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Original research article

TECHNIQUE ASSESSMENT OF THE JAVELIN RELEASE PERFORMED BY YOUNG SERBIAN ATHLETES

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Abstract. *The purpose of the present study was to indicate the biomechanical parameters of the delivery phase associated with performance in young javelin throwers. Seven right-handed young Serbian club level javelin throwers (19.0±1.0 yrs; 1.84±0.08 m; 81.0±5.2 kg) were recorded at 100 fps sampling frequency during competition. Spatial parameters (delivery stride length, distance to foul line, javelin grip height) and body configuration (joint angles, inclination of body segments) were extracted with a 2D-DLT kinematical analysis method. Model Technique Analysis Charts were used for the qualitative assessment of the throwing technique of the examined athletes. The relationship between the extracted biomechanical parameters and the official throwing distance was examined with a correlation analysis. The results revealed that the official throwing distance (46.43±4.89 m) significantly (p<.05) correlates (r>.78) with release velocity (16.0±1.4 m/s), release angle (36.4±1.4 deg), javelin grip height (1.21±0.07 m) and the braking leg knee angle at its final touchdown (153.0±11.4 deg). The most common technique errors observed during the delivery phase were the flexed elbow of the throwing arm, the large knee flexion of the braking leg and the lack of the braking leg's knee extension at the instant of release. The quantitative assessment revealed less favorable values in key biomechanical parameters compared to the results of other studies investigating elite young athletes. It is suggested that young javelin throwers' training should focus on performing the release of the javelin with a proximal to distal joint sequencing that optimizes the transfer of the kinetic energy along the body.*

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Key words: *overhead throwing, javelin carry position, track & field, biomechanical analysis, proximal to distal sequencing*

INTRODUCTION

Injuries occurring to javelin throwers are believed to be the result of bad throwing biomechanics (Bartonietz, 2000). Because of the above mentioned, proper throwing technique is commonly believed to be important for javelin throwers due to the large amount of loading on the joints of the throwing arm (Beitzel et al., 2014; Mohamed, Mohamed, Attia, & Awad, 2010). Nevertheless, even elite athletes fail to fulfill the criteria of an effective technique because of the complexity of the throwing movement (Maximov, 1979), thus it is not surprising that the majority of technique errors noted in young adult javelin throwers are observed during the delivery phase (Bakhit & Mohamed, 2010).

A search of the literature indicated that a limited number of biomechanical studies investigated young javelin throwers. A common finding of these studies is that the values of the release parameters are inferior compared to elite throwers (Aleksić-Veljković et al., 2012; Campos Granell, Brizuela, & Ramón, 2008; Saratlija, Zagorac, & Babić, 2013; Tsarouchas & Giavroglou, 1986; Zaharovska, 2007). Additionally, the javelin release angles were found to be strongly correlated with the positioning of the body segments at crucial time instances of the release phase in young throwers (Tazuke, 2009). However, young javelin throwers were found to have a notable differentiation concerning the angles of attack and yawn (Campos Granell et al., 2008) and the extension of the elbow joint of the throwing arm (Zaharovska, 2007), despite the existence of a similar pattern of energy transfer from segment to segment compared to adult athletes (Tsarouchas & Giavroglou, 1986). Additionally, female Serbian throwers were found to have inferior key javelin release parameters compared to elite athletes and further technique improvements in the pre-delivery and delivery phases were proposed (Aleksić-Veljković et al., 2012). Based on the above mentioned, it is evident that further research is required related to the biomechanical parameters interpreting the javelin release in young Serbian athletes.

The primary purpose of the present study was to quantify the spatio-temporal and kinematical parameters of the delivery phase and the release parameters of the javelin throw executed by young Serbian athletes during athletics competitions. The secondary aim of the study was to examine the progression of key biomechanical throwing parameters at distinct time instances of the final throwing action. Finally, the purpose was to investigate the correlation of the examined parameters with the official throwing distance of young adult javelin throwers. The correlation analysis could indicate the essential technique elements of javelin throwing in young athletes and thus to highlight where greater emphasis concerning specific drills should be given during the athletes' preparation.

