Journal of Human Sport and Exercise
E-ISSN: 1988-5202
jhse@ua.es
Universidad de Alicante
España

PANOUTSAKOPOULOS, VASSILIOS; KOLLIAS, IRAKLIS A.
Temporal analysis of elite men's discus throwing technique
Journal of Human Sport and Exercise, vol. 7, núm. 4, 2012, pp. 826-836
Universidad de Alicante
Alicante, España

Original Article

Temporal analysis of elite men's discus throwing technique

VASSILIOS PANOUTSAKOPOULOS , IRAKLIS A. KOLLIAS

Biomechanics Laboratory, Department of Physical Education & Sport Science, Aristotle University of Thessaloniki, Thessaloniki, Greece

ABSTRACT

Panoutsakopoulos V, Kollias IA. Temporal analysis of elite men's discus throwing technique. *J. Hum. Sport Exerc.* Vol. 7, No. 4, pp. 826-836, 2012. The purpose of this study was to investigate the relationship between the duration of the throw and the official throwing distance in a group of elite male discus throwers. The time analysis of the technique phases (i.e. preparation, entry, flight, transition, delivery, release) of the participants in a top international athletics competition was used in order to conduct the study. Data were retrieved after recording seven right-handed throwers (age: 28.8 ± 4.1 years, body height: 1.94 ± 0.09 m, body mass: 119.4 ± 11.6 kg) with a Casio EX-FX1 (Casio Computer Co. Ltd) digital video camera (sampling frequency: 300fps) and analyzing the captured throws with the V1 Home 2.02.54 software (Interactive Frontiers Inc.). The relationships among the duration of the technique phases of the throw and the official throwing distance were examined with Pearson Correlation Analysis using the SPSS 10.0.1 software (SPSS Inc.). Results revealed that no significant correlation ($p > 0.05$) existed among the average official throwing distance (63.04 ± 6.09 m) and the duration of the discus throw or the duration of each technique phase. The temporal and correlation analyses were in agreement with previous studies. The dominant style of release was the release with no support on the ground. The majority of the throwers spent a larger percentage of the delivery turn (transition, delivery and release phases) being in single than in double support. It was noted that a short duration of the transition phase, combined with lower values of the ratio of the time spent for the starting turn compared to the time spent for the delivery turn might be favorable regarding the achievement of a larger throwing distance. **Key words**: TRACK AND FIELD THROWS, OFFICIAL THROWING DISTANCE, SINGLE SUPPORT PHASE, DOUBLE SUPPORT PHASE, BIOMECHANICS.

Corresponding author. Biomechanics Laboratory, Department of Physical Education and Sport Science, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece.
E-mail: bpanouts@sch.gr
Submitted for publication November 2012
Accepted for publication December 2012
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202

doi:10.4100/jhse.2012.74.10

INTRODUCTION

The technique of the discus throwing consists of the preliminary swings, the preparation, the entry, the airborne, the transition, the delivery and the recovery (Bartlett, 1992). Under the perspective of leg support, the discus technique is structured as the double and single support starting phases, the supportless phase, and the single and double support delivery phases (Tidow, 1994).

Despite the fact that release velocity, height and angle are commonly presented as the most important biomechanical parameters at studies conducted in major track and field competitions (Ariel et al., 1997; Bandura, 2010; Bartonietz et al., 1996; Gregor et al., 1985; Knicker, 1992; Knicker, 1994a; Knicker, 1999; Miyanishi et al., 1998; Panoutsakopoulos, 2008; Stepanek & Susanka, 1987; Susanka et al., 1988; Terauds, 1978; Vodickova, 2008), scientific reports include the temporal analysis (i.e. the duration) of the above mentioned phases as useful information concerning the technique of the discus throw. The temporal analysis serves as a criterion for the comparison of the technique and its efficiency among competitors, since the time-relations of the different technique phases could interpret the interaction of the spatio-temporal parameters of the athlete+discus system with the work done to impel the thrower and the implement (Bartonietz et al., 1996). Additionally, selected temporal parameters were found to be correlated with the throwing distance (Ward, 1969, as cited in Ward and Ward, 1976b)

An intra-thrower consistency for the phase durations is notable, mainly for the overall timing from the start of the turn to the release (Bartlett, 1992). However, the modifications in throwing ability among different athletes result in a significant inter-thrower variability for the outcome of the temporal analysis of the discus throw (Bartlett, 1992), preventing scientists and practitioners to finger-point the optimum temporal distribution of the sequence of the throwing movement (Knicker, 1994b). Nevertheless, it has been suggested that deviations from the ideal individualized temporal pattern ("rhythm") results in poorer performance (Knicker, 1990). This could be interpreted under the general notion of the existence of a negative correlation between technique variability and performance, especially in male athletes (Dai et al., 2012). Based on the above, the inclusion of the investigation of the relationship between the duration of the throw and the official throwing distance is an interesting aspect in research concerning the analysis of discus throwing (Bartlett, 1992; Floria Martin, 2006; Knicker, 1994b; Leigh et al., 2008).

