Portuguese Journal of Sport Sciences
11 (Suppl. 2), 2011

KINETIC ANALYSIS OF TOE-ON TKACHEV ON UNEVEN BARS

David G. Kerwin and Gareth Irwin

Cardiff School of Sport, University of Wales Institute, Cardiff, Wales, UK

The purpose of this study was to explain the mechanics of the Toe-on Tkachev on Uneven Bars, and to identify how the release conditions were created. 3D video based data and inverse dynamics were used to analyze five different Toe-on Tkachevs recorded at the 2007 World Championships. Digitising and DLT techniques were combined with customised inertia modelling as input to standard inverse dynamics. Data were normalised to eliminate influences of height and mass. Hip action was characterised by a single large input which peaked close to the horizontal on the upswing, followed by a smaller negative shoulder power contribution as release was approached. The dominant role of positive hip extension was highlighted as a major factor contributing to the creation of the final body orientation and desirable release conditions.

KEYWORDS: women's gymnastics, joint moments, power and work

INTRODUCTION: In the past we have reported kinetic data on two variants of the women's Tkachev (Kerwin and Irwin, 2010) which highlighted different shoulder actions approaching release. It appeared that the inward variant offered gymnasts greater potential to execute more advanced forms of the Tkachev. A newer variant, the Toe-on Tkachev has been adopted by a number of leading international competitors and has enabled straight Tkachevs to be performed by women gymnasts. The new variant requires the gymnast to accentuate the piking action, seen in some traditional Tkachevs, to the point where the gymnast places her feet on the high bar as she swings past the horizontal on the downswing (Figure 1). She holds the Toe-on piked position until close to the horizontal on the upswing and then opens hip and shoulder angles to prepare for release and flight backwards over the high bar. As with all Tkachevs, gymnasts are faced with the challenge of maintaining backward angular momentum around the high bar to ensure suitable release conditions for flight over the bar, whilst also reversing the direction of angular momentum close to release providing forward rotation in flight. A parallel study (Irwin, Manning and Kerwin, ISBS 2011) has shown that the Toe-on Tkachev enables gymnasts to generate higher vertical velocities and greater angular momentum at release. The aim of the current study is to determine the actions made by gymnasts in the Toe-on Tkachev which enables them to develop greater forward rotating angular momentum. This will be achieved by comparing the kinetic profiles of the hips and shoulders in executing the Toe-on Tkachev with the corresponding values for the Outward and Inward variants previously reported.

METHOD: Data Collection: Data were collected at the 2007 Stuttgart World Gymnastics Championships using two 50 Hz digital video camcorders. The volume of interest was calibrated using two static (1 m x 1 m x 3 m) frames containing 48 known coordinates. The origin was defined as the centre of the high bar in its neutral position with the calibrated volume encompassing the analysed preparatory longswing, release and flight for each gymnast. Images of five Toe-on straddle Tkachevs were recorded from the cameras which were positioned with their optical axes intersecting the high bar. One camera was aligned along the high bar with the other approximately at right angles and viewing over the low bar.
Data Processing: Calibration and movement frames were digitised using PEAK Motus (Vicon Peak 9.0, UK) motion analysis system for both camera views. Movement data comprised images of the preceding Toe-on action, the release and flight phase of the straddle Tkachev. Digitising began once the gymnast had passed the handstand position at the start of the preparatory longswing, and continued throughout the longswing, release and flight. The centre of the high bar and the gymnast's head, right and left wrists, elbows, shoulders, hips, knees, ankles, and toes were digitised. A 12-parameter three-dimensional direct linear transformation (Marzan and Karara, 1975) was used to reconstruct the coordinate

data using the TARGET high-resolution motion analysis system (Kerwin, 1995). Customized segmental inertia parameters for each gymnast were determined using the height and mass of each gymnast, Yeadon's inertia model (1990), and limb lengths determined from the video data. Circle angle of the gymnast was defined by the vector formed between the mass centre, the neutral bar location and the right horizontal so that when the gymnast was in a handstand the circle angle was 90˚. All movement data were analysed throughout the reconstructed data and then cropped between a circle angle of 180° and the instant of release, to enable direct comparison with the previously published data (Kerwin and Irwin 2010).

Data Analysis: The reconstructed 3D coordinate data were processed with the 'ksmooth' function (MathCad^{14}™, Adept Scientific, UK) with the parameter 's' set to 0.10. This routine has similar characteristics to a Butterworth low-pass digital filter with the cut-off frequency set to 4.5 Hz (Kerwin and Irwin, 2006). The left and right sides of the body were averaged to produce a four segment planar representation of the gymnast, (arms, trunk, thighs and shanks). The instants of release and re-grasp were defined by quantifying 'grip radius' as the linear separation between the 'mid-wrists' and the centre of the high bar. Release was considered to have occurred once the grip radius exceeded 10% of the maximum value obtained during the preceding longswing. Release parameters and angular momentum were determined using the methods reported in Kerwin and Irwin (2010). Shoulder extension and hip flexion (joint angles closing) were regarded positive throughout the kinetic analyses. Inverse dynamics was used to determine joint moments (JM) and combined with joint angular velocities (⌉) to determine joint powers (JP). Integration of the power-time profiles was used to determine the respective joint work (JW) contributions. All values were normalised according to Hof's (1996) recommendations with the exception that each gymnast's height rather than leg length, often preferred for gait analyses, was used as the linear scaling component.