METHOD

Participants

Seven (*n*=7) young club level Serbian javelin throwers (age: 19.0 years ± 1.0, body height: 1.84 m ± 0.08, body mass: 81.0 kg ± 5.2) were examined during competition at the Test Event of the 3rd European Team Championships - 2nd League (Novi Sad, Serbia, June 17, 2011). All of the participants were right-handed competitive athletes, with no apparent or reported injury or disability. The investigation was conducted in accordance with the Institutional Research Committee's Guidelines for the use of human subjects.

Data acquisition and analysis

All trials during the competition were recorded with two stationary digital video cameras (JVC GR-DVL 9600 EG, Victor Co., Japan), operating with a sampling frequency of 100 fps. The first camera was positioned on a 1.2 m high fixed tripod, which was placed 22 m from the middle of the javelin throw runway. The recorded view was 9.7 × 3 m and included the landing after the impulse stride, the delivery phase, the release of the javelin and the follow through. The recorded area was calibrated using a 2.6 m × 2.0 m frame with 12 reference markers. These markers were used in order to produce two-dimensional coordinates with the use of a 2D-DLT analysis method (Kollias, 1997). The X-axis was parallel to the javelin throw runway and Y-axis was perpendicular to the X-axis. The second camera was placed on the stands at the beginning of the javelin throw runway and assisted the technical evaluation of the lateral movements of the participants and the javelin. Although the majority of the biomechanical studies have 3D kinematical analysis methods for the calculation of the release parameters, two-dimensional methods have found to be adequate for evaluating basic javelin release and flight parameters (Best, Bartlett, & Sawyer, 1995; Hubbard & Alaways, 1989; Viitasalo, Mononen, & Norvapalo, 2003).

From all the recorded videos, only the best attempt regarding to throwing distance was selected for further analysis using the A.P.A.S.-XP software (Ariel Dynamics Inc., Trabuco Canyon, CA). Eighteen anatomical points of the body (tip of the toe, ankle, knee, hip, shoulder, elbow, wrist and fingers on both sides of the body, the neck and the top of the head), both ends of the javelin and selected points in the recorded area were manually digitized in each field. The coordinates of the body center of mass (BCM) were calculated for every field according to the segmentational data proposed by Plagenhoef (1985). A 6 Hz cut-off frequency, based on residual analysis, was selected for smoothing. The accuracy of the 2D reconstruction was determined by Root Mean Square error, after randomly re-digitizing 5% of the captured frames. An error of 2.1 cm and 1.1 cm was found for the X- and Y-axis, respectively. The coordinates of the digitized points were used for the calculation of the kinematical parameters presented in this study. The parameters were defined as proposed by Bartonietz (2000). Spatial parameters [i.e. delivery stride length, SL_D (in m); distance to foul line, S_{FL} (in m); BCM height, H_{BCM}; javelin's grip height, H_{JAV} (in m), javelin's grip height, H_{JAV} (in %bh[a]), Javelin carry position, D_{JCP} (in m); javelin acceleration path, S_{JAV} (in m)] and body configuration [(left knee angle, θ_{Lk} (in deg); right knee angle, θ_{Rk} (in deg); left leg inclination, θ_{LL} (in deg); right elbow angle, θ_{Re} (in deg)] were calculated using the extracted coordinates of the digitized points. BCM (V_{BCM} in m/s), javelin (V_{JAV} in m/s) and joint linear velocity were calculated as the first-time derivative of their displacement.

The same procedure was applied for extracting the release parameters (velocity, V_0 (in m/s); height, H_0 (in m); height of release, H_0, (in %bh[a]); release angle, θ_0 (in deg); angle of position, θ_α (in deg); angle of attack, θ_β (in deg); release pitch rate, q_0 (in deg/s). The kinematical parameters were examined with respect to three selected time-instants of the delivery phase: the last right foot touchdown (T1), the last left foot touchdown (T2) and the javelin release (T3).

Finally, a combination of the Model Technique Analysis Charts proposed by McGill (1982) and Tidow (1996) were used for the qualitative assessment of the technique of the examined athletes. The adopted Analysis Charts were filled after viewing, field by field, with each recorded attempt of the participants from both video-cameras.