The purpose of the present research was to present the temporal analysis of elite discus throwers and to investigate the correlation between the duration of the throw and the official throwing distance. Technique phase durations will be examined under the perspective of identifying differences concerning the movement patterns for the execution of the throw. Results will add information to the existing knowledge about the temporal patterns of discus throwing and their effect to performance.

MATERIAL AND METHODS

Participants

The eight participants (age: 28.8 ± 4.1 years, body height: 1.94 ± 0.09 m, body mass: 119.4 ± 11.6 kg) of the men's discus throw event included in the last edition of the I.A.A.F. World Athletics Final (Thessaloniki, Greece; 12.09.2009) were studied. All participants were right handed. The selection of the competition was based on the fact that the top ranked athletes of the entire competitive season were permitted to participate.

Measures

The duration of each phase was extracted by replaying frame by frame the recorded attempts of the participants. In detail, the examined technique phases were defined as follows (Figure 1):

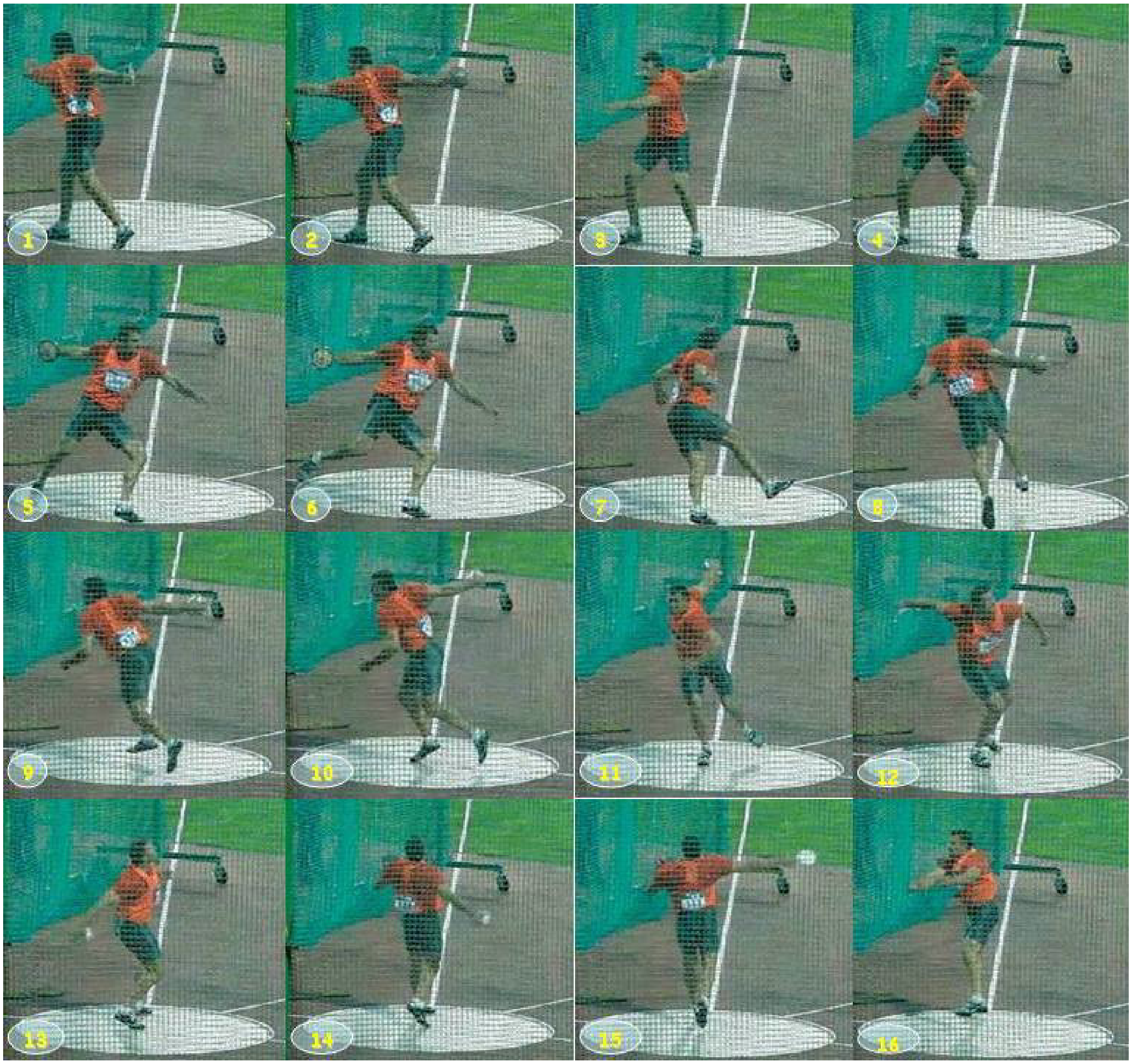

Figure 1. *Photosequence of the discus throwing technique exhibited by Virgilijus Alekna (LTU), winner with 67.63m at his 2nd attempt (Frame 1: Maximum Backswing - Preliminary Swing; 2-4: Preparation; 5-7: Entry; 8-9: Flight; 10-11: Transition; 12-13: Delivery; 14-15: Release; 16: Recovery).*

- Preparation (P): from the maximum backswing of the final preliminary swing until the take-off of the right leg (R1↑)-double support starting phase.
- Entry (E): from R1↑to the take-off the left leg (L1↑)-single support starting phase.
- Flight (F): from L1↑ to the touch-down of the right leg (R↓) in the middle of the circle-airborne or supportless phase.

- Transition (T): from R🡇 until the touch-down of the left leg (L🡇) at the far end of the circle-single support delivery phase.
- Delivery (D): from L🡇 until braking contact with the discus or until the right (R2🡅) or left leg (L2🡅) lost contact with the ground before the throw of the discus-double support delivery phase.
- Release (R): From either R2🡅 or L2🡅 until the release of the discus.

The preparation and entry phases consisted the starting turn. The delivery turn consisted of the transition, the delivery and the release phase.

Instrumentation and procedures

