MUSCULOSKELETAL WORK IN HIGH BAR PROGRESSIONS

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This study explained and assessed the similarity in joint kinetic profiles between the longswing (LS) and four progressions. Video recordings of four male gymnasts performing the LS and four progressions were quantified using 2D DLT techniques on an instrumented high bar. Inverse dynamic analyses quantified the muscle moments and work done at hips and shoulders. RMSD analysis between the work during the LS and progressions was used to group the progressions based on overall level of similarity to the LS. The least similar progression was the looped bar pendulum swing, whilst the most similar was the bent knee LS. This study has identified that progressions can be classified into those that are similar in terms of physical demand or movement pattern. This study raises the question should progressions be selected based on its kinetic or kinematic similarity to the target skill.

KEY WORDS: kinetics, inverse dynamics, specificity

INTRODUCTION: The longswing on high bar is the foundation of all competitive routines. Research into the longswing, over last two decades, has been dominated by two prominent research groups, in Loughborough (Yeadon and Hiley, 2000; Hiley and Yeadon, 2005) and Cologne (Arampatzis and Brüggemann, 1998, 1999) using forward and inverse dynamic modelling techniques to explain and optimise performance. Early work on the longswing (Okamoto *et al.,* 1987) and later work on the accelerated longswing (Yeadon and Hiley, 2000; Arampatzis and Brüggemann, 1998) established the importance of the hips and shoulders with the functional characteristics being displayed by a rapid hyper extension to flexion of the hips and hyper flexion to extension of the shoulder joint as the gymnast passes the lower vertical (Yeadon and Hiley, 2000). The preferred mode for teaching this skill is through the use of progressions which provide a safe and effective pedagogical methodology. When choosing progressions coaches attempt to replicate the physical demands and spatial and temporal characteristics of the target skill in the progression (Irwin *et al.,* 2005). Arising from specificity of training principle to develop a method to rank progressions based on their kinematic similarity to the longswing (Irwin and Kerwin, 2005). These authors concurred with earlier research suggesting that effective progressions should elicit similar movement patterns as the target skill (Elliott and Mitchell, 1991). An understanding of the musculoskeletal demand of the longswing and associated progressions, through a kinetic analysis, would provide a framework for the application of the principles of training specificity and overload (Dick, 2002) and building on previous research. Therefore, this study aims to utilise an inverse dynamics modelling approach to profile the moments, powers and work done at the hips and shoulders during four associated progressions and the longswing. The purpose was to explain the joint kinetic profiles of these progressions, to identify the physical demand placed on the performer and finally assess the similarity of each with the target skill

METHOD:

Data Collection: Four members of the Men's National Gymnastics Squad participated in this study (age = 22.5 $\pm$ 4.1 yrs, mass = 66.4 $\pm$ 7.2 kg, stature = 1.69 $\pm$ 0.05 m). Subject specific body segment inertia parameters were obtained using a geometric inertia model (Yeadon, 1990) to obtain subject specific body segment inertia parameters. All testing was performed in a gymnastic arena on a standard competition high bar. Each gymnast performed three series of four longswings and four progressions (Figure 1). The progressions were selected based on those currently used by International level gymnastics coaches. Images in the sagittal plane were recorded using a digital camcorder (Sony DSR-PD1100AP, 3-CCD, Japan) placed approximately 40 m from the centre of the activity at a height of 5 m with its optical axis at 80° to the plane of motion. The camera was operated at 50 fields per second with the electronic shutter set to 1/300 s. Calibration of the performance area was achieved by placing a single calibration pole of height of 5.176 m, containing four 0.10 m spherical markers, at three pre-marked locations to form a plane of approximately 5 m x 5 m. Reaction forces on the bar were recorded (1000 Hz) using strain gauges bonded in pairs to the bar's surface. Calibration was performed by loading and unloading the bar with known loads and recording the average voltages for each loading condition. Vertical and horizontal bar stiffness were used in combination with linear regression equations to predict vertical and horizontal bar forces (Kerwin and Irwin, 2006). Synchronization of the force and video data was achieved through the use of 20 LEDs (Wee Beasty Electronics, Loughborough, Leicestershire, UK) in the field of view of the camera which were sequentially illuminated at 1ms intervals. The force data capture and the LEDs were triggered simultaneously, enabling the force and video data to be matched to within 3 ms.