Statistical analysis

The data are presented by means of descriptive statistics (mean value, ± standard deviation; SD). The Kolmogorov-Smirnov test was run for testing the normality of distribution for each parameter. A two-tailed Pearson correlation analysis was used to investigate the possible correlations between the examined parameters and the official throwing distance. The progression of the examined parameters was studied with a one-way repeated measures ANOVA. Significant differences were followed up with pairwise comparisons using Bonferroni adjustment for multiple comparisons. The level of statistical significance was set at a = 0.05 for all analyses. All statistical procedures were conducted using the SPSS 10.0.1 software (SPSS Inc., Chicago, Il).

RESULTS

The participants threw the javelin in an average official distance (S_{OFF} in m) of 46.43±4.89 m. The most frequent observed technical errors were the flexed elbow of the throwing arm at the beginning of the throwing sequence, large knee flexion of the braking leg at its touchdown, the large angle of attitude, the loss of contact with the ground of the support leg prior the release and the lack of extending the braking leg's knee during the release.

The values of the kinematical parameters recorded at T1, T2 and T3 are presented in Table 1. The delivery phase (T1→T3 in s) had duration of 0.393±0.028 s, in which the single support phase (T1→T2 in s) was 0.246±0.036 s and the double support phase (T2→T3 in s) was 0.147±0.026 s. At T1, the axis of the javelin formed a 34.3±7.8 deg angle with the ground. Additionally, V_{BCM} was 5.2±0.7 m/s. The grip of the javelin was in an average horizontal distance of 0.92±0.11 m (equal to approximately 50.0% body height) behind the right hip joint and 0.10±0.06 m (= 5.4% body height) below the throwing shoulder. H_{JAV} at this instant was found to be positively correlated with S_{OFF} ($r = .83$, $p < .05$). Other significantly strong correlations ($r > .80$, $p < .05$) with S_{OFF} were revealed for H_{BCM}, V_{BCM}, D_{JCP} and V_{JAV}.

At T2, H_{BCM} was lowered by 0.16±0.05 m (= 8.7% of body height) compared to T1. SL_D was 1.37±0.18 m (= 74.6±9.5 % of body height). At the same time instance, V_{JAV} increased in 4 out of the 7 examined throwers. S_{OFF} significantly correlated with the extension of the braking leg's knee joint ($r = .83$, $p < .05$), V_{BCM} ($r = .89$, $p < .01$) and S_{FL} (1.52±0.73 m; $r = .80$, $p < .05$).

Table 1 Descriptive statistics (mean ± SD; *n* = 7) of the two-dimensional kinematical parameters at the last right foot touchdown (T1), the last left foot touchdown (T2) and the javelin release (T3)

Parameter	T1			T2			T3		
Body Center of Mass height (H_{BCM}, in m)	0.82	±	0.04	0.67	±	$0.06^{\#}$	0.76	±	$0.11^{\#\dagger}$
Body Center of Mass height (H_{BCM}, in %bh[a])	44.7	±	2.8	36.3	±	$3.5^{\#}$	41.5	±	$5.9^{\dagger}$
Body Center of Mass velocity (V_{BCM}, in m/s)	5.2	±	0.7	5.1	±	0.6	2.2	±	$0.4^{\#\dagger}$
Height of javelin's grip (H_{JAV}, in m)	1.21	±	0.07	1.09	±	$0.09^{\#}$	1.87	±	$0.16^{\#\dagger}$
Height of javelin's grip (H_{JAV}, in %bh[a])	66.1	±	4.2	59.5	±	$4.3^{\#}$	102.1	±	$8.8^{\#\dagger}$
Javelin carry position (D_{JCP}, in m)	-0.10	±	0.06	-0.07	±	0.03	0.30	±	$0.05^{\#\dagger}$
Left knee angle (θ_{Lk}, in deg)	160.0	±	9.8	153.0	±	11.4	141.5	±	16.8
Left leg inclination (θ_{LL},in deg)	51.3	±	6.7	53.4	±	7.0	69.7	±	$8.8^{\#\dagger}$
Right elbow angle (θ_{Re}, in deg)	140.6	±	13.6	142.1	±	11.9	138.6	±	16.9
Right knee angle (θ_{Rk}, in deg)	163.9	±	7.2	137.4	±	$12.3^{\#}$	106.9	±	$19.2^{\#\dagger}$