All four trials of the participants were recorded using a Casio EX-FX1 (Casio Computer Co. Ltd, Shibuya, Japan) digital video camera. The camera was fixed on a tripod placed on the stand and recorded the right-sided rear view of the circle. The sampling frequency was set at 300 frames per second. The best attempt concerning the official throwing distance (S_{OFF}) of each participant was selected for further analysis. The duration of each technique phase was extracted using the V1 Home 2.02.54 software (Interactive Frontiers Inc). Due to the selected sampling frequency, the accuracy of the present time analysis was ±0.0015 sec. The intra-observer reliability was 99.8%.

Statistical analysis

Results are expressed as mean values ± standard deviation (x ± SD). A two-tailed Pearson correlation analysis was used to examine possible correlations among the duration of the separate technique phases and the official throwing distance. The statistical analysis was conducted using the SPSS 10.0.1 software (SPSS Inc., Chicago, IL), with the level of statistical significance set at $p = 0.05$.

RESULTS

The official distance for the discus throw S_{OFF} ranged from 67.63 m to 48.61 m. However, 7 athletes achieving a mark near or over 62 m (Table 1). The medals were decided with throws over 65.50 m. 24.1% of the executed attempts were counted as failures. As for the athlete ranked in the 8th place, only his first throw (48.61 m) was performed and which was not considered as a representational for his ability (73.6% of his season best). Thus, results were extracted only for the first 7 athletes.

Table 1. *The participating athletes, the official throwing distance (S_{OFF}), their personal best (PB) and the result as percentage (%SB) of the season best record (SB@2009) before the competition (according to I.A.A.F., 2009).*

Rank	Athlete	Nation	S_{OFF} (m)	Trial	PB (m)	SB@2009 (m)	%SB
1	**Alekna**	LTU	**67.63**	2	73.88	69.59	97.2
2	**Harting**	GER	**66.37**	2	69.43	69.43	95.6
3	**Malachowski**	POL	**65.60**	2	69.15	69.15	94.9
4	**Kovago**	HUN	**65.60**	1	69.95	67.64	97.0
5	**Kanter**	EST	**65.34**	3	73.38	71.64	91.2
6	**Casanas**	ESP	**63.24**	2	67.91	67.17	94.1
7	**El Ghazaly**	EGY	**61.95**	2	66.58	66.34	93.4
8	**Israel**	EST	**48.61**	1	66.56	66.05	73.6
x			**63.04**		**69.61**	**68.38**	**92.1**
SD			6.09		2.78	1.90	7.7

Table 2 presents the time analysis for the best attempt of each participant. In the starting turn, the entry phase had a shorter duration than the preparation phase. As for the delivery turn, only the top two competitors (Alekna and Harting) had a longer double support delivery phase compared to the duration of the transition phase.

