Journal of Physical Education and Sport ® (JPES), 18 Supplement issue 1, Art 73, pp. 512 - 516, 2018
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

How kinematics influences shot put results in track and field of international level athletes (a case study)

ZLATKO SARAČEVIĆ [1], ALMIR ATIKOVIĆ [2], STANISLAV STANKO ŠTUHEC [3], IVAN ČUK [4]
[1,2] Faculty of Physical Education and Sport, University of Tuzla, Tuzla, Tuzla, BOSNIA AND HERZEGOVINA
[3,4] Faculty of Sport, University of Ljubljana, Ljubljana, Slovenia, Ljubljana, SLOVENIA (EU)

Published online: April 30, 2018
(Accepted for publication April 20, 2018)
DOI:10.7752/jpes.2018.s173

Abstract
Purpose: The purpose of research was to determine important kinematic variables, which determine result in shot put of international level athlete. Athlete used rotational technique of shot put, which is very demanding from movement coordination point of view. *Methods*: With MVN Xsens dress with 17 accelerometers (data acquisition 120 Hz) we measured 36 shot puts in 3D and used 276 variables. Result of shot put was measured with IAAF judge's method. All joint and segment variables – trajectories, velocities, angels and angular velocities in all 3 axis we analysed and the differences between release moment and 0.1 second before release were calculated. *Results*: With series of regression analysis, we extracted the best predictors and with final stepwise regression explained 47.4% of shotput result, and what is the most important, the best predictors are low (negative) difference of angular velocity in y axe of left upper leg, low (negative) difference of angular velocity in y axe of T12 vertebra, and high difference of left ankle angle to x axe. *Conclusion*: Importance of opposite throw hand body side, which should be fast deaccelerated and stopped turning in order to give throw arm a rock support for its activity as an open side kinetic chain.
Keywords: Kinetic Chain, Regression, Xsens Mvn , Throwing, Motion Analysis, Performance

Introduction

Track and field disciplines are very well explained with laws of physics (Bartlett, 2000; Lanka, 2000; Zatsiorsky, 2000). However when we are dealing with humans, we need to deal with human abilities and characteristics. As shot putters are not machines, they have variability in their activities, despite they look from outside observer very similar (Harasin, 2007). At the moment of shot release it is important, that shot is from as high point as possible and with maximum vertical and horizontal velocity and proper angle of release, so shot have parabola trajectory. Shot putter can use two different techniques, the first and the oldest is glide one, where athlete guides shot mostly in z and y axis and tries to maximise height and release velocity (Bartlett, 2000; Lanka, 2000; Zatsiorsky, 2000). Authors (Błażkiewicz et al., 2016) study transfer of mechanical energy between body segments during the glide shot put, they found statistically significant transfer in the study group between the following segments: right knee - right hip, left hip - torso, torso - right shoulder and right elbow - right wrist; the results of cluster analysis showed that the kinetic chain used during the final shot acceleration movement had two different models, and the difference between the groups were mainly in the energy generated by the hips and trunk. The second technique is rotational one where athlete turns around his longitudinal axis and then in proper time releases shot, during this technique athlete tries to transform shot angular velocity to linear one. For example authors (Zatsiorsky, 2000) extended simple physics determination model with human factors as start shot velocity, shot acceleration during turns, athletes movements during turn, kinematic changes during terms, shot acceleration during release, athletes movement during release.

Luhtanen et al. (1997) divide rotational technique into 6 phase: beginning position, where athlete is with back toward release position, the second phase is beginning of one leg support, the third phase is flight, the fourth phase is one leg support, the fifth phase is double leg support and the last phase is shot release. Most authors (Bartonietz, 1994a; 1994b; Lanka, 2000), agree, that the highest acceleration arms and shoulder during extension is determining 85-90 % of final shot distance. Čoh et al. (2000) determined shot put result with athletes morphologic characteristics, where those with large abdominal mass have lower capability of using

Corresponding Author ALMIR ATIKOVIĆ, E-mail: almir.atikovic@untz.ba

kinetic chain in relation rotation of shoulders to hips; also athletes with higher body mass have better ratio towards shot weight and can produce higher maximal force.