Note: [a]: %bh = value expressed as percentage of body height;
[#]: p<.05 compared to T1; [†]: p<.05 compared to T2

Table 2 Descriptive statistics of the release parameters of the analyzed javelin throwers and the respective correlation coefficient (*r*) with the official throwing distance (*n* = 7)

Parameter	Mean	SD	*r*	*p*
Release velocity (V_0, in m/s)	16.0	1.4	.91	.005*
Height of release (H_0, in m)	2.08	0.1	.21	.654
Height of release (H_0, in %bh[a])	113.1	4.0	.09	.845
Release angle (θ_0, in deg)	36.4	5.3	-.94	.002*
Angle of position (θ_α, in deg)	40.2	8.1	-.70	.078
Angle of attack (θ_β, in deg)	2.1	6.6	-.21	.645
Release pitch rate (q_0, in deg/s)	-3.6	7.6	-.47	.284

Notes: [a]: %bh = value expressed as percentage of body height; *: p < .05

Finally, at T3, V_{BCM} was decreased to 2.2±0.4 m/s, thus being 58.2± 4.3% slower than T1 ($F_{2,12} = 388.615$, $p < .001$, $\eta^2 = .985$). S_{JAV} was 1.50±0.10 m. The only spatio-temporal and kinematical parameter significantly correlated with S_{OFF} at T3 was V_{BCM} (r = .90, p < .01). Table 2 presents the release parameters in detail. S_{OFF} strongly correlated (r = .91, p < .01) with V_0. Additionally, results revealed a strong negative correlation (r = -.94, p < .01) of S_{OFF} with θ_0.

The repeated measures ANOVA method determined that H_{JAV} and H_{BCM} were significantly lower at T2 compared to T1 and T3 ($F_{2,12}$ = 156.260, p < .001, η^2 = .963 and $F_{2,12}$ = 8.586, p = .005, η^2 = .589, respectively). Additionally, θ_{Rk} was significantly flexing as the throwing action was evolving ($F_{2,12}$ = 39.228, p < .001, η^2 = .867). Finally, no significant differences were revealed concerning θ_{Re} ($F_{2,12}$ = .100, p = .906, η^2 = .016).