Table 2. *Duration of the discus throw phases, the sum (S1) of phases P→R and the sum (S2) of phases E→R (see text for the abbreviations used).*

ATHLETE	P (sec)	E (sec)	F (sec)	T (sec)	D (sec)	R (sec)	S1 (sec)	S2 (sec)
Alekna	0.800	0.387	0.100	0.170	0.176	0.027	1.660	0.860
Harting	0.620	0.420	0.083	0.180	0.200	-	1.503	0.883
Malachowski	0.510	0.394	0.053	0.183	0.157	0.027	1.324	0.814
Kovago	0.409	0.354	0.087	0.190	0.176	0.067	1.283	0.874
Kanter	0.555	0.377	0.070	0.223	0.153	0.027	1.405	0.850
Casanas	0.550	0.300	0.104	0.176	0.124	0.063	1.317	0.767
El Ghazaly	0.647	0.460	0.076	0.204	0.176	0.054	1.617	0.970
X	**0.584**	**0.385**	**0.082**	**0.189**	**0.166**	**0.044**	**1.444**	**0.860**
SD	0.122	0.050	0.018	0.018	0.024	0.019	0.152	0.063

There was no clear evidence of the existence of an identical movement pattern among the participants, since a 7-9% inter-individual variability was noticed concerning the time distribution of each phase at the throw (Figure 2).

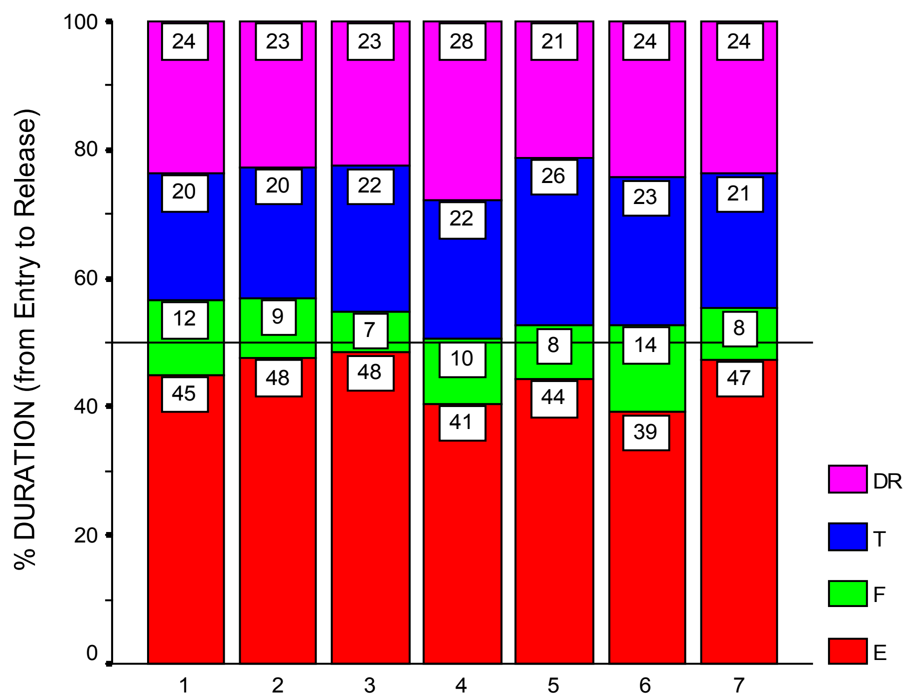

Figure 2. *The duration of the entry (E), the flight (F), the transition (T) and the delivery+release (DR) phase expressed as percentage of the summed duration from E to DR.*

Additional temporal parameters are presented in Table 3. Only Harting released the discus without braking contact with the ground. The majority of the throwers utilized the supportless style of release. Alekna and Harting had the lowest values of the ratio of the time spent for the starting turn compared to the time spent for the delivery turn. Additionally, both athletes were for a longer time in double rather than in single support in both the starting and the delivery turns.

Table 3. *The ratio (S:D) of the time spent for the starting turn (S_{TURN}) compared to the time spent for the delivery turn (D_{TURN}), the percentages of time spent in single support in the starting (E) and the delivery (T) turn, and the time instances of the final right (R2🡅) or left (L2🡅) leg take-off relative to the release of the discus.*

ATHLETE	S_{TURN} (sec)	D_{TURN} (sec)	S:D	E (%)	T (%)	L2🡅 (sec)	R2🡅 (sec)	Style of release
Alekna	1.187	0.373	0.31	32.6	49.1	-0.013	-0.027	Supportless
Harting	1.040	0.380	0.37	40.4	47.4	-	-	Double support
Malachowski	0.904	0.367	0.41	43.6	53.8	-0.027	-	Single support
Kovago	0.763	0.433	0.57	46.4	51.9	-0.060	-0.067	Supportless
Kanter	0.932	0.403	0.43	40.5	59.3	-0.027	-	Single support
Casanas	0.850	0.363	0.43	35.3	58.7	-0.030	-0.063	Supportless
El Ghazaly	1.107	0.434	0.39	41.6	53.7	-0.054	-0.024	Supportless
x	**0.969**	**0.393**	**0.41**	**40.0**	**53.4**	**-0.035**	**-0.051**	
SD	0.149	0.030	0.08	4.7	4.5	0.018	0.023	

Moderate and low correlation coefficients were revealed between the duration of the throw and the official throwing distance and among the durations of each separate technique phase (Table 4). These correlations were not statistically significant (p>0.05).

