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Prediction Of Throwing Distance in The Men's and Women's Javelin Final at the [2017 IAAF World Championships

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ABSTRACT

The purpose of this study was to use regularised regression models to identify the most important biomechanical predictors of throwing distance in elite male (M) and female (F) javelin throwers at the 2017 IAAF world championships. Biomechanical data from 13 male and 12 female javelin throwers who competed at the 2017 IAAF world championships were obtained from an official scientific IAAF report. Regularised regression models were used to investigate the associations between throwing distance and release parameters, whole-body kinematic and joint-level kinematic data. The regularised regression models identified two biomechanical predictors of throwing distances in both M and F javelin throwers: release velocity and knee flexion angle of the support leg at the moment of javelin release. In addition, the length of the delivery stride was an important predictor of throwing distance in M throwers, whereas the javelin's attitude angle and the distance between the whole-body centre

of mass and the centre of mass of the back foot at the beginning of the delivery phase were important predictors of throwing distance in F throwers.

Keywords

Biomechanics; LASSO; machine learning; regularised regression; sports

Introduction

The javelin is one of the four throwing events in the sport of track and field and as with all the four throwing events the objective is to throw the implement as far as possible. To maximise competition performance, javelin throwers need to optimise several technical parameters. Research has demonstrated that release parameters (e.g., release velocity and angle) are important predictors of javelin throwing distance (Bartlett et al., [2]; Viitasalo et al., [24]). Furthermore, data from the 1999 world championships showed that other release parameters, such as the angle of attack (i.e., the angle between the release velocity vector and the long axis of the javelin), are also important in relation to javelin throwing performance (Campos et al., [7]). In addition, research has also shown that whole-body and joint-level kinematic parameters are important predictors of javelin throwing distance. For example, the elbow flexion angle and shoulder abduction angle at the moment of release is also correlated with throwing distance (Murakami et al., [17], [18]; Saratlija et al., [22]). Other parameters thought to be important to javelin throwing performance include the sequencing, timing and phase durations related to the body's and javelin's kinematics (Bartonietz, [3]; Liu et al., [11]; Panoutsakopoulos & Iraklis, [19]).

Males and females both participate in javelin competitions. Although the only rule-related differences in the event are the weight and length of the implement (i.e., 800 g; 2.6–2.7 m for men and 600 g; 2.2–2.3 m for women) (IAAF, [8]), previous research has indicated that males and females exhibit biomechanical differences as they throw the javelin. For example, a comparison between males and females from the 1992 Olympic games demonstrated that males not only produced significantly greater release velocities but also exhibited greater release heights and smaller angle of attitude (i.e., the angle between the javelin's long axis and the horizontal axis) – although no differences were found in release or attack angles (Mero et al., [14]). In addition, differences between male and female javelin throwers exist in joint kinematics, such as trunk movement sequences (Liu et al., [11]). Specifically, right-handed elite male throwers initiated right hip abduction and internal rotation simultaneously after final left foot touchdown, while female throwers initiated their right hip abduction significantly later than internal rotation (Liu et al., [12]). Differences in release parameters and throwing biomechanics between male and female javelin throwers suggest the existence of sex-specific differences in technical prerequisites for achieving maximal performance (Leigh et al., [10]).

While research has provided information about the associations between throwing performance and release parameters, whole-body kinematics and joint-level kinematics in males and females (Liu et al., [11], [12]; Mero et al., [14]; Murakami et al., [18]; Whiting et al., [25]), similar information in elite throwers is much scarcer. Indeed, beyond the scientific reports from the IAAF world championships, which provide mostly simple descriptive biomechanical analyses, few studies examined the associations between throwing performance and biomechanical parameters in elite level throwers. An underlying problem, which limits the ability to analyse such associations, is the relatively small sample

