BIOMECHANICS OF TECHNIQUE SELECTION IN WOMEN'S ARTISTIC GYMNASTICS: FROM THEORY TO PRACTICE

Michelle Manning[12], Gareth Irwin[2], David G. Kerwin[2] and Marianne J.R. Gittoes[2]

School of Life Sciences, Kingston University, Kingston Upon Thames, UK[1]
Cardiff School of Sport, Cardiff Metropolitan University, Cardiff, Wales, UK[2]

This research aimed to determine effective technique selection for the female longswing through four themes: contemporary trend (T1), biomechanical conceptual (T2), musculoskeletal (T3) and energetic (T4) approaches. 3D video data at two elite competitions provided high ecologically validity. T1 identified the straddle Tkachev as the ideal vehicle with three distinct preparatory techniques (arch, pike, straddle) preceding it. Significant joint kinematic differences were not replicated in release parameters (T2) although joint kinetics highlighted greater physical demands in the pike (T3), with an energetics effectiveness score highlighting the arch as a technique promoting skill development (T4). Increasing knowledge and understanding allows coaches to optimise technique selection.

KEY WORDS: coaching, skill development, longswing, effective technique.

INTRODUCTION: Technique selection is a central feature of coaching when developing effective skill learning. In gymnastics many skills can be performed with different techniques and knowing which is best is the biggest challenge for coaches at all levels. The mindset of the coach is key to the technique selection process and the development of the gymnast (Irwin et al., 2005). Coaches observe skills as a series of body shapes and movement patterns that cause biomechanical changes that are often unobservable to the coach's eye. Effective coaching practices therefore require mechanical knowledge and understanding of the desired skills in order to develop technique and keep in line with the rapidly developing sport. The female longswing is a key skill that directly links to the development of more complex skills (Hiley & Yeadon, 2007). Although the backward longswing has received a high amount of research focus, variations in longswing technique have not. Previous researchers have highlighted the importance of the shoulder and hip joints in the success of the longswing; the varying movement patterns at these joints and resultant mechanics therefore require further investigation. Manning et al. (2011) identified that three distinct longswing techniques preceding the straddle Tkachev had varying joint kinematic characteristics during the previously defined functional phases (shoulder hyperflexion to extension and hip hyperextension to flexion; Irwin & Kerwin, 2005). However, a significantly earlier initiation of the shoulder and hip functional phase in the arch longswing did not significantly influence the key release parameters; therefore it was not apparent as to why one technique would be selected over another. Analysis into the musculoskeletal demands of each technique would provide coaches with insight into a scientific criterion to add to the technique selection process. Furthermore, previous researchers have established the importance of considering the biomechanical energetic input from gymnasts and their interaction within the gymnast-high-bar energy system (Arampatzis & Brüggemann, 2001). Providing coaches with information on the overall energy cost of each technique assists in gymnast preparation, technique development and technique selection. Therefore this research aimed to increase the knowledge and understanding of the biomechanics underpinning female longswing techniques to determine effective technique selection, with the overall aim to demonstrate the important link between theory and the underlying processes of practice.

METHOD: **Data Collection:** Data were collected from the qualification rounds at the 2000 Olympic Games (OG) and 2007 World Championships (WC). Video image data were obtained from two 50 Hz video cameras (Sony Digital Handycam VX1000E). Initially each of the 82 qualification routines from OG and 117 from WC were recorded with the age (17.7 ±