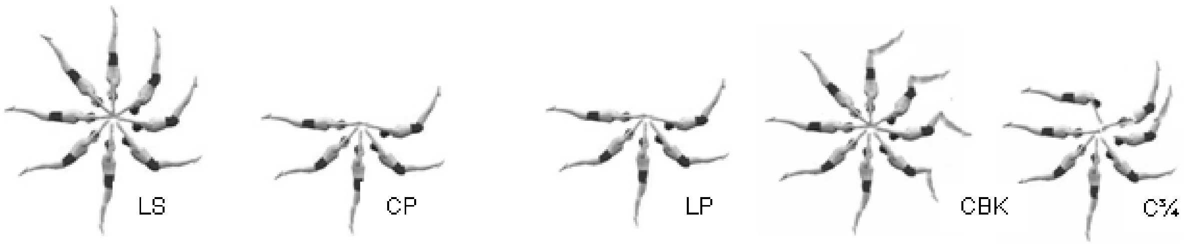

Figure 1. The chalked bar longswing (LS) and four associated progressions: Chalked bar pendulum swing (CP), Looped bar pendulum swing (LP), Chalked bar bent knee longswing Chalked (CBK), and Chalked bar ¾ longswing (C¾) (pictures adapted from Kerwin, 1999).

Data Analysis: The images of the calibration object and the gymnast were digitized using the high resolution TARGET motion analysis system (Kerwin, 1995). Camera calibration was achieved using an 8 parameter direct linear transformation algorithm. In each field the centre of the bar, the centre of the gymnast's head and his right wrist, elbow, shoulder, hip, knee, ankle, and toe were digitized. A digital low pass filter (6 Hz) was used to remove random error from the reconstructed co-ordinates. Joint kinetics were determined through the application of Newton's 2nd law of motion. The human performer was modelled as a pin-jointed four link system comprising arms, trunk, thighs and shanks. In order to minimize the propagation of errors the closest known forces were used to calculate the internal joint forces. As such a combined approach of 'bar down' to calculate the shoulder and hip forces and a 'toe up' to calculate the knee and hip forces was used. The average of the two estimated hip forces was used throughout the subsequent analyses. Muscle power (MP) was calculated as the product of the muscle moments (MM) and angular velocity (ω) providing a measure of the rate of work done (WD). The mechanical work was calculated from the time integral of the MP profiles for each joint and enabled the type of muscle action at each joint to be specified. MM, MP and WD at the shoulders and hips were calculated for each longswing and progression. The analysis focused primarily on the hip and shoulder functional phases occurring around maximum hip extension to flexion and maximum shoulder flexion to extension. In order to compare within and between gymnasts all digitised data were interpolated using a cubic spline function, (Mathcad, 2001, MathSoft Engineering & Education, Inc. Surrey, UK). The maximum height of the mass centre on the downswing and upswing phases of each skill defined the beginning and end points respectively. Root mean squared differences (RMSD) between the WD at the shoulders and hips were averaged to produce a '**Difference Score'** (DS). Using a similar RMSD analysis, within skill variability was calculated from the standard deviation of the RMSD's, providing a '**Variability Score'** (VS). Movements involved in this study were regarded as 'closed' because they were constrained by the bar and by the performance criteria set out by the international governing body (FIG, 2001) as such a low level of variability was considered desirable. Each RMSD was represented as a ratio of the range of each corresponding variable during the functional phases of the longswing. A score of **'Specificity Score'** was calculated as a product of the **DS** and **VS**.

RESULTS & DISCUSSION: The LS produced MP's at the shoulders which were consistently higher than that of the hips with maximum values of 14.4 ± 6.7 W·kg^{-1} and 6.0 ± 1.7 W·kg^{-1} respectively. The progressions showed a similar dominance for MP at the shoulder joint (Figure 2). The least similar progression to the LS in terms of MP was the CBK (9.4 ± 3.5 W·kg^{-1}), this finding concurs with Irwin and Kerwin (2005) regarding the similarity in shoulder kinematics for this progression. A dominant positive MP at the shoulders was shown to occur during the ascending phase of the LS and progressions, suggesting a concentric contraction taking place. This corresponds to the findings of Okamoto *et al.* (1987) and Arampatzis and Brüggemann (1998), although in the latter study the magnitudes were higher due to the fact they investigated the accelerated longswing. This study showed the MP at the hips to be lowest for the LS compared to all of the progressions (Figure 2). The maximum hip MP was achieved by the LP 8.5 ± 4.1 W·kg^{-1}, 30% higher that the target skill. In contrast Irwin and Kerwin (2005) found LP to be the most similar progression to the LS in terms of the hip kinematics. This suggests that although a similar movement pattern was being achieved the musculoskeletal loading was different to the final skill. Progressions which are biomechanically similar to the target skill may be more effective (Elliott and Mitchell, 1991); a concept which concurs with the principle of training specificity (Dick, 2002). However, there is a dichotomy in terms of whether LP would be effective or not, raising the question, should a progression be similar in terms of kinematics or kinetics in order to be more effective? Hip joint kinetics of the LS and the progressions displayed a consistent pattern during the descending phase i.e. a positive to negative pattern (90° – 180°) indicating a concentric to eccentric action at the hips (Figure 2). During the ascending phase, a large positive hip power was seen suggesting a concentric contraction. The WD at the hips and shoulders provided an indication of the energy requirement for the LS and progressions. It is evident from Figure 3, that the majority of WD by each progression occurred in the ascending phase, with the shoulder joint playing a dominant role compared to the hips. The CBK was the most similar progression to the LS in terms of physical demand and musculoskeletal contribution and was therefore ranked 1st. Conversely the LP and C¾ can be seen to be the least similar and were therefore ranked 4th and 5th respectively. These finding showed that progressions that had good similarity with the target skill in term of joint kinetics were not always the progressions that showed good similarity with joint kinematics (Irwin and Kerwin, 2005).