size of athletes who compete at the world championship level. In addition, another significant issue is that conventional statistical methods are not well adapted to problems where the number of predictor variables exceeds the number of observations (i.e., athletes or trials), as is often the case in sports biomechanics where a large number of kinematics or kinetic parameters are generated and analysed from relatively few observations. One solution to this problem is to use regularised regression models, which introduce penalization criteria, handle "wide" data sets (i.e., lots of variables and few subjects), eliminate irrelevant variables and improve prediction accuracy (Tibshirani, [23]). For example, Puel et al. ([21]) used a regularised regression model (least absolute shrinkage and selection operator – LASSO) to effectively predict tumble turn times in 10 elite male front crawl swimmers from over 51 biomechanical parameters. Since the regularisation within the LASSO regression automatically performs variable selection, the outputs from the regression model were also easy to interpret and provided clear insights for coaches (Puel et al., 2012). In a different study, Silveira et al. ([20]) used a similar model (i.e., LASSO) to reduce the number of variables, extract the main determinants to performance and reveal unique combinations of key determinants of 5 m time in 13 elite swimmers. In both cases, these results provided relevant contributions that increased the understanding of the biomechanics, provided insights for performance analysis and identified targets for training interventions to improve athlete performance (Puel et al., 2012; Silveira et al., 2018).

Given that regularisation models appear useful in the context of analysing elite level sports performance, the purpose of this study was to use regularised regression models to identify the most important biomechanical predictors of throwing distance in elite male and female javelin throwers at the 2017 IAAF world championships.

Methods

Data were obtained from the official biomechanical report of the 2017 IAAF World Championships (Bennet et al., [4], [5]). The report includes biomechanical data on the farthest throw from each of the 13 finalists in the men's javelin competition (Mean±SD; age: 25.9 ± 3.5 years; height: 1.89 ± 0.07 m; body mass: 92.8 ± 7.3 kg; personal best javelin throwing distance: 89.4 ± 3.1 m) and from each of the 12 finalists in the women's javelin competition (Mean±SD; age: 27.92 ± 4.9 years; height: 1.77 ± 0.05 m; body mass: 74.9 ± 4.9 kg; personal best javelin throwing distance: 66.9 ± 2.2 m).

Data collection and processing methods are outlined in detail in the freely available reports at <https://www.iaaf.org/about-iaaf/documents/research>. Briefly, three high-speed cameras were positioned in different locations around the stadium and used to record video during each throw. A single operator manually digitised video files from each camera with a Simi motion capture system (Simi Reality Motion Systems GmbH, Germany). The Direct Linear Transformation (DLT) procedure was used to calculate 3D coordinates of selected bodily landmarks. The coordinate data were filtered with a zero phase-lag, recursive second-order, low-pass Butterworth digital filter. A complete list of all biomechanical parameters is presented in Table 1.

Table 1. List of biomechanical parameters in the IAAF report from the 2017 world championships

#	Variable	Description
Y ₁	Throwing distance (m)	Distance the javelin between foul line and landing spot.
X ₁	Release velocity (m/s)	The resultant velocity of the javelin at the point of release.
X ₂	Release angle (°)	The angle between the javelin direction of travel and the horizontal at release.
X ₃	Release height (m)	The vertical distance from the javelin's grip to the ground at release.
X ₄	Attitude angle (°)	The angle between the javelin's longitudinal axis and the horizontal at release.
X ₅	Attack angle (°)	The difference between the angle of release and the angle of attitude at release.
X ₆	Sideslip angle (°)	The angle between the direction of the velocity vector at release and javelin's longitudinal axis (looking from behind).
X ₇	Trunk angle (°)	The angle between the trunk and the horizontal at release.
X ₈	Upperarm angle (°)	The angle between the upper arm and the horizontal at release.
X ₉	Forearm angle (°)	The angle between the forearm and the horizontal at release.
X ₁₀	Impulse phase (s)	The time between penultimate left foot contact and final right foot contact.
X ₁₁	Delivery phase (s)	The time between the final right foot contact and final left foot contact.
X ₁₂	Release Phase (s)	The time between final left foot contact and release.
X ₁₃	Approach velocity (m/s)	The velocity of the head at the start of the impulse phase.
X ₁₄	D _{imp} (m)	Distance of impulse step. The penultimate left foot contact to final right foot contact.
X ₁₅	D _{del} (m)	Distance of delivery step. The final right foot contact to final left foot contact.
X ₁₆	DFL (m)	The horizontal distance from the plant foot to the foul line at release.
X ₁₇	CM-RF (m)	The distance between the whole-body CM and the CM of the right foot at the beginning of the delivery phase.
X ₁₈	LF-JC (m)	The distance between the point of left foot contact and the javelin grip at the beginning of the release phase.
X ₁₉	TT-LTD (°)	The angle of the trunk relative to the vertical at the beginning of the release phase.
X ₂₀	SKF (°)	The angle of the supporting knee joint at the point of release and considered to be 180° in the anatomical standing position.