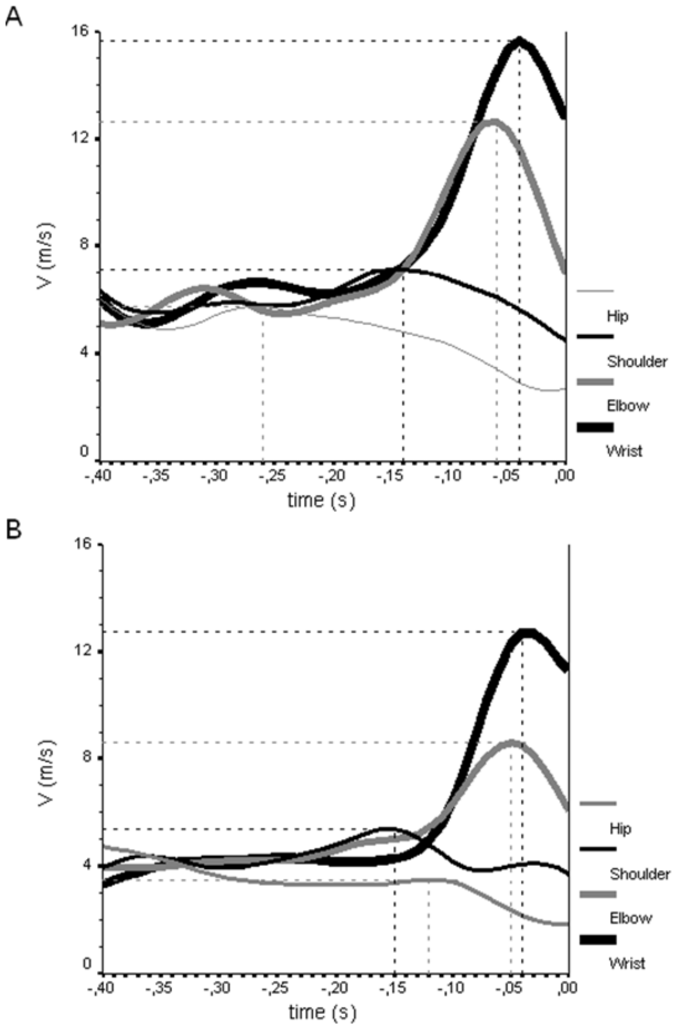

Fig. 1 Examples of a correct proximal-to-distal (A) and an incorrect mixed sequencing (B) of the body segments. Time instant .00 represents the instant of the release of the javelin. The vertical dashed lines indicate the timing of achieving maximum velocity for each joint, while the horizontal dashed lines mark the peak maximum velocity for each joint.

As for the sequencing of the body segments, proper proximal to distal (Figure 1A) and interrupted (Figure 1B) sequencing patterns were observed. The proper sequencing is evident in Figure 1A, where every distal joint marks a larger peak speed than proximal and after a reasonable time period. On the contrary, Figure 1B presents the non-optimal sequencing, since the hip joint reaches its peak speed after the peak speed of the shoulder joint. The lack of timing is also observed in Figure 1B, since the time period among peak speeds from joint to joint is not progressively decreased as in the example of Figure 1A.

DISCUSSION

The results indicated that performance of young intermediate level javelin throwers was associated with the high javelin carry position at the last support leg touchdown, the limited knee joint flexion of the braking leg at its final touchdown and the maintenance of the acquired velocity throughout the delivery phase. On the contrary, the large knee flexion of the braking leg at its touchdown and the lack of extending the braking leg knee during the release were the mentionable deviations observed with respect to the widely accepted throwing technique. It was noted that 52.4% of the throws performed by the examined athletes were foul, a percentage almost double than in javelin competitions at World Junior Championships (Scholz, 2006). S_{OFF} and V_0 were lower than reported previously for young javelin throwers (Campos Granell et al., 2008; Saratlija et al., 2013; Tsarouchas & Giavroglou, 1986). Nevertheless, the correlation coefficient between V_0 and S_{OFF} ($r = .91$) was within the range of those reported in previous studies (Bartonietz, 2000; Mero, Komi, Korjus, Navarro, & Gregor, 1994; Panoutsakopoulos & Kollias, 2013; Viitasalo et al., 2003). Although θ_α observed in the present study was similar to previous findings (Tsarouchas & Giavroglou, 1986), θ_0 was in average larger than reported for high level throwers (Viitasalo et al., 2003). Higher θ_0 compared to elite athletes were also noted in other reports (Campos Granell et al., 2008; Saratlija et al., 2013; Tsarouchas & Giavroglou, 1986). The average θ_β was 2.1° (range: -13.2 deg to 6.2 deg), being close to the proposed zero value (Bartlett, Müller, Lindinger, Brunner, & Morriss, 1996; Bartonietz, 2000).

H_{JAV} at T1 was found to be strongly correlated with S_{OFF}. It is generally suggested that the adoption of a higher D_{JCP} at the start of the delivery phase benefits the throw by affecting θ_β in a favorable way concerning the aerodynamical drag forces acting on the javelin during its flight (Morriss & Bartlett, 1996). Additionally, two other important factors dominate the javelin throwing action: the throwing arm action and the braking action of the front leg. At the beginning of the delivery phase, the throwing arm must be parallel to the ground and with no flexion at its joints, in order to put the javelin in a favorable position to achieve the bow tension of the athlete+javelin system (Tidow, 1996). However, it has being suggested that a flexed elbow at the beginning of the delivery phase is not always a mistake, but it might be beneficial for the throw by stimulating a stretch-shortening cycle function in the elbow extensor muscles, thus improving performance (Morriss & Bartlett, 1996). Nevertheless, this was not implemented by the examined throwers, since the throwing arm was kept constantly flexed at the elbow joint throughout the throwing phase. Additionally, a considerable minority of the examined athletes performed the throw without the commonly observed proper proximal-to-distal segmental sequencing (Liu, Leigh, & Yu, 2014). The second important element is the braking action, mainly done by the lead (left for right-handed throwers) leg. The extension of the braking leg knee angle during the delivery phase contributes to a higher H_0 and to a longer S_{JAV} by effecting on the vertical component of the javelin which eventually results to larger V_0 and θ_0 (Tidow, 1996). The results revealed that, besides the flexed left knee, the braking leg was rather inclined at the release, confirming previous reports for young throwers (Zaharovska, 2007). It is suggested that it is common for young athletes to have their braking leg's knee flexed during the delivery phase because of their limited capabilities for producing muscular strength (Maximov, 1979).