2.8 years), height (1.54 ± 0.07 m) and body mass (45.12 ± 6.88 kg) of the elite gymnasts by IOC and FIG approved researchers respectively prior to the competition. The methods followed a thematic approach; from Theme 1: *Contemporary trend analysis* where eighteen successfully executed straddle Tkachev recordings were selected for the subsequent three themes. Images of calibration objects at OG consisted of a single calibration pole with five equally spaced (1.0 m) spheres (0.1 m diameter) at six pre-measured locations giving 30 known coordinates. At the 2007 WC two static (1 m x 1 m x 3 m) cuboids giving 48 known coordinates provided the calibrated volume encompassing the analysed preparatory longswing. The origin was defined as the centre of the high bar in its neutral bar position. **Data Processing:** Theme 1: *Contemporary trend analysis* incorporated identification of release and re-grasp skills performed and the preparatory longswings preceding these skills. Longswing techniques were defined through visual inspection of shoulder and hip movement patterns consisting of degree of shoulder extension and hip flexion, location of movement (above or below the low bar) and presence of hip abduction. Calibration and movement frames for the 18 straddle Tkachev trials used within Theme 2-4 were digitised (Vicon Peak 9.0, UK) with calibration images consisting of ten frames for each camera and movement data comprising of the preparatory longswing, straddle Tkachev and re-grasp. Gymnast 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 135° and release. The left and right fifth MTP, ankle, knee, hip, shouder, elbow, wrist, centre of the gymnast's head and the centre of the high bar for each movement frame were digitised from each camera view. Data were time synchronised using the methods of Yeadon and King (1999) and a 12-parameter three-dimensional (3D) direct linear transformation (Marzan & Karara, 1975) was used to reconstruct the 3D coordinate data. Reconstructed 3D coordinate data were filtered with a low pass digital filter with a cut off frequency of 8 Hz. 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. A four segment planar representation of the gymnast was constructed by averaging the digitised coordinate data for the left and right sides of the body. **Data Analysis:** Theme 2: *Biomechanical conceptual approach* analysed the functional phases defined by Irwin and Kerwin (2005) as maximum shoulder flexion to extension and maximum hip extension to flexion. Corresponding joint kinematics were also reported together with release parameters consisting of angle of release, horizontal and vertical velocity of the gymnast's mass centre (CM) and angular momentum about the gymnast CM and bar. The instant of release was defined using a linear coordinate separation between the virtual mid-wrists and centre of the high bar (Manning et al., 2011) and occurred once the distance exceeded 10% of the maximum value obtained during the preceding longswing. Angular momentum (L) of each segment about its CM and of each segment about the whole body CM were summed over the four segments to determine L about the gymnast's CM. L values were further normalised (Ln and Ln_{bar}) by dividing by the product of 2π and the moment of inertia in the anatomical position (SS/s). Theme 3: *Biomechanical musculoskeletal approach* incorporated a two dimensional (2D) inverse dynamics analysis to calculate internal joint forces (IJF) and moments (JM) at the knees, hips, shoulders and high bar. Known zero forces at the toes were used with Newton's second laws of linear and angular motion to calculate net joint forces. Joint powers (JP) were calculated as the product of the previously defined JM and joint angular velocities to determine the nature of the muscle action occurring around the joint centres. The time integral of JP was calculated in determining joint work (JW) with JW at the shoulder, hip and knee joints summed to calculate total JW. Total JW represented gymnast energy contribution to the gymnast-high-bar total energy system. Theme 4: *Biomechanical energetics approach* determined longswing effectiveness by calculating the change in total energy (En_{Tot}) between a circle angle of 135° and release and dividing by change in gymnast energy (En_{Gym}) producing a biomechanical energetic effectiveness score. **Statistical Analysis:** Having met assumptions of normality (Shapiro-Wilkes) and homogeneity of variance (Levene's test), differences between discrete variables for the arch, straddle and pike longswings were quantified with an Analysis of

Variance ($p \leq 0.05$) with continuous data differences quantified by a percentage Root Mean Squared Difference.

RESULTS & DISCUSSION: *Contemporary trend analysis* (Theme 1): The straddle Tkachev was identified as the most frequently performed release and re-grasp skill from a backward preceding longswing across both competitions (53%). Of the backward longswings performed where negotiation of the low bar was required on the downswing, the arch (19%), straddle (35%) and pike (31%) longswings were the most distinct techniques employed. Building on from Theme 1 and the work of Manning et al. (2011) Theme 2: *Biomechanical conceptual approach* investigated the joint kinematics and key release parameters providing coaches with more in-depth knowledge of these varying techniques to perform the same skill. Significantly earlier initiation of the shoulder and hip functional phases in the arch technique (*$p<0.05$*), coupled with significantly greater hip extension (*$p<0.05$*) at the functional phase initiation than the pike technique. However, differences in joint kinematics were not reflected in key release parameters, in agreement with the findings reported by Manning et al. (2011). Therefore the selection criteria of one technique over another remained unclear and Theme 3 followed: *Biomechanical musculoskeletal approach.*

