THE MODEL OF SHOULDER JOINT OF GYMNAST INTERACT WITH THE LONG SWING GYMNASTIC ELEMENT ON PARALLEL BARS

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The purpose of this study was to identify the shoulder movement pattern which interacts with a long swing gymnastic movement (Belle). Four (4) national level gymnasts in China performed eight repetitions of movement (Belle), on the middle of parallel bars. Reflective markers (14mm) and ten high-speed cameras (ViconT40S,100Hz) were used to observe the time history of attached markers on the parallel bars and subjects. The coordinates of the necessary markers were calculated using ViconT40S digitizing software. The stiffness coefficient of the shoulder joints (K_S=31667.5 N.m^{-1}) were estimated through the model. The reaction on the Humeral head (R_S=194.45 N) at the vertical position of under the bars is very much lower than the other places. This implied shoulders at the bottom of the motion should be flexible and soft.

KEYWORDS: stiffness of shoulder, Belle movement, Humeral head, parallel bars.

INTRODUCTION: Gymnastic movements which start with the long swing are high difficult movements compare with other movements of parallel bars apparatus. Because of the verity of execution errors which were introduced by FIG (Code of Point,2017) and different types of body coordination: essential to utilize strain of the bars (Chandana et al.,2017) under the parallel bars apparatus. For this aspect, gymnasts use a special movement pattern for particular long swing movements (Belle type) to minimize execution errors (Chandana et al., 2018). National level gymnastic coaches in Hubei Province, China believe (<90% based on a survey in Hubei Province in China) preparation of shoulders and identification of the accurate movement pattern of shoulders entire long swing movement are difficult. As a solution for this problem, the shoulder movement pattern with providing stiffness properties of shoulder joints and reaction force on Humeral head interacts with the highly executed long swing movement (Figure 1.a) were investigated. These findings provide standards of the preparations of shoulders for Belle type gymnastic movements on parallel bars.

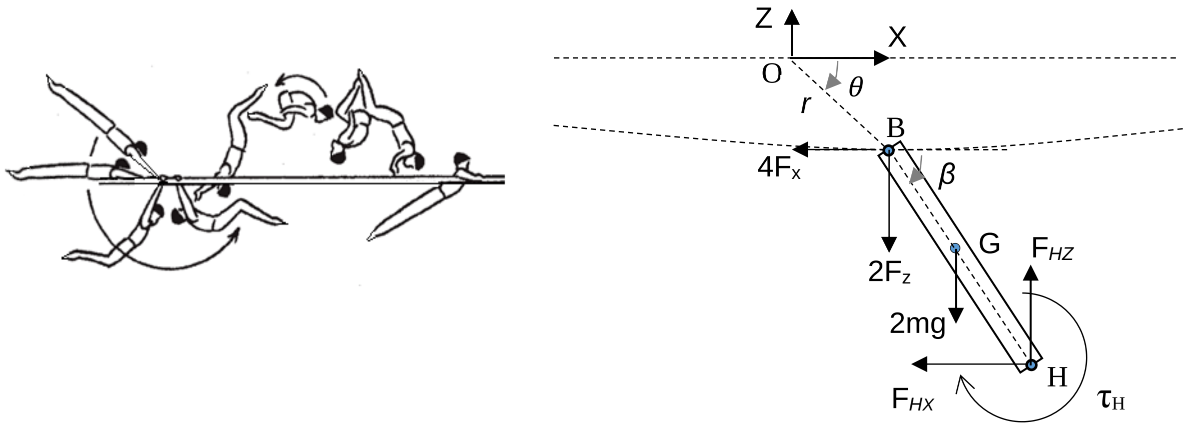
METHODS:
Data Collection: National level four (4) gymnasts in China performed eight repetitions of movement (Belle), under four different conditions (two directions on bars, at indoor and outdoor) on the middle of parallel bars. The best Belle movement (execution errors = 0.00) was considered to do the main calculation and other attempts were used to prove the validity and reliability of data. Belle type gymnastic movements are symmetric on the sagittal plane of the gymnast-parallel bars system. Reflective markers (14 mm) and ten high-speed cameras (ViconT40S, 100 Hz) were used to observe the time history of attached markers on the parallel bars and gymnast. The height of the parallel bars from the mat is 175 cm. The experiment was repeated for another height (185 cm) of the parallel bars to improve the validity of data.
Data Analysis: The time history of all necessary markers on gymnast's body segments (Head and Neck, Upper Arm, Lower Arm, Hand) and parallel bars (Chandana *et al*., 2017) were measured using a Vicon Nexus 2.2 software. Two markers attached around (10 cm) the middle point (B) of a bar. Hence, r, θ, and β (Figure 1.b) were calculated. A stable handstand position on the middle points of parallel bars was considered as an initial position of the dynamic movements of both parallel bars and gymnast at t=0 s. The initial displacement (on the sagittal plane) between Humeral head and Cervical Vertebra point (7th) is negligible at a handstand position on parallel bars. The kinematic and kinetic values of the gymnast-parallel bars system were calculated using Matlab R2014b software.