Another study (Čoh and Štuhec, 2008a; 2008b) explained the double leg phase with shot release is the most important phase of shot put as in this phase to generate maximal force is important difference of shoulder and hip angle, and to generate high trunk torsion which serves as potential (elastic) energy accumulation, which is released during release. They added list of important facts: velocity vector (combined of vertical and horizontal one) of shot release is the most important, velocity is consequence of previous phases, result depend on velocity vector, angle of velocity vector towards y axis and height of shot at the moment of release, shot velocity during rotational technique changes and the lowest is during flight phase, which should be as short as possible or even be without it, in second double leg phase athlete already give to shot 77% of velocity, to reach high shot position at the release it is important angle in right knee during maximal amortisation at the beginning of the second double leg support, it is important angular velocity of throw arm (elbow and shoulder), body mass index of high level athlete should be between 31.6 and 44.5. By (Bartlett, 2000; Young, 2003) optimal release angle is between 31 and 36 degrees towards z axis. In an investigation (Linthorne, 2001) found that release angles depend on athletes preferences according to their abilities and they are individual characteristics, by different release angles there can be achieved same results. As shown in this study (Lanka, 2000) emphases importance of acceleration and de acceleration mostly in movement from down to up, what is related to knee, hip, shoulder and hand, all on the throw arm body side.

Our aim was to analyse shot put results as case study (individual observation) of international elite shot putter, and to relate results with the change of kinematic parameters between time of release and 0.1 second before release (time of release was set according to results of experiment as in this moment throw hand have the closest value to 0 m/s in z axis).

We hypothesized that the maximum shot put length is expected to determine the kinematic parameters that will most contribute to maximizing the shot put results by rotational technique.

Material and Methods

Subject of case study was international level athlete with age of 32 years, with his height of 1.95 m and mass of 129.5 kg. His body mass index was 34.6 kg/m^2. His personal best results was 21.07 meters. In the season when he was measured his personal best was 19.70 m at World Championship, where he took 17th place. He voluntarily joint experiment, all rights within Helsinki declaration were respected.

To measure kinematic variables we used Xsens MVN inertial suit system with 17 three dimensional accelerometers /gyroscopes/ magnetometers placed on each foot, calf, thigh, hand, forearm, upper arm, shoulder, sternum, lower back and head. Xsens MVN system showed high validity and reliability in previous research (Brennan et al., 2011; Krüger and Edelmann-Nusser, 2010; Zhang, 2013) with error of up to 3 degrees for all axis. Result of shot put was measured according to IAAF rules (http://www.iaaf.org/about-iaaf/documents/rules-regulations/ IAAF Competition Rules 2016-2017 in force from 1 November 2015.pdf). All 36 throws were performed during one day experiment session, 18 throws in the morning from 10-11 o'clock, with individual warm up and individual intervals between throws, according to his experience and similarities towards his training schedules and another 18 throws were in afternoon between 16 and 17 o'clock. Experiment was held in late September short after athlete's last competition on sunny day with temperature between 20 and 22 degrees during experiment. Moment of release was determined with external high speed camera (120 Hz), which was synchronized with Xsens. As the moment of release it was counted with the first moment (frame) when shot was not in contact with hand or fingers.

To determine kinematic values: trajectories, velocities, angles, angular velocities for each segment and joint in each axe (x, y and z), we used Xsens Moven software from year 2009. We analysed 277 variables. Due to such extended list of variables, variables are not named and only variables, which were significant predictors of shot put results are named in the results section.

Statistics analysis were done with SPSS 23.0. For all variables we calculated Kolmogorov - Smirnov test, descriptive statistics, Pearson correlation coefficients and stepwise regression between shot put results and kinematic variables. Regression analysis were performed in the following two steps. In the first step we did stepwise regression analyse between shot put results and: body joints angles in each axe; angular velocity in all body joints in each axe; trajectory of each body segment in each axe; and velocity of body segment in each axe.

The best single predictors from the first step regressions were then summarized in the second step where again stepwise regression analyse was calculated. In the final stepwise regression analyse entered 31 independent variables and Shot put result as dependent variable. All statistics data were determined as significant when ($p < 0.05$).

