KINEMATICS AND ANGULAR MOMENTUM CONTRIBUTIONS TO THE TOE-ON TKACHEV ON UNEVEN BARS IN FEMALE GYMNASTICS

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The purpose of this study was to explain the mechanics of the Toe-on Tkachev on Uneven Bars, and identify whether this variant creates the release characteristics needed to perform more complex aerial body positions (e.g. straight). Images of 5 Toe-on Tkachev's performed at the 2007 World Championships were recorded with twin video cameras (50Hz). Digitising and 3D DLT techniques were combined with inertia modelling to develop customised profiles for the gymnasts. Greater flight time and angular momentum (L) suggest this variant may provide the gymnast with the opportunity to perform more complex aerial shapes. The dominant roll of the hip in the creation of L was highlighted.

KEYWORDS: gymnastics, Tkachev, segmental angular momentum.

INTRODUCTION: The Tkachev was introduced into artistic gymnastics by Soviet biomechanist and methodologist Smovevski in 1969; it was first performed in the late1970's in men's gymnastics and in the 1980's by women gymnasts (Nissenen, 1985). For both men and women the Tkachev has evolved into an essential skill for attainment of high difficulty scores. Altering the body position in the flight phase increases difficulty. Women most commonly perform this skill in either a straddle or piked body position. Men have progressed the skill further and have performed Tkachev in a straight body position and have even added twists. In female gymnastics post the 1996 Olympics the Tkachev skill has been made more popular due to change in the dimension of the bars with a inter bar distance increasing from 1.6 m to 1.8 m. Different versions are defined by shape in the flight phase, and swinging direction relative to the low bar (outward or inward) has also become an option. Kerwin and Irwin (2010) compared the outward and inward variants of the women's straddle Tkachev to investigate the influence of the positioning of the low bar on the musculoskeletal demands placed on the gymnast in performing each variant of the skill. These authors highlighted differences in the joint powers at the shoulders as well as release characteristics, and suggested that the inward version of the skill has the potential to allow gymnasts to perform more complex variants. The emergence in popularity of a the Toe-on Tkachev has raised new questions largely relating to whether this variant provides more opportunity for women to create the release characteristics needed to perform the straight Tkachev. The three variants of the Tkachev are illustrated in Figure 1.

Figure 1: Left = Inwards facing Tkachev, Middle = Toe-on Tkachev, Right =Outward facing Tkachev

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This initial study builds on previous research examining the advantages of different Tkachevs to see if the Toe-on variant produces different key release parameters, joint kinematics or angular momentum profiles compared to the previously reported outward and inward variants.

METHODS: **Collection:** Data were obtained from the 2007 Stuttgart World Gymnastics Championships and collected from two video camcorders at a frequency of 50 Hz. The performances were calibrated using two static (1 m x 1 m x 3 m) cuboids giving 48 known coordinates. The origin was defined as the centre of the high bar in its neutral bar position with the calibrated volume encompassing the analysed preparatory longswing. During the competition images of five Toe-on straddle Tkachevs were recorded.
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 longswing and the release and flight phase of the straddle Tkachev. Movement frames were cropped based on the circle angle of the gymnast defined by the vector formed between the mass centre and the neutral bar location and the right horizontal vector. Circle angle was defined as 90° when the gymnast was in a handstand position and continued to 450° as the gymnast returned to handstand. All movement data were analysed between a circle angle of 180° and release. 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 (Abdel-Aziz and Karara, 1971) was used to reconstruct the coordinate data using the TARGET high-resolution motion analysis system (Kerwin, 1995). Customised segmental inertia parameters for each gymnast were calculated using Yeadon's inertia model (1990), limb lengths determined from the video data and the height and mass of each gymnast.
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, (arm, trunk, thigh and shank). 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. Angular momentum (L) of each segment about its mass centre ($L_s = I \cdot \omega$) and of each segment about the whole body mass centre ($L_0 = m \cdot r^2 \cdot \omega_c$) were summed over the four segments to determine L about the body mass centre ($L = I \cdot \omega + m \cdot r^2 \cdot \omega_c$). Angular To account for gymnasts of varying size, L values were normalized (Ln and Ln_{bar}) by dividing by the product of 2π and the moment of inertia in the anatomical position (SS/s). Joint angles and angular velocities at the shoulders and hips were determined throughout the straddle Tkachev. Shoulder extension and hip flexion indicate closure of the respective joint angles and reported as positive values.

RESULTS AND DISCUSSION: The vertical velocity at release provided the longer flight time compared to the Inward and Outward versions reported by Kerwin and Irwin (2010) (Table 1). The longer flight time allowed the gymnast to utilize the greater angular momentum at release, and even allowing for a greater moment of inertia at release the gymnasts performing the Toe-on version were able to rotate faster as highlighted by the larger angular velocity. The angular velocity at release is 9% greater than the values for the inward, and double that for the outward variants reported by Kerwin and Irwin (2010). The horizontal velocity observed in this study was lower than the values previously reported for the outward and inward variants.

