PREDICTION OF THROWING DISTANCE IN THE MEN'S JAVELIN AT THE 2017 IAAF WORLD CHAMPIONSHIPS

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The purpose of this study was to identify key biomechanical parameters that predict throwing distance in elite male javelin throwers. Biomechanical data from 13 male javelin throwers who competed at the 2017 IAAF World Championships were obtained from a freely available IAAF report. A regularised regression model was used to determine the associations between throwing distance and release parameters, whole-body kinematic, and joint-level kinematic data. The model indicated that delivery step distance (r = 0.69), release velocity (r = 0.85), distance between left foot and javelin grip at the beginning of the delivery phase (r = 0.47), and the angle of the support leg's knee joint at the instance of release (r = 0.56) were all important predictors of throwing distance in elite male javelin throwers at the 2017 IAAF World Championships.

KEYWORDS: sports, biomechanics, machine learning, regularization, LASSO.

INTRODUCTION: The javelin is one of four throwing events in the sport of track and field. The objective of the event is to throw the javelin the farthest distance measured from the foul line. Previous research demonstrated that release parameters (e.g., release velocity and angle) are important predictors of throwing distance in elite javelin throwers (Viitasalo, et al., 2003; Bartlett, et al., 1996). In addition to studying the importance of release parameters to javelin throwing performance, researchers have also studied whole-body and joint-level kinematic data. A biomechanical analysis of the men's javelin final during the 1995 IAAF World Championships illustrated kinematic differences in shoulder and elbow joint kinematics between the top two finishers (Morris et al., 1997). In addition, analysis of the men's javelin final at the 1999 World Championships showed that the winning competitor had a longer acceleration path and exhibited more optimal release parameters (Campos, et al. 2004). Other parameters that are of purported importance to javelin throwing performance include the durations of key phases as well as the body's and javelin's respective positions during these phases (Bennet et al., 2018).

While release parameters appear to be consistently important predictors of throwing distance based on simple physical models of projectile motion, the importance of kinematic parameters are not as clear, especially in elite throwers. Small sample sizes of elite athletes represent an underlying problem that limits the use of traditional statistical methods and models to ascertain the associations between biomechanical parameters and sport performance. One recent solution to overcome this problem is to use machine learning processes, such as regularisation. For example, regularisation via least absolute shrinkage and selection operator (LASSO) regression selects only important parameters and removes redundant ones, and thus improves accuracy and interpretability of regression models (Tibshirani, 1996). Furthermore, regularisation via ridge regression improves the fit of regression models when there are more predictor than outcome variables (Zou & Hastie, 2005).

Given that sports biomechanists typically analyse large amounts of kinematic and kinetic parameters that are obtained from relatively few observations, regularisation may provide a solution to dealing these 'wide' data sets (i.e., lots of variables, but few subjects). For example, Puel et al. (2012) used a Lasso regression model to effectively predict swimming performance of ten elite male front crawl swimmers from over 51 biomechanical parameters. Since LASSO regression performs variable selection in addition to regularisation the model's outputs were easy to interpret and provided distinct coaching insight.

The purpose of this study was to identify biomechanical parameters that predict throwing distance in elite male javelin throwers at the 2017 IAAF World Championships. To this end, we used regularisation methods to reduce the number of variables in the model and to identify the most important biomechanical predictors of throwing distance in order to help develop technical models that can be used by coaches and practitioners to improve javelin throwing performance.

METHODS: All data were obtained from the freely available biomechanical report by the IAAF from the 2017 IAAF World Championships (Bennet, et al, 2018). The report includes biomechanical data on the best 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±3.1m).
Data collection and processing methods are outlined in detail in the online biomechanical report (https://www.iaaf.org/about-iaaf/documents/research). Briefly, however, three high-speed cameras were positioned in three different locations around the stadium and used to record video during each throw. A single operator digitised each video file with Simi Motion (Simi Reality Motion Systems GmbH, Germany). The Direct Linear Transformation (DLT) procedure was used to calculate 3D coordinate data, which were filtered with a zero phase-lag, recursive second-order, low-pass Butterworth digital filter. A list of all calculated biomechanical parameters is presented in Table 1.

Table 1: List of all biomechanical parameters in the IAAF report from the 2017 World Championships.

#	Variable	Description
Y_1	Distance (m)	Distance the javelin was thrown.
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's longitudinal axis 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	Angle of attack (°)	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 javelin throwing distance and biomechanical parameters were investigated with a regularised regression model. The model used elastic net regularisation by combining LASSO and ridge regression. The elastic net 'alpha coefficient' was set to 0.5, which essentially combines LASSO and ridge regression into the same model. The model was then cross-validated ten times across 100 'lambda' values. The lambda value that yielded the smallest cross-validated mean square error (MSE) was found, and the regression coefficients for the predictor variables that were one standard error from the minimum MSE were used and presented in the final model. In addition, simple linear correlation coefficients (Pearson's *r*) were calculated for all parameters that were retained by the regularised regression model.

