KINEMATICS AND AERODYNAMICS PARAMETERS ON PARALYMPIC DISCUS THROW

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The purpose of this present study was the kinematics and aerodynamic evaluation of a disabled discus throw. The sample was carried out by thirty one throws made by an athlete who was for three times Paralympics champion. For the kinematical analysis were used the 3D and 2D kinemetry method. The images were recorded by two high-speed cameras (120Hz) and a low speed one (60Hz). Aerodynamic analysis was calculated by drag and lift forces during flight phase. The results showed good correlations of drag and lift forces with flight distance, and no relation to wind and position to the range. Overall, it was concluded that the drag free equation applied to disabled discus throw can not predict the flight distance. The aerodynamic factors are significant to disabled athletes and require further researches.

KEY WORDS: kinematics, aerodynamics, Paralympic, discus throw.

INTRODUCTION:

Discus throw is one of oldest sports in athletics. It has been studied for a long time by coaches, scientists and biomechanics experts. Few studies involving discus throw (especially in disabled athletes) describe the forces who act on discus flight phase. It may be caused by minor release velocity and flight time, short trajectory so that it decreases the effects of aerodynamic forces on disabled throw. These are one of the most likelihood reasons that these studies ignore aerodynamics aspects. The purpose of this paper is to quantify whether aerodynamic effects on disabled discus throw are correlated with the kinematics variables or not to the flight distance by a disabled athlete.

METHOD:

The basic mechanical factors are kinematics and aerodynamics. Kinematics factors are related to release conditions such as discus speed (V_o), height (h) and angle (Θ) (Maronski, 1991; Bartlett, 1992). Aerodynamic forces acting on the discus flight are: relative wind velocity (V_{wind}), discus angle of attitude (Φ) and angle of attack (Ψ).
The horizontal range (R) of an object with V_0, Θ and h, can be simple analytically resolved (Miranda et al., 2004) by parametric equations in two steps:

$$(1)\quad h + V_0\,(sen\,\Theta)\,t - \frac{1}{2} g\, t^2 = 0$$

The positive value of t is used to calculate the range. Then, changing the value of (t) we can obtain the drag free range.

$$(2)\quad R = (V_0 \cos\Theta)\, t$$

The aerodynamics characteristics can significantly influence its trajectory (Sueyoshi & Maruyama, 1992). The aerodynamic coefficients of discus flight are: drag (C_{drag}) and lift (C_{lift}) measured by wind tunnel. According to Soong (1972) and Frohlich (1981), the forces acting on discus are respectively F_{drag} and F_{lift}. The drag and lift forces are showed on 3 and 4 equations below.

$$(3)\qquad F_{drag} = \frac{1}{2} C_{drag} \rho A V^2_{rel}$$

$$(4) \qquad F_{lift} = \frac{1}{2} C_{lift} \rho A v^2_{rel}$$

Data Collection: 31 throws were recorded by one expert Paralympics female athlete that belongs to the F-56 class. The athlete is three times gold medalist on Paralympics games and nine times world champion. The athlete has both legs amputated. Six landmarks define the anthropometric model and the center of the discus was digitalized. The kinematics data was collected by two synchronized high-speed cameras (120 Hz) were positioned at 3.5 meters in distance from the thrower and at 4 meters in height, 120º in angle between one another as well. One of them (60 Hz) stands alone perpendicular to the thrower. The software Peak Motus V. 4.2. (Peak Performance Technologies) was the data processing system. The spatial calibration used 24 points frame calibration with the DLT coordinates. The mean square error (in meters) was 0,0057 to X ; 0,0043 to Y and 0,0113 to Z axis. The 3D coordinate data were smoothed by a Butterworth digital filter with appropriate cut-off frequency. The values of V_0, h, and Θ were used on the drag free equations and the drag free results were compared to the official range. The values of V_0, V_{wind}, discus angle positions Ψ and Φ were used on aerodynamic equations and these results were correlated to (R) and release parameters.
Data Analysis: The SPSS (Statistical Package for the Social Sciences) version 14.0 was used to calculate the Pearson correlation between kinematics factors and the flight distance. The correlation between kinematics and aerodynamic factors, the correlation between aerodynamics factors and the flight distance and the T-test were applied in order to verify the drag free predicted range and the official range differences.