Fig. 1. Positioning of the sensors on body

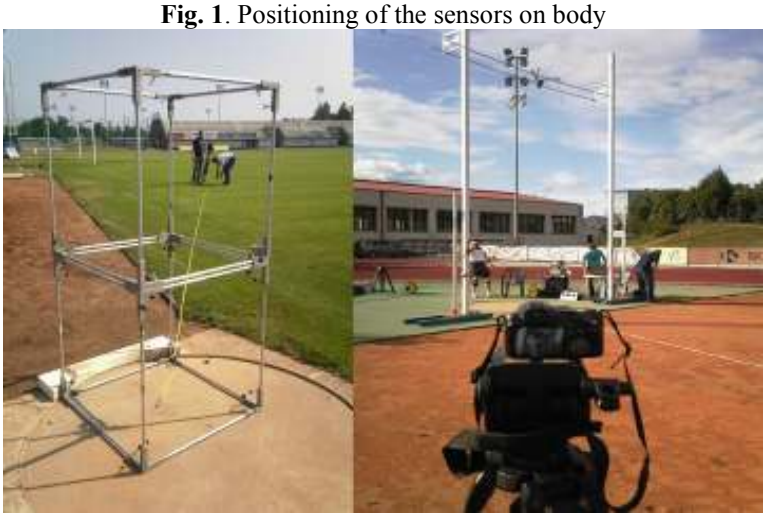

Fig. 2. View of the calibration frame and cameras

Results

Out of 277 variables, 30 variables were not normal distributed according to Kolmogorov - Smirnov test. Non normal distributed variables were excluded from further analysis. Among included independent variables were two linear velocities, 14 angles and 15 angular velocities. Descriptive statistics show shot put results are slightly lower than athletes maximum result in season in average 17.58 m (Table 1), however still his best result at experiment was 18.05 m. Pearson correlation coefficients between values change in last 0.1 second before release and with Shot put results were medium low, or low, even non-significant (Table 2), turn of T12 vertebra around y axe was not significant with Shot put result, however when calculating partial correlation it was middle high and significant. Angle change of left ankle to x axe is positively related to results, while angular velocity of upper left leg and T12 vertebra around y axe were negative correlated. Final stepwise regression was significant up to the third step, when stopped with multiple correlation of .689 and 47.4% of explained variance of Shot put result (Table 3).

Table 1. Descriptive statistics

Variable	XA	SD
Shot put result (m)	17.58	0.36
0.1 second before release		
Ax_joint Left Ankle (rad)	42.93	10.68
ωy_Left upp_leg (s^{-1})	9.47	1.09
ωy_T12 (s^{-1})	13.31	2.06
Moment of release		
Ax_joint Left Ankle (rad)	46.48	11.89
ωy_Left upp_leg (s^{-1})	8.75	2.12
ωy_T12 (s^{-1})	12.24	1.77
Difference		
Ax_joint Left Ankle (rad)	3.54	8.69
ωy_Left upp_leg (s^{-1})	-0.72	1.73
ωy_T12 (s^{-1})	-1.07	0.97

Legend: A-angle, x,y – axe, ω – angular velocity, upp-upper, T12-thoracal vertebra 12

Table 2. Pearson correlations coefficients between variables values in time of release – 0.1 second before release

Variable	Ax_joint Left Ankle (rad)	ωy_Left upp_leg (s^{-1})	ωy_T12 (s^{-1})
Shot put result (m)	.306*	-.422*	-.277
Ax_joint Left Ankle (rad)		-.019	.105
ωy_Left upp_leg (s^{-1})			-.297*

Legend: A-angle, x,y – axe, ω – angular velocity, upp-upper, T12-thoracal vertebra 12, *p<0.05

Table 3. Regression analysis results dependant variable Shot put result

Step	R	R Square	Change Statistics				
			R Square Change	F Change	df1	df2	Sig. F Change
1	.422	.178	.178	7.359	1	34	.010
2	.597	.356	.178	9.117	1	33	.005
3	.689	.474	.119	7.217	1	32	.011