Table 1
Mean [±SD] release parameters for the Toe-on straddle Tkachev on uneven bars

	Toe-on (n=5)	Outward* (n=5)	Inward* (n=5)
T_{flight} (s)	0.57±0.04	0.48 ± 0.02	0.40 ± 0.10
θ (°)	67 ± 3	40 ± 13	60 ± 6
V_y (m/s)	-1.58 ± 0.11	-1.67 ± 0.13	-1.92 ± 0.20
V_z (m/s)	1.98 ± 0.26	1.89 ± 0.33	1.49 ± 0.71
I_{ss} (kg/m^2)	7.63 ± 1.41	5.16 ± 1.39	6.14 ± 1.43
ω (rad/s)	-2.47 ± 0.70	-1.18 ± 0.15	-2.26 ± 0.44
L_n (SS/s)	-0.39 ± 0.11	-0.22 ± 0.05	-0.33 ± 0.07

(*= Kerwin and Irwin, 2010).

There is a greater angle of release for the Toe-on version, as the gymnast extends the hip joint to reach the release point (Figure 2). Angles at the hips and shoulders are illustrated against circle angle in figure 2. From figure 1 it is clear that a vigorous opening of the hip joint from approx 330º of rotation about the bar.

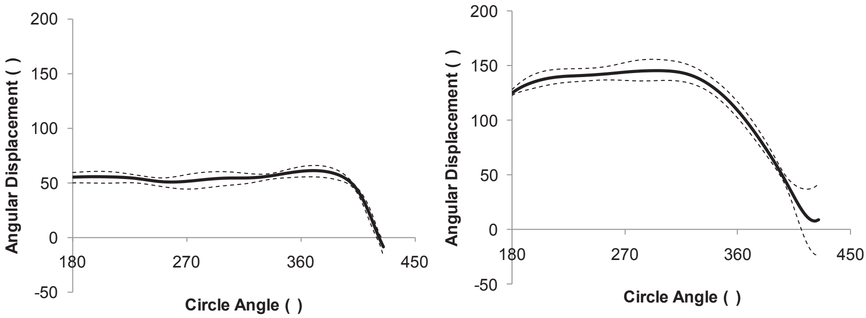

Figure 2: Shoulder (left) and hips (right) angle during the preparatory longswing preceding the Tkachev

The hips extend through a range of approximately 140º as the gymnast prepares for release. The angle of the hips at release angle shows large variability between gymnasts. Three gymnasts release with their hips in a hyper extended and two in a flexed position. The hyper extended position is characteristic of the traditional Tkachev and allows the gymnast to enhance the reversal of rotation during the ascending phase. The shoulders during this phase remain in a pseudo static position with approximately 55º of shoulder flexion, until the final quadrant when shoulder joint opens (flexion) and the gymnast prepares for release (Figure 2). The angular momentum profile is shown in Figure 3.0. Successful performance of this skill is determined by the trajectory of the mass centre and the reversal of angular momentum up to the point of release. Figure 3.0a shows the dominant role the legs play in angular momentum and as one would expect this coincides with the dynamic hip flexion action shown in Figure 2. The rate of change of angular momentum is greatest at the approximately 360º of rotation as the gymnast enters the final quadrant which also coincides with the point at which the angular velocity peaks.

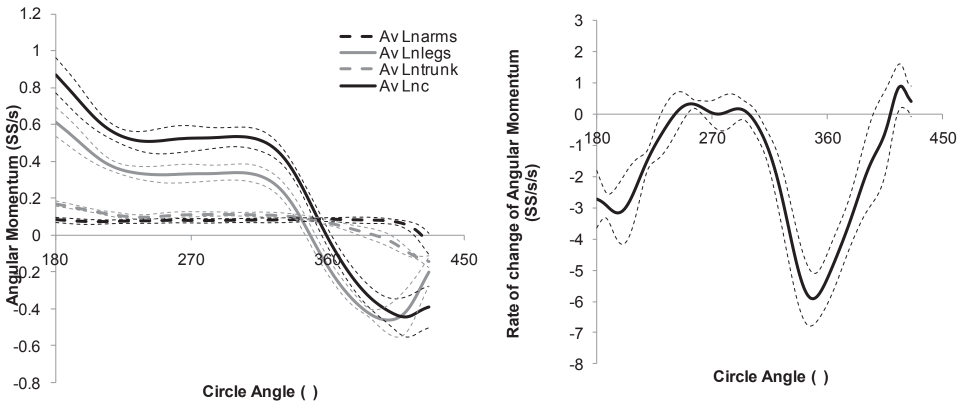

Figure 3: Angular momentum (left), about the mass centre, and for the arms, legs and trunk separately and the Rate of change of angular moment about the mass centre (right).

CONCLUSION: The Toe-on Tkachev on Uneven bars appears to be an advancement of the Inward variant of this previously reported skill. It enables gymnasts to increase key release variables, particularly vertical velocity, (and hence flight time) and angular momentum. In so doing the environment is created in which body shape in the flight phase can be changed, to the point where straight Tkachevs are beginning to appear following Toe-on Tkachevs in women's competitions. From this study coaches should consider the dominant role of the hips in developing specific release characteristics. The current study provides a good example of the coaching-biomechanics interface, whereby meaningful scientifically grounded information from an ecologically valid setting, allows coaches to develop a mind-set of how the skill works. Further research into the joint kinetics will provide a more detailed explanation of the kinematic characteristics described in the current study.

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