The Stiffness and damping coefficients of the parallel bars for 175 cm parallel bars height from the mat were considered as following Table 1(Chandana *et al*., 2017 and Chandana *et al*., 2018).

Table 1: Stiffness and damping coefficients of the parallel bars

K_x (N.m^{-1})	C_x (N.s.m^{-1})	K_z(N.m^{-1})	C_z (N.s.m^{-1})
28,601	3.9496	9101	10.90

Model of Arm: Gymnast's two arms at the dynamic situation (t=t) represent as shown in Figure 1.b. BH considered as rigid arms till just before the release the bars. The points B and H are moving on the sagittal plane (XZ plane) of the gymnast-parallel bars system. Dynamic strains of metal pots and wooden bars due to their displacements from stable positions cause to occur forces act on the point B (Chandana et al., 2018).



(a) (b)

Figure 1: (a) The long swing movement (Belle) as shown in FIG code of point 2017, page 128. (b) Free body diagram of the Arms (BH) of the player on XZ-plane of the gymnast-parallel bars System at time t=t. F_{Hx} and F_{Hz} are components of the reaction force on the proximal end of the Upper Arm. τ_H is a muscle torque around the shoulder joint. O is the origin of the coordinate system. It also represents the middle point between two middle points of parallel bars. F_X and F_Z are generated due to the horizontal displacement of a top of the metal post and vertical displacement of the middle point of the parallel bars. Maximum displacement of B point on YZ-plane is negligible with compare to it on XZ- plane.

To derive following dynamic equations (1 and 2) of the motion (Figure 1.b) of two arms (BH), the Kane’s procedure (Levinson & Kane, 1985) and Lagrange equation were used.

$$F_{HX} = \frac{1}{r\cos 2\theta}\left(-Ar\sin\theta + B\cos\theta\right) \rightarrow (1),$$

$$F_{HZ} = \frac{1}{r\cos 2\theta}\left(Ar\cos\theta - B\sin\theta\right) \rightarrow (2) \text{ Where } \theta\text{: } \frac{\pi}{4} \prec \theta \prec \frac{3\pi}{4},$$

$$A = 2m\left[\ddot{r} - l_{BG}\{\ddot{\beta}\sin(\beta-\theta) + \dot{\beta}^2\cos(\beta-\theta)\} - r\dot{\theta}^2 - g\sin\theta\right]$$

$$+4(K_X r + C_X\dot{r})\cos\theta - 2(K_Z r + C_Z\dot{r})\sin\theta, \text{ and}$$

$$B = 2mr\left[2\dot{r} + r\ddot{\theta} + l_{BG}\{-(\dot{\beta}^2 + \dot{\theta}\dot{\beta})\sin(\beta-\theta) + \ddot{\beta}\cos(\beta-\theta)\}\right]$$

$$-2r\left[2(K_X r + C_X\dot{r})\sin\theta + (K_Z r + C_Z\dot{r})\cos\theta\right]$$

K and C are spring damp coefficients of parallel bars (Chandana *et al*., 2017).