Table 4. *Correlation matrix presenting the relationships among the official throwing distance and the duration of each separate technique phase (see text for the abbreviations used).*

	P	E	F	T	D+R
S_{OFF}	0.232	-0.072	0.049	-0.365	-0.196
P		0.387	0.342	-0.278	-0.158
E			-0.484	0.274	0.283
F				-0.493	0.201
T					0.004

DISCUSSION

The duration of the discus throw from the entry up to the release found in the present study (0.77 – 0.97 sec) was in reasonable agreement with those (0.57 – 0.93 sec) found in the literature, despite the fact that the average duration of the entry (0.39 sec) was slightly longer than the average entry duration reported in the past (Gregor et al., 1985; Knicker 1988, as cited in Tidow, 1994; Knicker, 1992; Knicker, 1994a; Knicker, 1999; Leigh et al., 2008; Miyanishi et al., 1998; Miyanishi & Sakurai, 2000; Panoutsakopoulos, 2008; Susanka et al., 1987; Topalov, 1991; Ward & Ward, 1976a; Ward & Ward, 1976b). This was evaluated as a positive factor for performance, since the turn must not be as fast as possible in order to accelerate the discus to its optimum (Endermann, 1974). No statistically significant correlations were observed among the official throwing distance and the durations of each separate phase, confirming results of previous studies (Floria Martin, 2006; Knicker, 1994a; Knicker, 1994b).

The inter-individual variability (7-9%) noted in the present study was lower than reported previously (Panoutsakopoulos, 2008). This could be due to the larger homogeneity of the athletes examined in the present study compared to the above mentioned study. The variations of the phase durations have reported to be considerably small, since elite male discus throwers perform the throw with constant timing patterns (Knicker, 1999; Leigh et al., 2008). In general, a good consistency concerning the technique elements is expected in male throwers (Dai et al., 2012) and the variability in the duration of each technique phase has been attributed to the adoption of different styles when performing the throwing technique (Bartlett, 1992; Bartonietz et al., 1996; Bartonietz, 2000; Bartonietz, 2009; Miyanishi et al., 1998).

The first double and the first single support phases are important for the development of the velocity of the discus at the first stages of the throw (Dapena, 1993). The duration of the first double support phase in an indirect pointer of the amplitude of the reach of the throwing arm and the length of the discus path which it can be accelerated (Stepanek & Susanka, 1987). This is the reason why it is of importance not to have a fast first double support (Grigalka & Papanov, 1979). Additionally, the technique executed with a slightly longer flight phase followed by a relatively short transition phase is characterised by a “dynamic launch” concerning the starting turn (Stepanek & Susanka, 1987). It is believed that the best throws can be executed when a certain level of discus velocity is already reached during the preliminary phases, aided with a considerable gain in the final single support phase (Knicker, 1999). So, the larger time spent for the starting turn compared to the duration of the transition phase is an indicator that the larger portion of the acceleration of the discus was accomplished at the decisive phase of the delivery (Stepanek & Susanka, 1987).

Another rigid criterion for identifying the correct discus throw technique is the duration of the flight phase (Song et al., 2009; Stepanek & Susanka, 1987). It is supposed that the flight time should be short (Dyson, 1977; Hay, 1985; Schwartz, 1986). The time spent in airborne was found to be connected with the flight path of the right foot (for right-handed throwers) from the entry phase to the planting for the delivery (Bartlett, 1992). The quickness of this movement is relied on the relationship between the pivoting foot and the thrower’s center of gravity (Dyson, 1977). In the case of a high jump turn, the extended flexion of the single support knee joint and the wrong lead arm action at the beginning of the turn have been indentified as the main reasons for an elongated flight phase (Endermann, 1974). The above have lead to the consideration of the summed duration of the flight and the transition phases is an important factor for the maintenance of the speed of the discus and for the establishment of a proper coordination of the throwing movements at the delivery phase (Milanovic et al., 1997). Furthermore, the total duration of the delivery turn reveals two types of throwers (Miyanishi et al., 1998): the “speed dominant” (development of discus release velocity relied on the horizontal speed during the transition) and the "strength dominant" (increase of the vertical than the horizontal speed of the discus during the delivery turn).

