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MECHANICAL LOADING OF THE GYMNAST'S MOTOR SYSTEM DURING SWINGS ON RINGS

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Abstract. The aim of this work was to identify the mechanical loading of the gymnast's motor system during forward and backward swings on gymnastic rings. A junior gymnast of the First Class, aged 14, with body mass 53.1 kg and body length 1.61 m, participated in the study. He executed a series of ten cyclic swing movements on rings with his maximum amplitude. Kinematic variables of the gymnast's centre of mass (COM) as well as reaction forces in the cables were measured and synchronized using the SIMI MOTION movement analysis system. Two separate phases of mechanical loading of the motor system have been identified: resistance phase and non resistance phase. In the non resistance phase the gymnast attains similar values of the COM's momentum but different angular displacements. In the resistance phase the forces acting on the motor system have their maximum. They amount to 5.5 BW for the forward swing and 6.5 BW for the backward swing movement. The maximum rate of change of the force for forward and backward swing is 42.6 BWs^{-1} and 67.4 BWs^{-1}, respectively. These two variables differentiate the mechanical loading of the gymnast's motor system between forward and backward swings. The reaction force produced by the gymnast is significantly greater during the execution of forward swings. It seems probable that horizontal displacements of COM may be the factor responsible for reduction of the mechanical loading experienced by the gymnast.

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Key words: Gymnastic rings - External loading - Swing movements

Introduction

Exercises with the use of gymnastic rings can be divided into three categories: swings, force and balance. The most basic of these exercises are swings. An execution of a swing overloads the gymnast's motor system. This unusual longitudinal deformation results from the fact that the gymnast's COM is placed

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below the point of grip on the rings. The force of gravity causes the gymnast's vertical fall, whereas the reaction force of the cable is directed upward. The resulting upper limbs and spinal column overload may attain values over 2100 N per each shoulder joint [2]. The profile of the cable tension force exerted by the gymnast's arms was recorded for the forward [2,7,11,13,15] and backward [1,5,11,21, 22,23] giant circle exercises with the use of a force transducer.

In the gymnastic rings exercises the reaction force changes depending on the phase of the swing and the ring deflection in respect to the vertical axis. This force is identified with impact force [8]. It was found that an over twelve-fold overload causes a longitudinal deformation of as much as a few percent of the total body length [1,16]. Overloads of such magnitude result in injuries of the upper limbs and spinal column, as well as chronic pains [2,3,4,6,12].

At this point it should be noted that elastic shock absorbers in ring cables [14], as well as swings teaching control devices [9] have been used for quite some time. However, with the evolution of exercise techniques, cable tension during execution of the same gymnastic elements has doubled over the last 30 years. For instance, in the '70s values of 4 to 6 times body weight (BW) [10,15] were registered, in the '80s these values attained 10 BW [2,13] and in the '90s – 12 BW [18,21]. The positive outcome of that research is the decision of Fédération Internationale de Gymnastique (FIG) concerning the obligatory introduction of cable reaction force attenuating elements to gymnastic equipment in mass production. Nevertheless, latest research results do not confirm that the elasticity of equipment reduces mechanical overload affecting the gymnast. It is emphasized [1,24] that the mechanism of overload reduction is rather dependent on gymnast's technique. The elastic properties of the equipment are the least important factor regarding overload reduction.

Due to different overloads in different swing types, attention was focused on the tendency to reduce reaction force while executing cyclic swings. The aim of this study is to analyze the reaction force affecting the gymnast in respect to swing direction.

Materials and Methods

Research was carried out on a 14-year-old class 1 gymnast, with 53.1 kg of body mass and 1.61 m of height. The subject executed a series of 10 maximal swings from straight hang position to straight hang position from the rings. Both the cable reaction force F(t) and videotape recordings were made. The movement was recorded in the sagittal plane using the SIMI Motion system, which also permitted the synchronization of kinematic and dynamic variables of the swings.

Two TFs-10/120 strain gauges operating in full bridge mode were mounted in both cables independently. An external load of 2500 N was applied to each ring. The output signal was transmitted through a Mikrotechna amplifier to a PC computer.