RESULTS: The shoulder movement entire Belle movement was measured with respect to the Cervical Vertebra (7th) position (CV). Initially, the displacement between HH and CV is negligible (*p*=2 mm, see the Figure: 3 near to 0.1s). Assumed that shoulder movements on XZ-plane can be represented by a linear massless spring damper (Linge et al., 2006 and

Levinson & Kane, 1985) between HH and CV. $F_{HZ} = K_S\, p + C_S\, \dot{p}$, where K_S (shoulder stiffness) and C_S are spring damp coefficients.

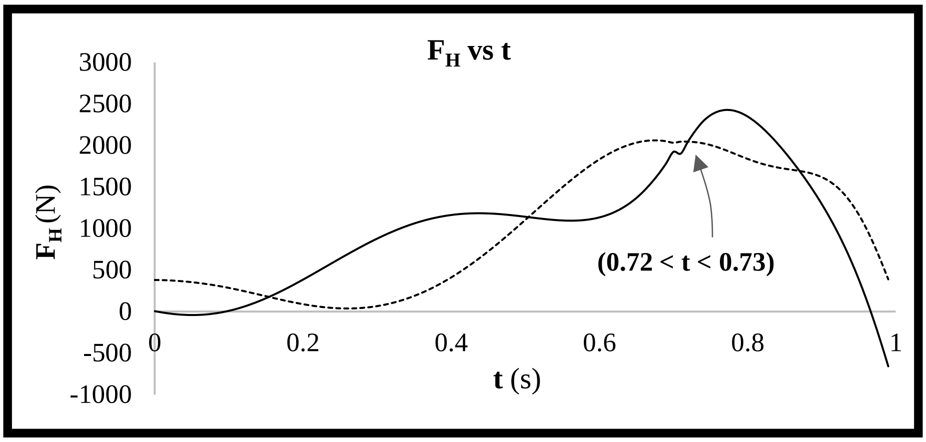


Figure 2: $F_{HZ} = K_S\, p + C_S\, \dot{p}$ and $F_{HZ} = 2m_{BH}(\ddot{r}-g) + 2F_Z + 2m_{BH}\,(r + l \cos\theta_Y)\,\dot{\beta}^2$ graphs show dashed line and solid line respectively. The p is the displacement of Head of the Humerus from Cervical Vertebra (7th) on XZ-plane for best attempt among 8 attempts (execution errors=0.00).

These two graphs are only satisfied all kinematics of Arms at the right of the bottom (two frames were considered at the bottom: t = 0.72 s and t=0.73 s) of the movement (Figure 1.a). Angles β and θ are 90^0. The θ_Y is a shoulder angle from the vertical line on YZ-pane.

Table 2: Kinematics of the arms at t = 0.72s and t = 0.73s of the movement (Figure 1.a).

Time (s)	F_{HZ} (N)	r (m)	$\ddot{r}$ (m.s^{-2})	θ_Y (deg)	$\dot{\beta}$ (deg.s^{-1})	p (m)	$\dot{p}$ (m.s^{-1})
0.72	2051.1	0.0460	-1.74226	1.56	262.64	0.03125	0.158
0.73	2181.7	0.0459	-2.00138	1.56	257.92	0.03333	0.150

At t = 0.72s; K_S=32,716 N.m^{-1}(for an Arm) and at t = 0.73s; K_S = 30,619 N.m^{-1} (for an Arm) Average of K_S for one Arm assuming damping factor is small. K_S is 31,667.5 N.m^{-1}.