The associations between outcome (i.e., javelin throwing distance) and predictor (biomechanical parameters) variables were investigated with two regularised regression models; one for the male throwers and one for the female throwers. All predictor variables were standardised so that magnitude differences in measurement scales would not influence the shrinkage of regression coefficients. The regularised regression models used an elastic net adjustment with an 'alpha' coefficient of 0.5. Each model was cross-validated 10 times across 100 "lambda" values and the mean square errors (MSE) at each value were calculated. For male and female throwers, the model with the smallest MSE was identified so that the model that was one standard error from the minimum MSE could be established. This 'minimum MSE model' represents a more parsimonious model and includes only the most important predictor variables and their regularised regression coefficients. Since the regularised regression coefficients of all other variables have shrunken to '0' during the regularisation process, the retained variables are automatically deemed as significant predictors and illustrates how regularisation eliminates irrelevant variables and performs variable selection. While the predictor variables were standardised before regularisation, the regularised regression coefficients are presented in the original measurement scale. Pearson's correlation coefficients (r) were calculated for all variables retained by each regularised regression model and used to further identify only those variables that had a significant association ($p < 0.05$) with javelin throwing distance.

Results

The regularised regression model for the male throwers indicated that delivery step distance (D_{del}), release velocity (R_{vel}), the distance between left foot and javelin grip at the beginning of the delivery phase (LF-JC) and the angle of the support leg's knee joint at the moment of release (SKF) was all important predictors of javelin throwing distance (Table 2). Furthermore, the simple linear regression identified D_{del} , R_{vel} and SKF as significant biomechanical predictors of throwing distance in male throwers (Table 2).

Table 2. A regularised regression model with descriptive data (Mean, 95% Confidence Intervals [95% C.I.] and minimum [Min] and maximum [Max] values) regularised regression coefficients (RRC) and simple linear regression coefficients (r) for elite male throwers

	Mean	95% C.I.	Min	Max	RRC	r	p-value
D_{del} (m)	1.79	[1.62, 1.95]	1.48	2.26	1.61	0.69	0.01
R_{vel} (m/s)	27.9	[27.5, 28.4]	26.7	29.2	1.10	0.85	0.01
LF-JC (m)	1.90	[1.85, 1.95]	1.79	2.04	0.19	0.47	0.11
SKF (°)	162	[149, 176]	126	192	0.01	0.56	0.04

Variables in **bold** represent variables with p -values < 0.05

The regularised regression model for the female throwers indicated that the distance between the whole-body centre of mass and the centre of mass of the right foot at the beginning of the delivery phase (CM-RF), LF-JC, a distance of the impulse step (D_{imp}), R_{vel} , approach velocity, angle of attack, attitude angle, SKF and upper arm angle was all important predictors of javelin throwing distance (Table 3). In addition, the simple linear regression identified R_{vel} , attitude angle, CM-RF and SKF as significant predictors of throwing distance in female throwers (Table 3).

