout the race is required to provide an assessment of the total effect of obstacles on both sexes. Twenty years after the inclusion of the women's event at official competitions, such research will provide coaches with contemporary information about technique and their relationship to race outcome.

The values found for this elite-standard sample of steeplechasers provide an indication to coaches and athletes of the typical values found in competition. For example, the results confirmed that a take-off distance of approximately 1.5 m was suitable for men (Schmolinsky, 2000), and provided equivalent empirically based evidence for women steeplechasers; in addition, the normative data that were relative to stature allow for more individualised applications. However, although the results found could be used as guides for coaches, the considerable variation found for some variables shows that there was a range of approaches taken to negotiating the water jump section. This is not unexpected, as athletes vary in technical and anthropometric measures (although the CV for stature was ≤ 4.1% for both sexes), as well as in terms of how quickly they negotiated the water jump, all of which should be taken into account when coaching individual athletes (Benson, 1993). The large CV values for spatial variables amongst women (e.g., take-off distance, landing distance and exit step length) were not accounted for solely by variations in stature, and reflect the wide range of techniques adopted by women athletes, and how it can be prudent for women to train differently for the event from men (Hunter & Bushnell, 2006). By contrast, lower variation amongst athletes occurred within the velocity values: of the 17 variables included in Table 1, approach velocity, take-off velocity and exit velocity were amongst the bottom half for CV amongst both sexes. These findings, along with the very large correlations between velocity variables and 9 m time (and the few correlations between spatial variables and 9 m time), indicate that several different approaches to clearing the water jump can be successful and the mean values found are an inexact guide for coaches.

The main strength of this new research is that the data had high ecological validity as the analyses were within the setting of an IAAF World Championship final. The natural setting of this observational study does mean, however, that those benefits that the controlled environment of the laboratory provides were not available. For example, the last lap in both races was the only viable opportunity to analyse the water jump as the athletes were too close together on previous laps to digitise them accurately, and even with a more spread-out field at the last water jump, many athletes still possibly needed to alter their clearance technique to account for the presence or positioning of other athletes. The results of this study might differ from those of others, e.g., Hunter et al. (2008), because in that study they analysed the same number of athletes (N = 13) but on each of the seven laps. The natural setting also meant that it was not possible to analyse the winner of the men's race, whose technique differed from most other athletes in that he did not make contact with the barrier but hurdled it instead. Future studies at world-class competitions that give a sense as to how the last water jump clearance differs from previous laps would help indicate the effects of fatigue or sprint finishes on technique and complement this study and that of Hunter et al. (2008). Nonetheless, the results from all other competitors who finished demonstrate clearly the kinematics of world-class steeplechasers and can be used, with some caveats, as a model of excellence by coaches.

CONCLUSIONS

This was the first study to analyse the water jump clearance in the setting of World Championship steeplechase finals. Although it is important to be technically proficient at all aspects of the clearance, the variable that most delineated better and worse water jump clearances was the landing distance. With regard to practical implications for elite-standard steeplechasers and their coaches, the key areas an athlete must optimise are approaching the barrier with a high running speed (that is maintained after leaving the pit), achieving a high clearance height over the barrier, pushing off the barrier to achieve a greater landing distance that helps to ensure that time is not lost when exiting the water, and an individual technique that takes into account the athlete’s height and technical strengths. In terms of future directions for this event, this new study provides the IAAF with original scientific information concerning the challenge for women steeplechasers to negotiate the water jump as effectively as men in its current configuration.

DISCLOSURE STATEMENT

The data collection and initial data analysis were supported by funding provided by the IAAF as part of a wider development / education project; however, the nature of the data is purely descriptive and not associated with any governing body, commercial sector or product. No funding was provided for the writing of this manuscript. The results of the present study do not constitute endorsement by the IAAF / World Athletics. Athanassios Bissas is the Director of the “Athletics Biomechanics” company; all other authors declare no competing interests.