RESULTS: The regularised model was able to predict throwing distance to within an MSE of 2.67m^2. The regularisation model indicated that delivery step distance (D_{del}), release velocity (R_{vel}), distance between left foot and javelin grip at the beginning of the delivery phase (LF-JC), and the angle of the support legs knee joint at the instance of release (SKF) were all important predictors of javelin throwing distance (Table 2). All other parameters within the regularised regression model exhibited regression coefficents equal to zero, and thus did not contribute to throwing distance.

Table 2: Descriptive data, regularised regression coefficients (RRC), and simple linear regression coefficients (Pearson's *r* and *p*-value) for all parameters with non-zero regression coefficients.

	D_{del} (m)	R_{vel} (m/s)	LF-JC (m)	SKF (°)
Mean	1.79	27.9	1.90	162
S.D.	0.27	0.7	0.08	21.6
Min	1.48	26.7	1.79	126
Max	2.26	29.2	2.04	192
RRC	1.61	1.10	0.19	0.01
r	0.69	0.85	0.47	0.56
p	0.01	0.01	0.109	0.04

Discussion: The purpose of this study was to identify key biomechanical parameters that predict throwing distance in elite male javelin throwers. The results from the regularised regression model suggest that four biomechanical parameters are associated with throwing performance of the 13 finalists in the men's javelin competition at the 2017 IAAF World Championships.

The model demonstrated that the step distance during the delivery phase (D_{del}) exhibited the largest regularised regression coefficient and second largest Pearson correlation coefficient. The direction of the correlation between D_{del} and throwing distance suggests that throwers who exhibited D_{del} produced farther throwing distances. Similarly, a within-subject study that compared each person's farthest throws to their shortest throws showed a significant difference in step distance during the delivery phase such that longer throws were associated with greater delivery steps (Whiting, et al., 1991). It is interesting to note that one of the coaches who helped with the original IAAF report commented that the D_{del} for all three medallists were over 2 m in distance. The results from the current study therefore support the coach's notion.

Release velocity (R_{vel}) exhibited the second largest regularised regression coefficient and the largest Pearson correlation coefficient. Based on analysis and application of simple projectile motion equations these findings are perhaps not too surprising. The ability to generate high R_{vel} differentiates not only novice and elite javelin throwers (Bartlett, et al., 1996), but also contributes to success at the Olympic level (Mero, et al., 1994). However, it should be noted that correlation between R_{vel} and throwing distance is not perfect, which likely reflects the complex interplay between all projectile motion parameters, and specifically between R_{vel} and release angles.

The horizontal distance between left foot and javelin grip positions at the beginning of the release phase (LF-JC) exhibited a smaller regression coefficient than delivery phase step distance and release velocity. Specifically, greater LF-JC distances were associated with farther throwing distances, which suggests that throwers who exhibited longer acceleration paths during the release phase also produced farther distances for the javelin throws. Similarly, Bartlett et al. (1996) reported that the distance between the javelin grip and right hip at the start of delivery phase was significantly greater in elite than novice throwers. Given the agreement between studies, LF-JC may thus reflect an important technical parameter and predictor of throwing distance despite the small regression coefficient.
Finally, the angle of the supporting leg's knee joint at the point of release (SKF) was also associated with javelin throwing distance. More specifically, throwers who displayed a straighter and less bent supporting leg were able to attain farther throws. A previous study between short throws and long throws performed by the same individual supports the importance of support leg angle at the point of release because longer throws were characterized by larger and less flexed supporting leg knee joint angles when compared to the shorter throws (Whiting, et al., 1991).
Collectively, the results of the regularised regression model suggest that LF-JC, D_{del}, and SKF are important parameters in predicting javelin throwing distances. Greater magnitudes for the first two parameters likely reflect longer paths of acceleration of the javelin, whereas greater magnitudes for the last parameter presumably reflect a more impulsive transfer of energy at the point of release. Together these three parameters may reflect technical characteristics that ensure the potential for high release velocities, which in turn are necessary for large throwing distances. Although these results come from a cross-sectional study in elite javelin throwers, researchers, coaches, and athletes may want to try to evaluate the effects of increasing LF-JC and D_{del} and maintaining a large SKF angle during the javelin throw in order to increase release velocity and throwing distance.

CONCLUSION: The regression model indicated that delivery step distance, release velocity, horizontal distance between left foot and javelin grip at the beginning of the delivery phase, and the angle of the support leg's knee joint at the instance of release were all important predictors of throwing distance in elite male javelin throwers at the 2017 IAAF World Championships.

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