The limited number of participants and the two-dimensional nature of the analysis set limitations for the generalization of the outcome of the study and for the comprehension of the throwing action in the three-dimensional space. Nevertheless, the sample of the young Serbian intermediate club level javelin throwers executed the throw using a large in duration delivery phase and a poor braking action, which resulted in less effective values concerning the release parameters compared to high level adult throwers. The acquisition and the profound execution of the javelin technique are essential in order to optimize the throwing distance with the exploitation of the speed and power abilities of the athletes (Frane, Borović, & Foretić, 2011).

CONCLUSION

The present study confirms the importance of release velocity on javelin performance, thus adding information to the limited knowledge reported in the literature. It is suggested that young javelin throwers' training should at least focus on performing the release of the javelin with a better leg braking action and a definitive proximal-to-distal segmental sequencing of the throwing side. Further research is required concerning the impact of these technique elements on the release parameters of the javelin and their improvement through training. Under this perspective, emphasis should be given to improve the performance of the motor abilities related to the javelin throwing distance, along with drills for constantly improving body positioning and orientation through a goal oriented selection of specific exercises.

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PROCENA TEHNIKE U MOMENTU IZBAČAJA KOPLJA MLADIH SRPSKIH ATLETIČARA

Cilj ovog istraživanja je bio da se ukaže na biomehaničke parametre faze izbačaja sprave i njihova povezanost sa sportskim nastupom kod mladih bacača koplja. Praćeno je i zabeleženo (frekvencija uzorkovanja: 100 fps) sedam desnorukih mladih srpskih bacača koplja (19.0 ± 1.0 god; 1,84 ± 0,08 m; 81.0 ± 5.2 kg) u toku takmičenja. Prostorni parametri (dužina koraka pri izbačaju, udaljenost do prestupne linije, visina hvata koplja) i konfiguracija tela (uglovi u zglobovima, nagibi segmenata tela) analizirani su putem 2D-DLT kinematičke metode. Grafikoni analize modela tehnika su korišćeni za kvalitativnu procenu tehnike bacanja ispitivanih sportista. Odnos između izdvojenih biomehaničkih parametara i zvanično izmerene udaljenosti bacanja je ispitan korelacionom analizom. Rezultati pokazuju da je utvrđena dužina bacanja koplja (46.43 ± 4.89 m) statistički značajno ($p < .05$) u korelaciji ($r > .78$) sa brzinom (16.0 ± 1.4 m / s), uglom izbačaja koplja (36.4 ± 1.4 stepeni), visinom hvata (1.21 ± 0.07 m) i uglom kolena odrazne noge u kontaktu sa podlogom pri izbačaju koplja (153.0 ± 11.4 deg). Najčešće tehničke greške uočene tokom faze izbačaja sprave bile su: fleksija u zglobu lakta izbačajne ruke, prevelika fleksija u zglobu kolena odrazne noge, kao i nedostatak ekstenzije odrazne noge u momentu izbačaja koplja. Kvantitativnom procenom rezultata utvrđene su manje povoljne vrednosti u ključnim biomehaničkim parametrima u odnosu na rezultate drugih, sličnih studija. Predloženo je da se u obuci i treningu mladih bacača koplja naglasi sam izbačaj koplja u pravcu proksimalnog ka distalnom sekvenciranju zglobova, odnosno, u pravcu koji najviše optimizuje prenos kinetičke energije kroz telo.

Ključne reči: *bacanja iznad glave, položaj za nošenje koplja, Atletika, Biomehanički analiza, proksimalno-distalni redosled*