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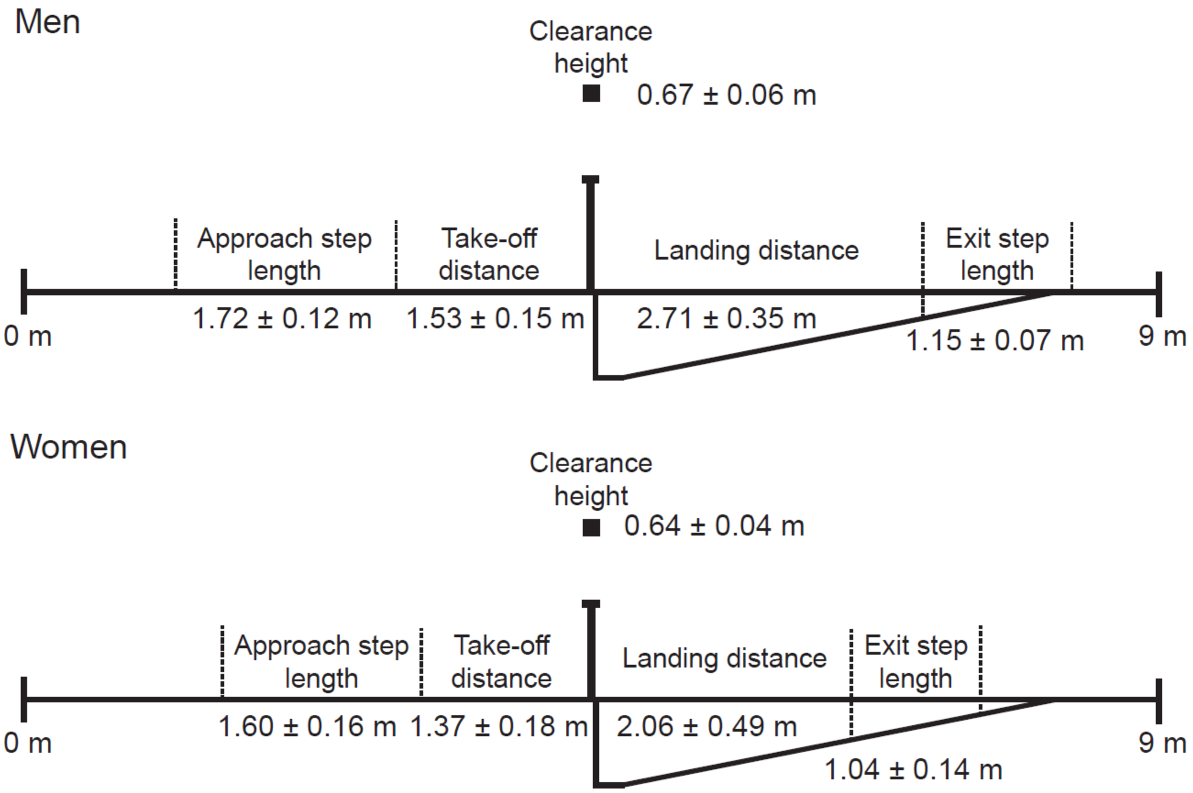

Figure 1. Visual representation of the approach step length, take-off distance, clearance height, landing distance and exit step length. The barrier is shown in the middle of the 9 m section length, with the water pit to its right. The diagram is approximately to scale, with separate diagrams for men and women. The mean values found in the respective events are also shown (with further details in the Results section).

Table 1. Mean ± SD values for key spatiotemporal variables for the water jump phase in World Championship men and women steeplechasers. Coefficient of variation (CV) values for each variable are shown in brackets. Between subject effects (sex-based comparisons) that were significant at $P < 0.05$ are shown in bold with their respective Cohen's *d* values.

	Men	Women	*P*	*d*
9 m time (s)	1.81 ± 0.16 (8.9%)	1.96 ± 0.19 (9.6%)	**0.035**	**0.88**
Approach velocity (km·h^{-1})	20.15 ± 1.23 (6.1%)	18.41 ± 1.34 (7.3%)	**0.002**	**1.36**
Approach step length (m)	1.72 ± 0.12 (7.2%)	1.60 ± 0.16 (10.3%)	**0.042**	**0.84**
Approach step length ratio (%)	96.5 ± 7.7 (8.0%)	96.5 ± 8.5 (8.8%)	1.000	0.00
Take-off velocity (km·h^{-1})	20.32 ± 1.20 (5.9%)	18.46 ± 1.09 (5.9%)	**< 0.001**	**1.62**
Take-off angle (°)	30 ± 2 (7.9%)	28 ± 2 (7.0%)	**0.029**	**0.91**
Take-off distance (m)	1.53 ± 0.15 (9.6%)	1.37 ± 0.18 (12.9%)	**0.017**	**1.02**
Take-off distance ratio (%)	86.0 ± 8.4 (9.7%)	82.7 ± 10.0 (12.1%)	0.373	0.36
Clearance time (s)	0.76 ± 0.09 (11.2%)	0.67 ± 0.10 (14.6%)	**0.014**	**1.04**
Clearance height (m)	0.67 ± 0.06 (8.9%)	0.64 ± 0.04 (6.5%)	0.153	0.58
Landing distance (m)	2.71 ± 0.35 (13.0%)	2.06 ± 0.49 (23.9%)	**0.001**	**1.52**
Landing distance ratio (%)	151.4 ± 16.4 (10.8%)	124.2 ± 28.1 (22.6%)	**0.007**	**1.18**
Exit velocity (km·h^{-1})	16.45 ± 1.33 (8.1%)	15.12 ± 1.34 (8.9%)	**0.018**	**0.99**
Exit step length (m)	1.15 ± 0.07 (5.9%)	1.04 ± 0.14 (13.6%)	**0.025**	**0.94**
Exit step length ratio (%)	64.3 ± 4.3 (6.7%)	63.0 ± 8.1 (12.8%)	0.591	0.21
Change in velocity (km·h^{-1})	–3.70 ± 0.52 (14.0%)	–3.29 ± 0.65 (19.8%)	0.084	0.70
Change in velocity (%)	–18.4 ± 2.7 (14.8%)	–17.9 ± 3.6 (19.9%)	0.672	0.17