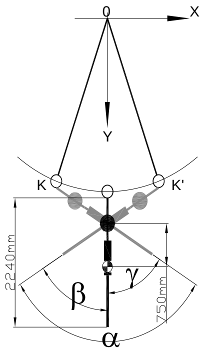

Fig. 1
Schematic view of swing kinematics
0XY - reference frame; β - range of the forward swing; γ - range of the backward swing; α - angular range of the COM's movement in respect to the vertical axis: $\alpha=\beta+\gamma$; YX - vertical amplitude of the COM's movement; K–K' - horizontal amplitude of the rings' movement

Fig. 1 shows a swing in the 0XY reference frame. The swing direction was defined based on gymnast's position in respect to the equipment. In the adopted reference frame β is the angle of forward excursion of the body in respect to the vertical 0Y axis. Similarly, γ measures backward excursion of the body in respect to 0Y axis. The swing range, α, is defined as the angle between the two extreme excursions of the body, i.e. it is equal to the sum of β and γ.

Gymnastic rings have a fixed point of attachment 0. Movable point K (the gymnast's grip point on the rings) changes position in the 0X axis, along a section of a circle K–K', whose radius equals to the length of the cables 0K. Each ring has three degrees of movement freedom in respect to point 0. In the case discussed, grip point K can change its position in the viewing plane. Adding the rings' movement and the swing movement of the body in the sagittal plane results in complex movement patterns of the COM along both the vertical (0Y) and horizontal (0X) axis.

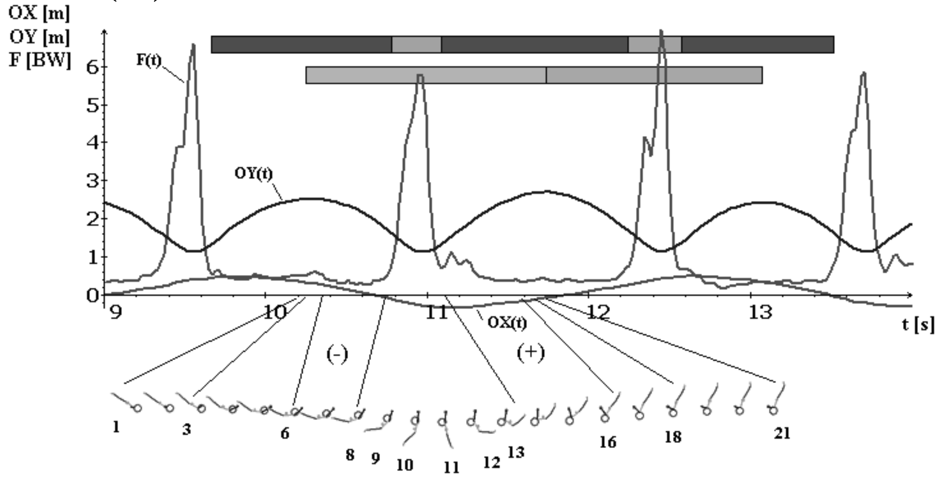

Fig. 2

Reaction force of the rings and oscillations of the COM during a series of four maximal swings

0X - COM's horizontal excursion; 0Y - COM's vertical excursion; F(t) - longitudinal reaction force of the cables; 1-10 - descending phase; 11-21 - ascending phase; 8-13 - resistance phase; 1-8 and 13-21 non resistance phase

Reaction force of the rings F(t) and linear oscillations of the COM during four swings with the maximal swing range α are shown in Fig. 2. The dependencies presented there have the following properties:

1. The minimal value of the cable reaction force F(t) corresponds to the highest position of the COM in respect to grip point K,
2. The maximal value of the cable reaction force F(t) corresponds to the lowest position of the COM in respect to grip point K,
3. The linear oscillation of the COM closely corresponds to angular oscillation of the longitudinal axis of the body in 0XY reference frame,
4. Duration of one cycle (forward swing β and backward swing γ) is equal to the linear and angular period of oscillations of the COM. It also closely corresponds to the cycle of the cable reaction force F(t).

Results

Cable reaction force F(t) during the swings has physical signs of unresistant and resistant movement phases (stick diagram – Fig. 2). Numeric data referring to the series of 10 forward and backward swings is included in Table 1. The vertical component of the COM movement is designated as 0Y, while the horizontal component as 0X. The angular range of the COM's longitudinal axis in respect to vertical axis is denoted by α, β, γ. A plus sign (+) is adopted for the descending and a minus sign (-) for the ascending phase of the momentum of COM's trajectory – Fig. 3. The cable reaction force value F is given in BW units (BW is the quotient of cable reaction force and gymnast's body weight). The overloading that affects the gymnast is expressed as rate of change of the force, i.e. F'(t)=dF/dt, where F is reaction force and t is time.