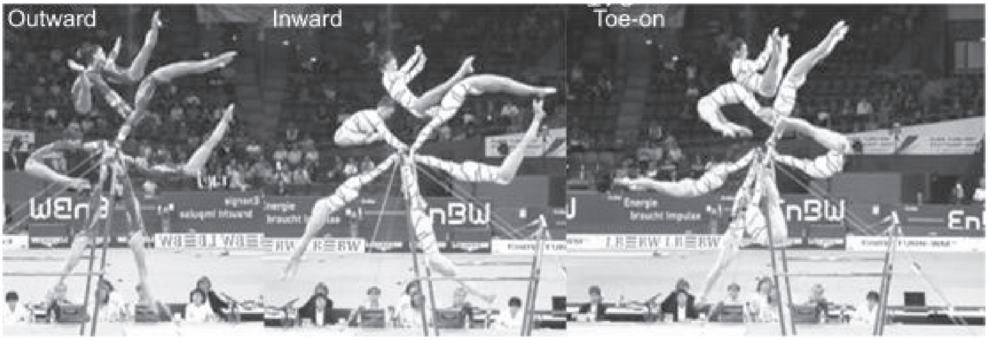

Figure 1: Outward, Inward and Toe-on Straddle Tkachevs (Stuttgart 2007)

RESULTS & DISCUSSION: Increased vertical velocity at release, and hence longer flight time coupled with greater angular momentum was evident from the data reported by Irwin, Manning and Kerwin (ISBS 2011). The hip joint angle remained around 140˚ for the majority of the preparatory longswing, between the downswing and upswing horizontals and only opened as release was approached (Figure 2). The final hip angle varied across the five competitors from slightly dished, to slightly arched. The shoulder angle was constant for half the circle and then all the gymnasts opened up to full flexion at release. The corresponding hip moments were close to zero until after the bottom of the circle and then peaked negatively at around -0.35 before rising rapidly to 0.2 at release (Figure 2). The shoulder moments peaked early in the circle, before the lower vertical, then dropped close to zero before rising slightly at release. The impact of these two interacting sets of variables revealed in the power profiles shows a dominant positive hip power peak close to a circle angle of 360˚ and relatively low contributions from the shoulders throughout the circle until release when a small negative spike in power occurs (Figure 2). This latter characteristic was seen in

Portuguese Journal of Sport Sciences
11 (Suppl. 2), 2011

the Inward variant of the Tkachev. The most striking difference between the joint power curves for this skill compared to the Outward and Inward variants is the later and larger single hip positive peak in the Toe-on rather than the smaller twin peaks reported for both previous variants. There was a small contribution from the shoulders throughout the circle until the very last part of the rotation. Tihis is in contrast to the positive shoulder contribution reported in the Outward Tkachev, particularly between 270˚ and 360˚ and to a lesser extend in the Inward. The almost fixed shoulder angles throughout the majority of the circle minimizes the need for a large contribution from shoulder power, but the dramatic single pulse of hip power around a circle angle of 360˚ facilitates the rapid extension of the body in preparation for release and coincides with the peak in angular velocity of the hip.

Table 1
Hip and Shoulder Work (Hof Normalised) for Outward, Inward and Toe-On straddle Tkachev on uneven bars.

	Outward	Inward	Toe-on	Outward	Inward	Toe-on
Joint Work	Hips	Hips	Hips	Shoulders	Shoulders	Shoulders
Positive	90%	82%	89%	71%	35%	29%
Negative	10%	18%	11%	29%	65%	71%
Total Work						
Positive	48%	44%	77%	70%	35%	29%
Negative	5%	10%	10%	30%	65%	71%

(Data sourced from Kerwin and Irwin, 2010).