The majority of the throwers utilized the supportless style of release as noted in the past (Badura, 2010; Bartonietz et al., 1996; Gemer, 1974; McCoy, 1984). The leg take-off pattern at the release of the discus, as observed for the throwers utilizing the supportless style, was consisted with previous observations concerning the timing (McCoy, 1984) and the sequencing (the right leg took off first followed by the take-off of the left leg; Stepanek & Susanka, 1987). These findings should be considered under the suggestions that the style of release is affected by the orientation of the last rear foot placement (Badura, 2010) and the distance between the feet during the delivery phase (Lockwood 1963, as cited in Hay, 1985).

Some selected individual temporal patters are worth mentioning in order to retrieve indications concerning the effectiveness of the exhibited throwing techniques by the examined athletes. For example, Alekna and Casanas could be identified as "dynamic launchers", since their movement patterns were similar to the description of this style according to Stepanek and Susanka (1987). However, Casanas had the longer flight duration and the shortest entry and delivery phases than the other competitors, elements that are indicators of an inefficient technique (Hay & Yu, 1995; Song et al., 2009; Stepanek & Susanka, 1987). In another interesting case, Kovago had the highest value of the ratio of the time spent for the starting turn compared to the time spent for the delivery turn, since he exhibited the fastest starting turn and the slowest delivery turn. The same athlete also had the earliest initiation of the supportless style of release among the examined throwers. These findings could be indicators of a "strength dominant" style adopted because of the inadequate acceleration of the discus in the early phases of the throw (Dapena, 1993; Knicker, 1999; Milanovic et al., 1997; Miyanishi et al., 1998; Stepanek & Susanka, 1987). Finally, the top two placed participants (i.e. Alekna & Harting) had the lowest values of the ratio of the time spent for the starting turn compared to the time spent for the delivery turn, mainly because of the larger duration of the starting turn. However, despite exhibiting a similar timing pattern, El Ghazaly was not as successful at the examined competition, This fact stresses that the definition of the release parameters and other important technique elements derived by a biomechanical analysis are essential for the adequate understanding of discus throwing technique.

As noted elsewhere (Bartonietz et al., 1996), results indicated differences among the athletes concerning the time distribution between the transition and the delivery phases within the delivery turn. The average duration of transition phase recorded in the present study was longer than the delivery (53.4% and 46.6% respectively). This finding was in agreement with previous findings (Bartlett, 1992; Bartonietz et al., 1996; Knicker, 1990; Knicker, 1994; Susanka et al., 1988), whereas lower level discus throwers exhibit an almost 50% vs. 50% distribution (Floria Martin, 2006; Panoutsakopoulos, 2008). It is worth noticing that only the first and the second thrower had a longer double support delivery phase compared to the duration of the transition phase. However, if the duration of the release was added to the duration of the delivery phase, the time portion of the delivery turn spent in single support was smaller in the vast majority of the examined throwers. The longer duration of the delivery+release phase is not a surprising finding, since previous studies have reported ratios about 55% and 45% for the delivery and the transition phase, respectively (Knicker, 1999; Miyanishi et al., 1998). It is believed that the faster execution of the transition phase results in a larger acceleration of the discus (Carr, 1970; Endermann, 1974; Hay, 1985; Schmolinsky, 1983; Tidow, 1994), resulting to a greater amount (68%) of the discus velocity developed during the last double support phase (Hay & Yu, 1995). It is supported that the longer time spent during the turns is beneficial for performance, since it composes an essential element concerning the factors that result in a greater release velocity of the discus, factors such as the force applied to the discus (Voicik, 1983), the enlargement of the moment of force (Hulten, 1980) and the elastic energy storage in the throwing arm (Ariel et al., 1997). Nevertheless, the duration of the foot contact with the ground during the delivery phase does not seem to be a determining factor for discus throw performance (Yu et al., 2002), since the proper timing of movements within the individualized temporal pattern consists the most essential factor contributing for the longest throw (Bergeron, 2000).

CONCLUSIONS

The temporal analysis of the technique phases serves for the evaluation of the discus throwing technique. Constant timing patterns were observed for the participants despite the absence of a significant relationship among the duration of the technique phases and between the duration and the official distance of the throw. It seems that a short duration of the transition phase, combined with lower values of the ratio of the time spent for the starting turn compared to the time spent for the delivery turn might be favorable regarding the achievement of a larger throwing distance. Further combined temporal and kinematical analysis of discus throwing is proposed for the better evaluation of the techniques exhibited by elite male athletes and for the determination of the crucial factors influencing performance in this throwing discipline.