Table 3. A regularised regression model with descriptive data (Mean, 95% Confidence Intervals [95% C.I.] and minimum [Min] and maximum [Max] values) regularised regression coefficients (RRC) and simple linear regression coefficients (r) for elite female throwers

	Mean	95% C.I.	Min	Max	RRC	r	p-value
CM-RF (m)	-0.23	[-0.29, -0.17]	-0.35	-0.03	-4.96	-0.68	0.02
LF-JC (m)	1.79	[1.74, 1.84]	1.66	1.92	-3.73	-0.24	0.46
D_{imp} (m)	1.68	[1.52, 1.84]	1.12	1.98	0.66	0.52	0.08
R_{vel} (m/s)	24.3	[23.7, 24.9]	23.0	26.4	0.59	0.71	0.01
Approach Velocity (m/s)	5.93	[5.46, 6.39]	4.67	7.16	0.14	0.48	0.12
Angle of Attack ($^{\circ}$)	5.86	[1.89, 9.82]	-3.00	17.4	-0.04	-0.55	0.06
Attitude Angle ($^{\circ}$)	40.7	[37.2, 44.3]	34.6	51.0	-0.02	-0.61	0.04
SKF ($^{\circ}$)	169	[159, 180]	146	191	0.02	0.64	0.03
Upperarm Angle ($^{\circ}$)	42.3	[33.4, 51.1]	24.8	64.8	-0.01	-0.51	0.09

Variables in **bold** represent variables with p -values < 0.05

Discussion

The purpose of this study was to use regularised regression models to identify the most important biomechanical predictors of throwing distance in elite male and female javelin throwers at the 2017 IAAF world championships. The results from these models suggest that three biomechanical predictors were associated with throwing performance in the male throwers and four biomechanical predictors were associated with throwing performance in the female throwers. In general, while release velocity and knee flexion angle of the support leg at the moment of javelin release were important biomechanical parameters in predicting javelin throwing distances for both sexes, the length of the delivery step was an additional predictor in male throwers whereas attitude angle and the distance between the whole-body centre of mass and the centre of mass of the right foot at the beginning of the delivery phase were additional important predictors in female throwers. The observed discrepancy in the number of biomechanical predictors of throwing distances between males and females may reflect a more technical throwing pattern in female athletes since there are more biomechanical variables that contribute and would have to be controlled, to maximize performance (Liu et al., [12]).

Male and female throwers shared two common biomechanical variables that were associated with throwing performance; release velocity and support knee flexion angle. Specifically, greater release velocities and smaller knee flexion angles of the support leg (i.e., front/block) were associated with better javelin throwing performance. The ability to generate high release velocity differentiates not only a novice and elite javelin throwers (Bartlett et al., [2]) but also contributes to success at the Olympic level (Mero et al., [14]). The fact that release velocity appeared in the regularised regression model of both groups is thus not surprising. It should be noted, however, that the correlation between release velocity and throwing distance is not perfect, which likely reflects the complex interplay between release parameters (Maier et al., [13]). This complex interplay may be particularly relevant for female throwers since the attitude angle was a significant predictor of throwing distance within their regularised regression model. An experimental study showed that lower attitude angles, especially in combination with lower attack angles, were primary determinants of the aerodynamic distance achieved by the javelin (Leigh et al., [9]). While the attack angle was also present as a predictor of

throwing distance within the regularised regression model of female throwers, it did not exhibit a significant correlation with throwing distance. Given that the regularised regression model accounts for the presence of and the correlation between, multiple variables the results from previous findings of the interaction between the different types of release angles may be driven by the attitude angle and suggest that it is a more important predictor than release and attack angles. The other biomechanical variable that predicted javelin throwing distance in both groups was the knee joint angle of the support leg at the point of release. This finding is supported by a previous study on biomechanical differences between short and long throws in the same throwers in that the knee joint angles of the support leg were straighter during longer throws compared to shorter throws (Whiting et al., [25]). Furthermore, effective blocking of the support leg at final foot strike is thought to facilitate the transfer of kinetic energy from the upper body to the javelin (Morriss et al., [16]). Given the similarity across studies, knee flexion angle of the support leg at the end of the release phase may thus reflect an important technical parameter related to javelin throwing distance.