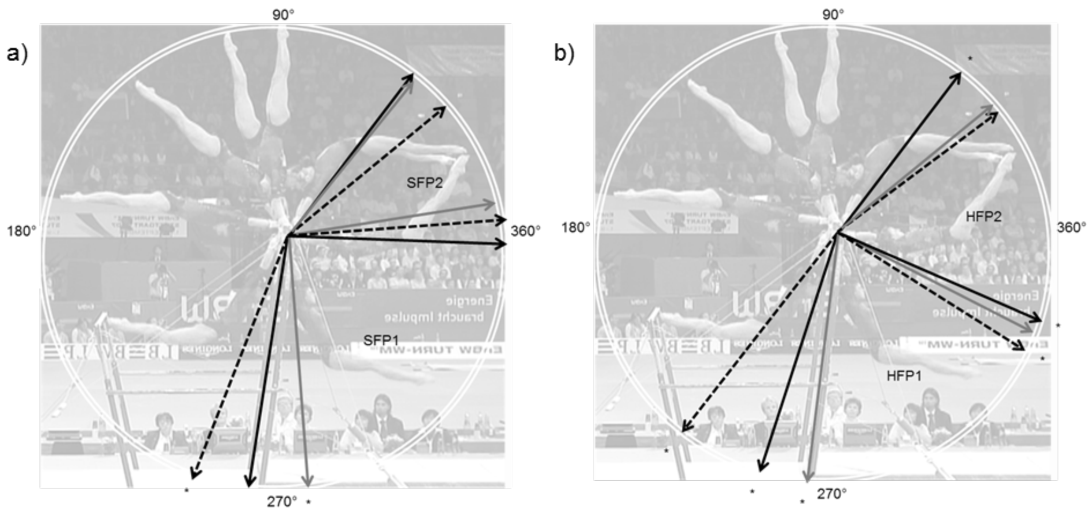

Figure 1: Dartfish™ image of a) shoulder (SFP) and b) hip (HFP) functional phases (1 & 2) for the arch (dashed), straddle (black) and pike (grey) longswing. * Denotes significant difference ($p \leq 0.05$).

Theme 3 highlighted that the pike longswing had significant greater physical demand placed at the gymnast's hips with a significantly earlier concentric action to initiate the second functional phase with greater work contribution during this period. Similarly at the shoulder joint the pike longswing executed a greater shoulder flexion joint moment to prepare the gymnast for release. The physical requirement inferred by Theme 3 of the pike longswing provides coaches with understanding of prescribing specific physical preparation activities compared to the comparative longswing techniques. Building on Themes 1-3, Theme 4: *Biomechanical energetics approach* applied a novel effectiveness score to further investigate the gymnastics energetic contribution to the total gymnast-high-bar energy system. For each longswing technique En_{Tot} decreased as the gymnast negotiated the low bar with the gymnast adding to the system through muscular action (En_{Gym}) on the ascent. The arch longswing was highlighted as the technique that over came the energy deficit during the descent phase, had an increase in energy to successfully complete the straddle Tkachev and has 23% of energy remaining in reserve (Figure 2). Compared to the pike technique that utilised all their gymnast energy to overcome the deficit in energy due to energy lost in the descent phase, the arch longswing is potentially the key technique for the development of more complex skills or combinations of skills.

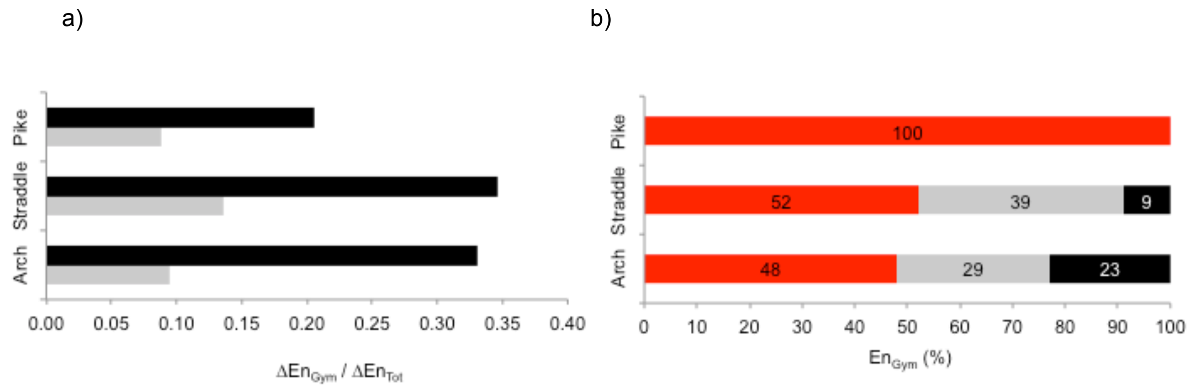

Figure 2: a) Increase in normalised gymnast energy (black) and total energy (grey). b) Percentage of gymnast energy utilised to overcome deficit in total energy (red) and increase total energy (grey) with remaining gymnast energy (black).

CONCLUSION: The thematic approach has allowed the research findings to emerge in a meaningful and ecologically valid manner. The findings can be directly linked to enhancing coaching knowledge and providing further insight into the trends in elite gymnastics competition and identified varying techniques to perform the Tkachev (Theme 1). Biomechanical analyses provided knowledge of the techniques performed developing coaches' conceptual understanding of these skills and providing insight into the underlying mechanisms controlling these skills (Theme 2). The pike longswing was identified as requiring varying physical preparation to the contrasting techniques (Theme 3) with potential development opportunities also highlighted with the arch longswing having excess energy to develop more complex versions and combinations of skills (Theme 4). Coaches have access to knowledge that they can employ to optimise the technique selection process with potential to customise technique selection to the needs of individual gymnasts.

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