REFERENCES

1. ARIEL G, FINCH A, PENNY A. Biomechanical analysis of discus throwing at the 1996 Atlanta Olympic Games. In: WILKERSON J, LUDWIG K, ZIMMERMANN W (Editors), *Proceedings of the 15th International Symposium on Biomechanics in Sports,* pp. 365-371. Denton, TX: Texas Women's University; 1997. [Back to text]
2. BANDURA M. Biomechanical Analysis of the Discus at the 2009 IAAF World Championships in Athletics. *New Stud Athl.* 2010; 25(3/4):23-35. [Back to text]
3. BARTLETT RM. The biomechanics of the discus throw: A review. *J Sports Sci.* 1992; 10(5):467-510. doi:10.1080/02640419208729944 [Back to text]
4. BARTONIETZ K. Deutsche werfer mit bärenkräften – Teil 1. *Leichtathletiktraining.* 2009; 20(10-11):21-25. [Back to text]
5. BARTONIETZ K. Die wurfdisziplinen bei der WM '99 - Teil 2. *Leichtathletiktraining*. 2000; 11(4):24-29. [Back to text]
6. BARTONIETZ K., BEST RJ, BORGSTRÖM A. The throwing events at the World Championships in Athletics 1995, Göteborg - Technique of the world's best athletes Part 2: Discus and javelin throw. *New Stud Athl.* 1996; 11(1):19-44. [Back to text]
7. BERGERON J. Technique and rhythm in the throws. *Track Coach*. 2000; 153:4884-4886, 4893.
8. CARR GA. The discus throw technique. *Athl Coach.* 1970; 4(2):5-9. [Back to text]
9. DAI B, LEIGH S, LI H, MERCER VS, YU B. The relationships between technique variability and performance in discus throwing. *J Sports Sci.* 2012; doi:10.1080/02640414.2012.729078. [Back to text]
10. DAPENA J. An analysis of angular momentum in the discus throw. In: BOUISSET S, METRAL S, MONOD H (Editors)*, Proceedings of ISB Proceedings of the XIVth Congress of the International Society of Biomechanics (Volume 1).* Paris: Societe de Biomecanique; 1993; 306-307. [Back to text]
11. DYSON GHG. *The Mechanics of Athletics (7th edition).* Cambridge: Hodder and Stoughton Educational; 1977. [Back to text]
12. ENDERMANN F. Another look at discus throwing. In: WILT F (Editor). *The throws: contemporary theory, technique and training.* Los Altos, CA: Tafnews Press; 1974; 67-69. [Back to text]

13. FLORÍA MARTÍN P. *Análisis biomecánico del lanzamiento de disco. Categorización de variables de eficacia de la técnica.* Tesis Doctoral, Universidad Autónoma De Madrid; 2006. [Back to text]
14. GEMER GV. Munich-Observations and comments on the discus. In: WILT F (Editor). *The throws: contemporary theory, technique and training.* Los Altos, CA: Tafnews Press; 1974; 70-72. [Back to text]
15. GREGOR RV, WHITING WC, McCOY RW. Kinematic analysis of Olympic discus throws. *Int J Sports Biomech.* 1985; 1(2):131-138. [Back to text]
16. GRIGALKA O, PAPANOV V. Wolfgang Schmidt throws the discus. *Soviet Sport Rev.* 1979; 14(1):37-40. [Back to text]
17. HAY JG, YU B. Critical characteristics of technique in throwing the discus. *J Sports Sci.* 1995; 13(2):125-140. doi:10.1080/02640419508732220 [Back to text]
18. HAY JG. *The Biomechanics of Sports Techniques (3rd edition).* Englewood Cliffs, NJ: Prentice-Hall Inc.; 1985. [Back to text]
19. HULTEN CA Jr. *A biomechanical analysis for developing diagnostic parameters of the discus throw through cinematography.* Master Thesis, Southern Connecticut State College; 1980. [Back to text]
20. I.A.A.F. http://www.iaaf.org/waf09/results/.html; 2009. [Back to text]
21. KNICKER A. Discus throw. In: BRÜGGEMANN G-P, KOSZEWSKI D, MÜLLER H (Editors), *Biomechanical research project Athens 1997: Final Report*. Oxford: Meyer & Meyer Sport Ltd.; 1999; 161-174. [Back to text]
22. KNICKER A. Kinematic analyses of the discus throwing competitions at the IAAF World Championships in Athletics, Stuttgart 1993. *New Stud Athl.* 1994a; 9(3):9-16. [Back to text]
23. KNICKER A. Kinematic analyses of the discus throwing competitions at the World Athletics Championships 1993 in Stuttgart. In: BARABAS A, FABIAN G (Editors*), Proceedings of the 12th International Symposium on Biomechanics in Sports.* Budapest: Hungarian University of Physical Education; 1994b; 363-370. [Back to text]
24. KNICKER A. Kinematic characteristics of the discus throw. *Modern Athl Coach.* 1992; 30(1):3-6. [Back to text]
25. KNICKER AJ. Determining factors in discus throwing of top level athletes. In: BRÜGGEMANN G-P, RÜHL JK (Editors), *Proceedings of the First International Conference on Techniques in Athletics (Volume 2).* Köln: Deutsche Sporthochscule; 1990; 670-677. [Back to text]
26. LEIGH S, GROSS MT, LI L, YU B. The relationship between discus throwing performance and combinations of selected technical parameters. *Sports Biomech.* 2008; 7(2):173-193. doi:10.1080/14763140701841399 [Back to text]
27. McCOY RW. Kinematic analysis of discus throwers. In: DALES GG (Editor), *Proceedings of the IX International Track & Field Coaches Association Congress*. Kalamazoo, MI: NCAA DIV I TCA; 1984; 96-99. [Back to text]
28. MILANOVIC D, HRASKI Z, MEJOVSEK M. Kinematic analysis of a discus throw - a case study. In: Milanovic D. (Editor). *Zbornik Radova, 1. Medunarodna Znanstvena Konferencija "Kineziologija - Sadasnjost i Buducnost"*. Zagreb: Fakultet za Fizicku Kulturu; 1997; 136-139. [Back to text]
29. MIYANISHI T, SAKURAI S, WAKAYAMA A, TOGASHI T, KAWAMURA T. A three-dimensional angular momentum analysis in the Asian top discus throwers. *Jap J Biomech Sports Exer.* 1998; 2(1):10-18. [Back to text]
30. MIYANISHI T, SAKURAI S. Angular momentum analysis of men's discus throwers in 1998 USA Track & Field championships. In HONG Y, JOHNS DP (Editors), *Proceedings of XVIII International Symposium on Biomechanics in Sports.* Hong Kong: The Chinese University of Hong Kong; 2000; 806-809. [Back to text]