RESULTS:

The kinematics results are similar to the able-body throwers. The major difference is the lowest discus speed (52% less) because the thrower stays seated. Discus height at release in our study is proportional to 90% of perceptual total seated body height that agrees to able-body throwers results in some other studies (McCoy et al., 1985; Robert et al, 1985; Poprawski, 1988). The trunk size is the most important value to discus height on disabled athletes because they throw on a seated support with standard size (0,75 m). The release angle range agrees with able bodies throwers 31º to 39º (Yu & Silvester, 2002) and disabled throwers with the same functional classification (Chow & Mindock, 1999). The table 1 shows the descriptive statistics of throw parameters. The aerodynamics factors were calculated by drag and lift equations (9 and 10 respectively) in each throw and were correlated to the range, discus angles and wind positions. The F_{drag} force presented good correlation values with range (r=0,75) (Figure 1a). It was caused because the drag forces increase proportionally to the square discus speed (Soong, 1976). The correlation of V_0 with the range is r=0,96. The F_{lift} correlation with range had a good correlation of r=0,82 (Figure 1b). It was caused because the increase on lift forces during the flight can increase directly the flight time of discus (Table 2).

Table 1 Descriptive statistics of throw parameters

Parameters	Mean	Standard Deviation	Min /Max	Variation
R	20,94m	0,46	(20,22 – 21,88) m	2%
V_0	13,63m s^{-1}	1,61	(11,51 – 16,7) ms^{-1}	11,5%
h	1,64m	0,05	(1,5 – 1,75) m	3%
Θ	35,8º	2,11	31,7° – 39°	5%
Φ	34,2º	3,03	29° – 43°	8,8%
Ψ	-1,59º	2,81	-7,5° – 5,5°	187%
V_{wind}	0,54m s^{-1}	0,7	(-0,69 – 2,18) ms^{-1}	129%

Other parameters such as height and angles are no linear correlated with range or aerodynamic forces. The V_{wind} presented no correlation with the range and just a poor correlation with aerodynamic forces (Table 2).

The T-test to equal samples was measured to identify significant differences between drag free range and official range. The results showed difference for P (T<=t) uni-caudal (Table 3).

Table 2 Correlation between release parameters, range and aerodynamic forces.

Parameters	R	F_{drag}	F_{lift}
V_0	0,96	0,75	0,83
h	-0,01	-0,02	0,02
Θ	-0,13	0,03	0,03
Φ	0,04	0,03	0,02
V_{wind}	0,11	0,58	0,57

Table 3 Mean and standard deviation of the results by drag free equation and official range. Correlations and T- test between them for (p< 0,05).

Range	Mean	Standard deviation	Correlation	T-test
Drag free	18,13m	3,35m	0,95	<0,001
Official	20,96m	0,48m	-	-

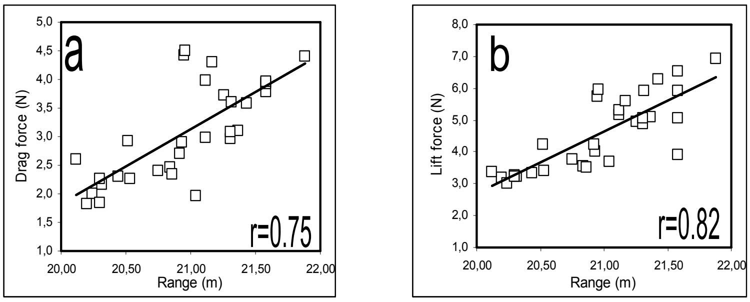

Figure 1: Correlation between range and aerodynamic forces a- drag forces r=0,75; b- lift forces r=0,82.