In addition to the shared biomechanical variables that predicted javelin throwing distance in both groups, the regression model for male throwers included one additional variable: the distance between the back and front foot during the delivery phase. Given that this distance reflects the length of step during the delivery phase of the javelin throw, the regression and correlation results suggest that male throwers with longer delivery phase step lengths also threw the javelin farther. This result is similar to the findings of Whiting et al. ([25]) who showed that male throwers significantly increase step distances during the delivery phase as they increased throwing distance from shorter to farther throws. It is interesting to note, that in the current study the distance of the delivery step exhibited the second-largest Pearson correlation coefficient, which suggests that this was a very important determinant of throwing distance in the male throwers at the 2017 world championship. This assertion was supported by commentary from the coaches within the original IAAF report, who noted that the step distance during the delivery phase of all three medallists exceeded 2 m. While this finding does not immediately indicate that all throwers should aim to increase the distance of their delivery phase step, the statistical advantages of the regularised regressions do suggest that this biomechanical variable should be considered as an important predictor of throwing distance within a multi-variate model of javelin throwing performance and that coaches and researchers should consider manipulating and observing whether an increase in delivery step distance leads to a concomitant increase in performance.

Similar to their male counterparts, female throwers exhibited two additional distinct biomechanical variables that predicted javelin throwing distance. These variables included the attitude angle and the distance between the centre of mass of the whole-body and the centre of mass of the back foot at the beginning of the delivery phase. Specifically, smaller attitude angles and greater (negative, i.e., backward) horizontal distances between the centre of mass of the body and the foot at the beginning of the delivery phase were associated with better javelin throwing performance in female throwers. Previous research suggests that the backward lean of the body at the beginning of the delivery phase increases the acceleration path of the javelin and allows the thrower more time to exert force on the javelin (Morriss & Bartlett, [15]; Panoutsakopoulos & Iraklis, [19]). While it may not be feasible to indefinitely increase either the backward lean or the horizontal distances between the centre of mass of the body and the foot at the beginning of the delivery phase, the importance of these variables as a

predictor of javelin throwing distance in female throwers suggests that coaches and researchers should try to determine if there is an optimal range for these variables that could maximise throwing performance.

The results of the current study should be interpreted in light of several limitations. First, the findings and their interpretations are based on data from one competition and may not necessarily reflect the best performance of each athlete (e.g., only 1/12 females and 2/13 males threw a personal best during the competition). Still, the throwing distances produced by the male and female throwers were indicative of world-class performance. Second, only a single trial from each thrower was analysed. Without multiple trials for each thrower, it is unfortunately not possible to calculate and examine within-subject variation, which limits important information about thrower-specific biomechanical predictors of javelin throwing performance (Button et al., [6]). Third, manual digitisation of body landmarks during data processing steps may introduce methodological errors that could influence the calculation of biomechanical variables. However, all data were digitised by a single-experienced operator, which likely reduced the amount of variability in the data (Bartlett et al., [1]). Fourth, some of the correlations may not have reached significance due to the low sample size and/or high variance relative to sample size. However, the consistency in the results between regularised regression models and the correlation analysis suggests that the findings are robust despite the low sample size. Lastly, the results and interpretations are limited by the cross-sectional design of the current study and it remains to be determined whether focusing on improving any of the identified biomechanical predictors would improve throwing distance or inadvertently increase risk of injury.

Conclusion

Elite male and female javelin throwers at the 2017 IAAF world championships shared two biomechanical variables that predicted throwing distances; release velocity and knee flexion angle of the support leg. In addition, the length of the delivery step was an additional predictor of throwing distance in male throwers whereas attitude angle and the distance between the whole-body centre of mass and the centre of mass of the right foot at the beginning of the delivery phase was additional important predictors of throwing distance in female throwers.

Disclosure statement

No, potential conflict of interest was reported by the authors.

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