31. PANOUTSAKOPOULOS V. Biomechanical analysis of the men's discus throw in the Athens 2006 I.A.A.F. World Cup in Athletics. http://www.sportsci.com/start/apas/studies/Panoutsakopoulos-DISCUS.pdf; 2008. [Back to text]
32. SCHMOLINSKY G. *Track and Field.* Berlin: Sportverlag; 1983. [Back to text]
33. SCHWARTZ GK. Fundamentals of discus throwing. *Track Field Q Rev.* 1986; 86(1):22-25. [Back to text]
34. SONG Q, MAO D, JIA G, ZHANG C. Discus throwing technique diagnose for elite discus throwers of Shandong. *J Shandong Institute Phys Edu Sport.* 2009; 25(11):61-63. [Back to text]
35. STEPANEK J, SUSANKA P. Discus Throw: Results of a biomechanic study. *New Stud Athl.* 1987; 2(1):25-37. [Back to text]
36. SUSANKA P, DUMBROVSKY M, BARAK F, STEPANEK J, NOSEK M. Biomechanical analysis of the discus throw. In: BRÜGGEMANN G-P, SUSANKA P (Editors), *Scientific Report on the II. World Championships in Athletics, Rome 1987 (Book 3).* London: International Athletic Foundation; 1988; 1-61. [Back to text]
37. TERAUDS J. Computerised biomechanical cinematography analysis of discus throwing at the 1976 Montreal Olympiad. *Track Field Q Rev.* 1978; 78(1):25-28. [Back to text]
38. TIDOW G. Model technique analysis sheets. Part IX: The discus throw. *New Stud Athl.* 1994; 9(3):47-68. [Back to text]
39. TOPALOV L. A low squatting alternative for throwing the discus. *Track Field Q Rev.* 1991; 91(3):25-29. [Back to text]
40. VODICKOVA S. Comparison of some selected kinematic parameters of the best and the worst throws of the elite discus throwers at the Ludvik Danek's meeting. *Rozprawy Naukowe AWF We Wroclawiu.* 2008; 26:27-29. [Back to text]
41. VOICIK M. The discus throw. *Track Field Q Rev.* 1983; 83(1):19-22. [Back to text]
42. WARD P, WARD R. USA discus camp – preliminary report. *Track Field Q Rev.* 1976a; 76(1):29-39. [Back to text]
43. WARD RD, WARD PE. A kinematic and kinetic approach to discus technique analysis. *Track Field Q Rev.* 1976b; 76(1):22-28. [Back to text]
44. YU B, BROKER J, SILVESTER JL. A kinetic analysis of discus throwing techniques. *Sports Biomech.* 2002; 1(1):25-46. doi:10.1080/14763140208522785 [Back to text]