DISCUSSION:

The (V_0) correlation with range (r=0,96) shows that initial discus speed correlates strongly to flight distance by able-body. The (V_0) determines the flight distance when there are few changes from angle and height (Banja & Tashiro, 2004).
There is no linear correlation between height and range (r=-0,07). Despite initial height discus throw is cited in literature as an important factor (Frohlich, 1981), this study found a small variation of only 3%.
The release angle of discus (Θ) presented does disagree to values with old able-body throwers papers (Cooper,1959; Ganslen, 1964; Teraudus, 1978; Woicik, 1983) which was probably caused by methodological data treatment problems at that time. On the other hand, it agrees with other recent papers (Bartlett, 1992) and computational simulations for V_0 values close to this study (Sueyoshi & Maruyama, 1992). It also agrees with evaluation on disabled thrower for the same functional class (Chow & Mindock, 1999). The values are between 30° - 40°. The Θ, ϕ and Ψ has no correlation to the flight distance because they are non-linear behaviors.
There is no correlation between wind velocity (V_{wind}) and range. It was probably caused because the wind velocity was not present on 42% of trials in this study but the best throw happened with wind blowing against the throw.
The values of drag free range calculated by equations 3 and 4 presented a mean error compared to official range of 1,37m, the standard deviation was major on drag free results. The T- test showed that was significant between the official and the drag free range (Table 3).

The drag forces presented a good correlation with range (r=0,75). The most significant correlation value was between the lift forces and the range (r=0,82). The increase of lift forces probably affects positively the discus flight time and increases the range.

CONCLUSION:

The aerodynamic forces are significant factors on Paralympics discus flight. The correlation between drag, lift and range (in some cases) has good significant levels. Aerodynamic factors (in low speed of discus) have a true influence on flight distance so that it can be measured and used in equations to predict the range. Other conditions such as atmospheric and wind positions deserve more attention. The drag free equation must be applied only in low velocities and short trajectories (for example shot put) or high velocity projects with low aerodynamic influences (for instance, the hammer throw). In this case, the drag free equations demonstrate significant differences to official range and can't be applied to predict flight distance on Paralympics discus throw. More numerical analysis and studies can be developed to apply kinematics and aerodynamics effects to predict flight distance. Coaches and athletes must understand the influence of aerodynamic factors in order to take the maximum advantage on throw effects in range.

REFERENCES:

Banja, T. Tashiro T. (2004). Three-dimensional kinematic analysis of disabled discus *throwing. Proceedings on 2004 Preolimpic Congress*, 2, 300-303.

Bartlett, R. (1992). The biomechanics of discus throw: A review. *Journal of sport scienc*e, 10, 467-76

Chow, J., Mindock, S. (1999). Discus throwing performance and medical classification of wheel chair athletes. *Science in sport and exercise,* 31, 1272-78.

Cooper, L., Danzel, D., Silverman, E. (1959). Flight of the discus. *Athletic journal*, 34, 35-8.

Frohlich, C. (1981). Aerodynamics effects on the discus flight. *American Journal of Physics*, 49, 1125.

Ganslen, R. (1964). Aerodynamic and mechanic forces in discus flight. *Athletic journal*, 44, 68-73.

Hay, J., Yu, B. (1995). Critical characteristics in technique in throwing the discus. *Journal of Sport Science*,13, 2, 125-8.

Mccoy, R., Whiting, M., Rich, R., Gregor, R. (1985). Kinematics analysis of discus throwers. *Track and technique,* 9, 1, 2902-9.

Maronski, R. (1991). Optimal distance from the implement to the axis of rotation in hammer and discus throws. *Journal of Biomechanics*, 24, 11.

Miranda, E., Nikoslskaya, S., Riba, R. (2004). Minimum and terminal velocities in projectile motion. *Revista brasileira de ensino de física,* 26, 2, 125-131.

Poprawski, B. (1988). A critical review of "a new look at discus throwing" *Journal Article Track Technique,* 104, 3322- 9.

Robert, J., Gregor, R., Whiting, W., Mccoy, R. (1985). Kinematics analysis of Olympic discus throws. *Journal of Sport Biomechanics*, 1, 131-136.

Soong, T. (1976). The dynamics of discus throw. *Journal of Applied Mechanics*, 98, 22, 5-11.

Sueyoshi, Y., Maruyama, A. (1992). Optimal release angle on discus throw through computer simulation. *Journal of Biomechanics*, 25, 717.

Teraudus, J. (1978). Computerized biomechanical cinematography analysis of discus throwing at the 1976 Montreal Olympiad. *Track and field Quarterly Review*, 78, 25.

Woicik, M. (1983). The discus throw. *Track and field quarterly review*, 83, 19.

Yu, B., Broken, J., Silvester, J. (2002). A kinect analysis of discus throwing techniques. *Sport biomechanics,* 1, 25-34.