Table 2. Correlation analysis of key spatiotemporal variables for the water jump phase in World Championship men steeplechasers. Correlations were significant at $P < 0.05$ and $r \geq 0.70$ (shown in bold).

	Approach velocity	Exit velocity	9 m time	Clearance time	Clearance height	Take-off distance
Approach velocity		**$r = 0.92$** **$P < 0.001$**	**$r = -0.74$** **$P = 0.004$**	$r = -0.23$ $P = 0.442$	$r = 0.36$ $P = 0.226$	**$r = 0.76$** **$P = 0.003$**
Exit velocity	**$r = 0.92$** **$P < 0.001$**		**$r = -0.73$** **$P = 0.005$**	$r = -0.32$ $P = 0.293$	$r = 0.42$ $P = 0.156$	$r = 0.66$ $P = 0.015$
Approach step length	$r = 0.46$ $P = 0.117$	$r = 0.27$ $P = 0.368$	$r = -0.19$ $P = 0.546$	$r = -0.05$ $P = 0.860$	$r = 0.05$ $P = 0.861$	$r = 0.46$ $P = 0.115$
Take-off velocity	**$r = 0.85$** **$P < 0.001$**	**$r = 0.87$** **$P < 0.001$**	$r = -0.53$ $P = 0.061$	$r = -0.28$ $P = 0.352$	$r = 0.33$ $P = 0.270$	**$r = 0.77$** **$P = 0.002$**
Take-off angle	$r = -0.68$ $P = 0.011$	$r = -0.61$ $P = 0.027$	$r = 0.58$ $P = 0.037$	$r = 0.43$ $P = 0.142$	$r = 0.12$ $P = 0.696$	$r = -0.54$ $P = 0.054$
Landing distance	$r = 0.36$ $P = 0.230$	$r = 0.34$ $P = 0.261$	$r = -0.57$ $P = 0.041$	**$r = 0.76$** **$P = 0.003$**	**$r = 0.75$** **$P = 0.003$**	$r = 0.18$ $P = 0.567$

Table 3. Correlation analysis of key spatiotemporal variables for the water jump phase in World Championship women steeplechasers. Correlations were significant at $P < 0.05$ and $r \geq 0.70$ (shown in bold).

	Approach velocity	Exit velocity	9 m time	Clearance time	Clearance height	Take-off distance
Approach velocity		**$r = 0.88$** **$P < 0.001$**	**$r = -0.75$** **$P = 0.003$**	$r = 0.57$ $P = 0.044$	$r = 0.66$ $P = 0.013$	$r = 0.39$ $P = 0.194$
Exit velocity	**$r = 0.88$** **$P < 0.001$**		**$r = -0.70$** **$P = 0.008$**	$r = 0.34$ $P = 0.263$	$r = 0.41$ $P = 0.168$	$r = 0.07$ $P = 0.816$
Approach step length	$r = 0.48$ $P = 0.095$	$r = 0.14$ $P = 0.646$	$r = -0.23$ $P = 0.450$	$r = 0.27$ $P = 0.377$	$r = 0.41$ $P = 0.166$	**$r = 0.73$** **$P = 0.004$**
Take-off velocity	**$r = 0.94$** **$P < 0.001$**	**$r = 0.82$** **$P = 0.001$**	$r = -0.63$ $P = 0.021$	$r = 0.48$ $P = 0.098$	$r = 0.64$ $P = 0.018$	$r = 0.51$ $P = 0.076$
Take-off angle	$r = -0.57$ $P = 0.041$	$r = -0.66$ $P = 0.013$	$r = 0.47$ $P = 0.107$	$r = -0.39$ $P = 0.184$	$r = -0.48$ $P = 0.168$	$r = -0.15$ $P = 0.634$
Landing distance	**$r = 0.81$** **$P = 0.001$**	**$r = 0.77$** **$P = 0.002$**	**$r = -0.87$** **$P = 0.001$**	**$r = 0.85$** **$P < 0.001$**	**$r = 0.71$** **$P = 0.007$**	$r = 0.26$ $P = 0.401$