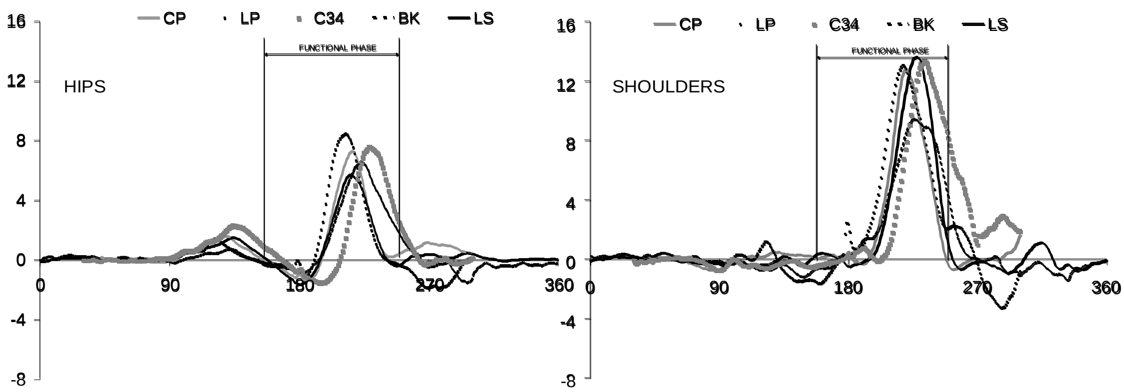

Figure 2. Average muscle power at the hips and shoulders during a chalked bar longswing (LS) and four associated progressions (Chalked bar pendulum swing (CP), Looped bar pendulum swing (LP), Chalked bar bent knee longswing Chalked (CBK), and Chalked bar ¾ longswing (C¾).

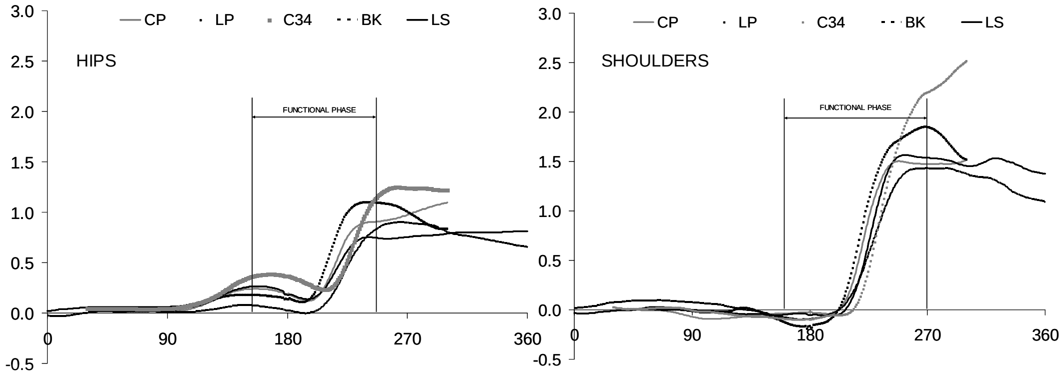

Figure 3. Average work done at the hips and shoulders during a chalked bar longswing (LS) and four associated progressions (Chalked bar pendulum swing (CP), Looped bar pendulum swing (LP), Chalked bar bent knee longswing Chalked (CBK), and Chalked bar ¾ longswing (C¾).

CONCLUSION: Progressions that cause gymnasts to use similar levels of energy to the LS are placing a stress on the musculoskeletal system in a specific manner. Although the energy level, in a progression, may be similar, this does not always correspond to similarities in the movement pattern. As a consequence the physiological adaptations which occur through training may not be effective or desirable. Different classifications of progressions may exist with those that replicate the movement pattern (kinematics) and those that replicate the physical demand (work done/ energy). This study has generated further questions for example, how is skill development effected by the choice of type of progression?

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