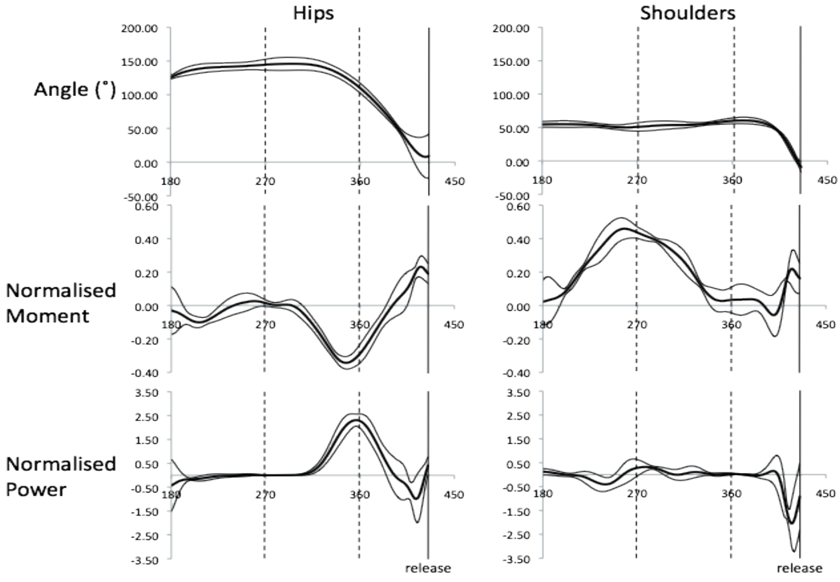

Figure 2: Joint angle (˚), normalised joint moments and normalised joint powers for the hips and shoulders during Toe-on Tkachev, from 180˚ (horizontal on the downswing) to release. Each graph shows a mean (bold) ±1 sd (feint) for 5 gymnasts.

Knee joint work contributed about 2% to the total work and was not included in this analysis. The joint work contributions for the hips and shoulders are reported in Table 1. Initially each contribution is expressed as a percentage of the total at the joint work, split into positive and negative components. This is followed by a summation of the hips and shoulders to produce total work and then the individual contributions are reported to highlight the major positive input from the hips and the negative work contribution from the shoulders used in the Toe-on technique. Considering each joint's contribution as previously reported (Kerwin and Irwin, 2010), and summarized in Table 1, the patterns for the hips are close to those seen for the Outward Tkachev, whilst the shoulder contributions are similar to those seen for the Inward variant. If the values are reviewed with reference to the whole skill, with each positive and negative contribution expressed as a percentage of the total work by the gymnast, then dominance of the hip contribution over the previous variants is clear with 77% of the positive work coming from the hips. This compares to less than 50% for the Outward and Inward variants. The smaller positive contribution from the shoulders is similar to the Inward variant and less than half that seen for the Outward Tkachev. When negative work is considered, the hips contribute 10% or less in each of the three variants, but the shoulders make a substantial input to the Inward and Toe-on versions of this skill. It would appear that the adoption of the Toe-on action in the Tkachev, achieves the goal of attaining improved release conditions by extending the advantages previously attributed to the Inward variant over its Outward counterpart. The Toe-on technique also appears to make little musculoskeletal demand on the gymnast in the early part of the circle, but places the gymnast in an advantageous position to deliver high positive hip power and moderate negative shoulder power in preparation for release.

CONCLUSION: The Toe-on Tkachev on Uneven bars appears to be an advancement of the Inward variant of this popular release and re-grasp skill in women's artistic gymnastics. The Toe-on technique enables gymnasts to increase key release variables, particularly vertical velocity, (and hence flight time) and angular momentum. Gymnasts achieve these favourable release conditions through a single large positive hip power input coupled with a and smaller negative shoulder power contribution in the final part of the preparatory Toe-on longswing. The apparent ease with which female gymnasts appear to be able to perform this skill indicates that it is likely to grow in popularity as gymnasts attempt to increase their difficulty scores by performing piked and even straight version of the Tkachev. From this study coaches should consider training that specifically emphasizes the key role that the hips play in executing this skill. The final body position of the gymnast at release also appears to be less demanding than has been previously reported for the Outward or Inward variants and so provides the gymnast with more freedom to concentrate on working in the phase from a circle angle of 300 to 400˚. The current study provides an example of how the coaching-biomechanics interface can use scientifically grounded data from an ecologically valid setting to inform technique development. Further research into the joint kinetics of gymnasts performing the Toe-on Tkachev where piked and straight version are included could help to further understanding of the individual joint contributions to this challenging skill.

REFERENCES:

Hof, A.L. (1996). Scaling gait data to body size, Letter to the Editor, *Gait & Posture*, 4, 222-223.

Kerwin. D.G. and **Irwin, G.** (2010). Musculoskeletal work preceding the outward and inward Tkachev on uneven bars in artistic gymnastics. *Sports Biomechanics*, 9 (1), 16-28.

Kerwin, D.G. (1995). Apex/Target high-resolution video digitising system. In J. Watkins (ed.), *Proceedings of the Sports Biomechanics section of the British Association of Sports and Exercise Sciences,* (pp1-4). Leeds: BASES.

Marzan, G.T. and Karara, H.M. (1975). A computer program for direct linear transformation solution of the collinearity condition and some applications of it. In Proceedings of the Symposium on Close-Range Photogrammetric Systems (pp. 420- 476). Falls Church. VA: American Society of Photogrammetry.

Yeadon, M.R. (1990). The simulation of aerial movement. Part II: A mathematical inertia model of the human body. *Journal of Biomechanics*, **23**, 67-74.

Acknowledgement

The authors would like to thank the Institute for Applied Training Science Leipzig for their assistance with the collection of the video data.