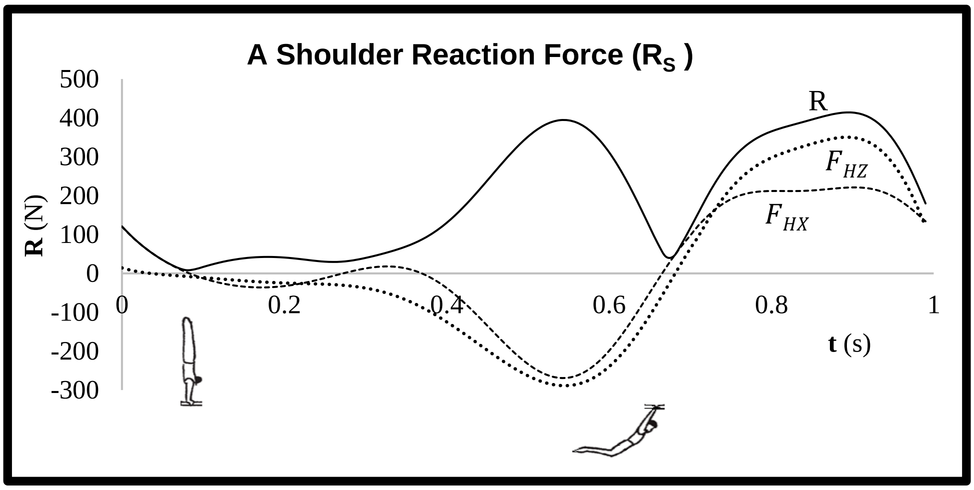


Figure 3: Resultant reaction force on H is R = $\sqrt{F_{HX}^2 + F_{HZ}^2}$, where F_{HX} and F_{HZ} are components of reaction force R as shown in Figure 1.b. R_S = R/2 for highly executed Belle of a gymnast (58kg).

DISCUSSION: The shoulder kinematics and kinetics are described the specific dynamic movement pattern of shoulder movements interact with the long swing movement. The gymnast starts long swing movement with the stable handstand position on the parallel bars (t=0, R_s~ 100 N). The R_s is very small at 0.1 s due to shoulder movement up and dawn. After that, the gymnast extends his entire body with flex shoulders (no more than 180^0) and chest-in position (C-shape of the posterior side of the upper body). In this period, the range of relative displacement of Head of Humerus (HH) from the Cervical Vertebra (7^{th}) is (0–0.1175 m) and muscle torque on the sagittal plane gymnast-parallel bars system are very small. After first 90^0 of the motion, the gymnast was improved muscle torque until 18.11N.m. However, at the bottom of the motion, the player maintains the soft shoulders (muscle torque around a shoulder is small) with low reaction force ($8.17N \leq R_S \leq 410.26N$) on the HH as illustrated in Figure 1.b. The average reaction force on the HH is 194.45N at the bottom of the motion (Figure:3). Just after released the bars, muscle torque and reaction force improved significantly to prepare for the rotation. Before releasing the bars HH shows the maximum relative displacement from the Cervical Vertebra (7^{th}) as 0.0423m at 0.78s of the motion. The biomechanical model of shoulders consists of a linear spring damper between Cervical Vertebra (reference point on the sagittal plane) and HH to examine the elastic behaviour of shoulder joints on XZ-plane. The gymnast (58kg) has a 31,667.5 $N.m^{-1}$ stiffness coefficient (Table:2 and Figure:2) to perform the long swing movement (Figure:1.a).Though most of coaches and players in China believe that the reaction force on shoulders is optimising at bottom of the motion of Belle, experimentally shows that reaction force on HH is minimized by gymnasts. Because player prepared his body for the rotation. Therefore, the upper body moved upward direction with respect to HH. Also, the head and neck segment kept at right middle of the arms. These facts clearly describe that special shoulder movement (soft shoulders) need to prepare specially at bottom of the motion. Finally, gymnast felt soft shoulders at bottom of the motion brings soft landing on parallel bars (Figure:1.1). Hence reduced execution errors which were introduced in specific deductions for the parallel bars as shown in ‘Article 14.3 Specific Deductions for the Parallel Bars’ (Code of Point 2017) and prevented shoulder injuries from incomplete landing on bars in China.

CONCLUSION: This study identified the most common cause of injuries (78% shoulder injuries due to the incomplete landing on bars) based on Belle movement on parallel bars in Hubei Province, China. Specially beginners always try to apply maximum force to pull the bars at the bottom of the Balle movement. If it is, gymnasts fail to transfer maximum elastic energy from parallel bars to rotations as well as reduced rotation speed. Hence, players couldn't extend the body at the landing position on the bars and occur shoulder injuries. Solution for these matters is a soft shoulders: reaction force on shoulders ($R_{S,Av}$=194.45 N), head and neck inside the arms, hip extended, upper body need to move upward respect to HH at the bottom of the Belle movement on parallel bars, and the stiffness coefficient of the shoulder joint is nearly K_S=31,667.5 $N.m^{-1}$of Chinese gymnasts.

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