Table 4. Stepwise regression between shot put results and kinematic variables

Step		Beta	t	Sig.	Zero-order	Partial
1	ωy_Left upp_leg (s^{-1})	-.422	-2.713	.010	-.422	-.422
2	ωy_Left upp_leg (s^{-1})	-.553	-3.780	.001	-.422	-.550
	ωy_T12 (s^{-1})	-.442	-3.019	.005	-.277	-.465
3	ωy_Left upp_leg (s^{-1})	-.558	-4.156	.000	-.422	-.592
	ωy_T12 (s^{-1})	-.480	-3.554	.001	-.277	-.532
	Ax_joint LeftAnkle	.346	2.686	.011	.306	.429

Legend: A-angle, x,y – axe, ω – angular velocity, upp-upper, T12-thoracal vertebra 12

Discussion

With modern research equipment (Xsens inertial suit) it was possible to get insight into the human variance during performing same task. Previous researches were mostly focused on the throwing hand body side. According to previous research during rotational technique it is important to maximise velocity vector, optimise angle of velocity vector with z axe and to maximise height of shot release. To reach these three factors there are many possibilities.

Authors (Bartonietz, 1994b; Luhtanen, 1997; Lanka, 2000) agreed, that the highest acceleration arms and shoulder during extension is determining 85-90 % of final shot distance, our results where 47.4% of result is determined with other factors, or this factors supress arms and shoulder extension importance are not in opposite direction. It is important to understand mechanics of throw. Our results show what is important to do to give arms and shoulders of the throwing hand possibility to act with maximum performance. Our slightly different approach, where we did not enter into our analysis just positions, but changes in kinematical values in last 0.1 s before release revealed us a new important dimension, which was not proved or public before. Novelty of our research results is that non-throwing hand side must be a solid rock on which is mounted one side open ended kinetic chain. To make such solid rock it is important at first to overtake with left ankle (by results, but feet is the body part which is in contact with ground) in last 0.1 second prior the shot release and to prepare solid support base for rest of the non-throwing body side, which have to stop with rotation around y axis as soon as possible. Stopping of non-throwing body side allows athletes to change position of relative y axe from the centre of body to non- throwing hand side and therefore allows to throwing hand side to continue with gained inertia, while with changed y axis, also tangential velocity of hand and shot rises.

Despite our athlete did not stop completely, but just deaccelerate significantly his non-throwing arm body side, he was able to take advantage in improving results. We can just imagine what could happen if athlete would be able to stop non-throwing arm completely. Such results are also related with physical conditioning of shot putters. Lou (2014) found their national shot put champion have severe lack of strength on the right side, however Lou did not determine reasons for such one sided physical condition neither named throwing arm, but asymmetry exist.

Authors (Judge and Bellar, 2012) found out athletes who are using rotational technique have lower results on strength tests comparing to those using glide technique, however authors at the end suggest test bench press strength is more important for glide technique, according to their results we could concluded rotational technique requires completely different approach in physical conditioning, where non dominant side will have to be in near future better adopted to such mechanics, but not only the muscle strength will be important, but also legs flexibility in sense of inward and outward rotation.

Conclusions

In track and field shot put is a discipline where two main techniques: glide and rotational are present. Rotational technique is much more complex and up to now most of research were proving throwing hand arm, and side are dominant in final shot put results. Our research showed opposite throwing arm side prepares

conditions that throwing arm can serve as an open ended kinetic chain, while non-throwing side is a base (rock) support that all the potential of throwing side can be utilized. From new point of view, coaches can utilize new conditioning programs and be more focus not only on throwing hand side, but also on non-throwing side.

Acknowledgement

Authors acknowledge the support from the Slovenian Research Agency (research core funding No. P5-0147 In Slovenian: Kineziologija monostrukturnih, polistrukturnih in konvencionalnih športov = Kinesiology of monostructural, polistruktural and conventional sports).

References

Bartlett, R. (2000). Principledsof throwing. In; *Biomechanics in Sport* (Ed. Zatsiorsky, VM), Blackwell Science Ltd, 365–380.

Bartonietz, K. E. (1994a). The energy relationship in rotational and glide shot put. *Modern Athlete and Coach*, 32(2), 7–10.

Bartonietz, K. E. (1994b). Rotational shot put techique: biomechanical findings and recommendations for training. *Track & Field Quarterly Review*, 93(3), 18–29.

Błażkiewicz, M., Łysoń, B., Chmielewski, A., & Wit, A. (2016). Transfer of mechanical energy during the shot put. *J Hum Kinet*, 52, 139–146. http://doi.org/10.1515/hukin-2016-0001

Brennan. A-, Zhang. J., Deluzio, K., & Li, Q. (2011). Quantification of inertial sensor-based 3D joint angle measurement accuracy using an instrumented gimbal. *Gait Posture*, 34(3), 320–323. doi: 10.1016/j.gaitpost.2011.05.018. Epub 2011 Jun 29.

Čoh, M., Štuhec, S., Smajlović, N., & Supej, M. (2008). Comparative 3-D analysis of the rotational shot-put technique. *Biomechanical Diagnostic Methods in Athletic Training*, 27–34.

Čoh, M., & Štuhec, S. (2008a). 3-D kinematic model of rotation shot-put technique. V: ČOH, Milan (Ed.). *Biomechanical diagnostic methods in athletic training*. Ljubljana: Faculty of Sport, Institute of Kinesiology, 15–25.

Čoh, M., & Štuhec, S. (2008b). 3-D kinematic analysis of the rotational shot put technique. *New Studies in Athletics*, 20(3), 57–66.

Della Croce, U., Leardini, A., Chiari, L., & Cappozzo, A. (2005). Human movement analysis using stereophotogrammetry. Part 4: assessment of anatomical landmark misplacement and its effects on joint kinematics. *Gait Posture*, 21(2), 226–237. DOI: 10.1016/j.gaitpost.2004.05.003

Harasin, D. (2007). Vrednovanje kinematičkih parametara rotacijske tehnike bacanja kugle [In Croatian: Evaluation of kinematic parameters rotation technique shot put]. (Doctoral thesis), Faculty of Kinesiology University of Zagreb.

Judge, L. W., & Bellar, D. (2012). Variables associated with the of personal best performance in the glide and spin shot put for U.S. collegiate thrower. *International Journal of Performance Analysis in Sport*, 12(1), 37–51.

Krüger, A., & Edelmann-Nusser, J. (2010). Application of a full body inertial measurement system in alpine skiing: a comparison with an optical video based system. *J Appl Biomech*, 26(4), 516–521. https://doi.org/10.1123/jab.26.4.516

Lanka, J. (2000). Shot puting In Biomechanics in sport (Ed. Zatsiorsky VM), 435–457 Internacional Olympic Commitee.

Linthorne, N. P. (2001). Optimum release angle in the shot put. *J Sports Sci*, 19(5), 359-372. DOI: 10.1080/02640410152006135

Lou, Y. T. (2014). Distribution of joint isokinetic muscle strength in shot putters. *Chinese Journal of Tissue Engineering Research,* 18(29), 4647–4652. DOI: 10.3969/j.issn.2095-4344.2014.29.010

Luhtanen, P., Blomqvist, M., & Vanttinen, T. (1997). A comparasion of two elite shot putters using the rotational shot put technique. *New Studies in Athletics*, 12(4), 25–33.

Supej, M. (2010). 3D measurements of alpine skiing with an inertial sensor motion capture suit and GNSS RTK system. *J Sports Sci*, 28(7), 759–769. DOI: 10.1080/02640411003716934

Xsens. MVN Biomech system Xsens Technologies B.V. Enschede, The Netherlands. Available online: http://www.xsens.com (accessed on 20 June 2016).

Young, M. A. (2003). Critical Factors in The Shot Put. *Track coach*, 5299–5305.

Zatsiorsky, V. M., (2000). Biomechanics in sport. International Olympic Commitee.

Zhang, J. T., Novak, A. C, Brouwer, B., & Li, Q. (2013). Concurrent validation of Xsens MVN measurement of lower limb joint angular kinematics. *Physiol Meas*, 34(8), 63–69. DOI: 10.1088/0967-3334/34/8/N63