Table 1
Spatial and temporal characteristics of a series of ten maximal swings

Swing direction	Backward swing	Forward swing
Mean – Standard deviation	X±SD	X±SD
β (°)	- -	85±13
γ (°)	102±15	- -
Displacement COM Y (m)	1.63±0.14	1.74±0.25
Displacement COM X (m)	0.41±0.12	0.40±0.10
Momentum COM X (kg m s^{-1})	55.8±13.3	61.8±15.4
Momentum COM Y (kg m s^{-1})	214.6±16.6	224.6±19.7
F max (BW)	6.46±0.49	5.49±0.54
F min (BW)	0.30±0.05	0.23±0.05
GRAD (BW s^{-1})	67.4±10.3	42.6±7.1
t_F	0.172±0.017	0.172±0.010

β - angular range of the forward swing; γ - angular range of the backward swing; F_{max} - maximal reaction force of the cables; F_{min} - minimal reaction force of the cables; t_F - time in which the reaction force increments

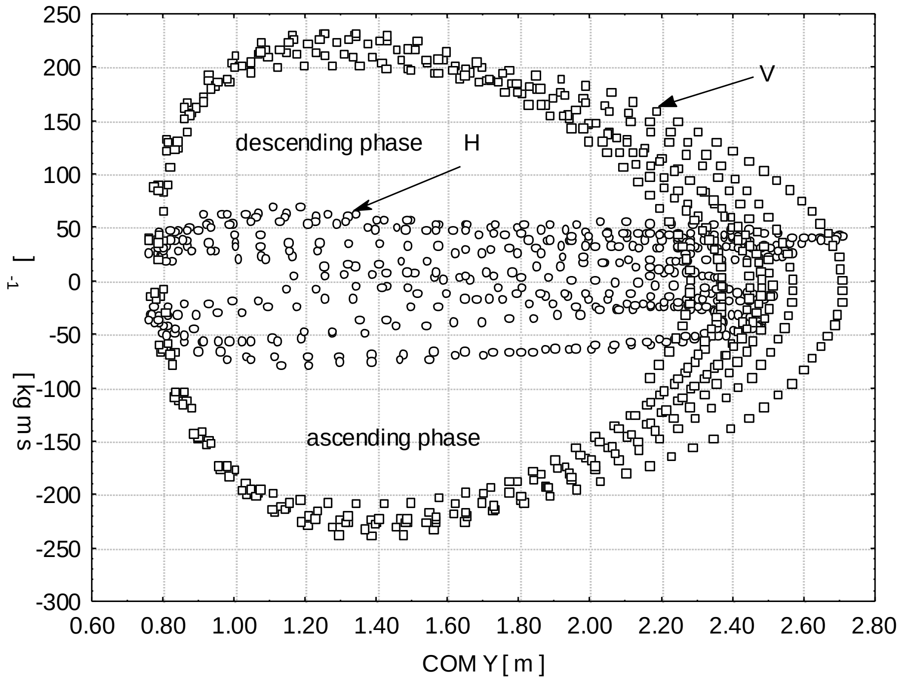

Fig. 3
Swing parameters
V - COM's momentum vertical excursion, H - COM's momentum horizontal excursion

Physical parameters of the cyclic swings differ in linear and angular range of the swings, the maximal cable reaction force values F, and the force gradient:

1. COM's descending path for the backward swing is, on average, 6% longer than that of the forward swing,
2. The angular range of the forward swing β is, on average, 17% wider than that of the backward swing γ,
3. The maximal cable reaction force F while executing a backward swing is, on average, 15% greater then while executing a forward swing,
4. The force gradient of the backward swing is, on average, 37% greater than that of the forward swing.

There is a close relation between the range of swings and the magnitude of cable reaction force. The interaction between the gymnast and the equipment depends on the gymnast's position and the swing direction (Fig. 2). The gymnast exerts pressure on the cables in the maximal and pulls them in the minimal range of the swing. Thus, the gymnast controls his body position. This control requires constant cable tension. The minimal cable reaction force amounts to 0.25 of the gymnast's body weight. Reaction force values recorded during the backward swing (positions 1-6) were slightly higher than those of the forward swing (positions 16-21). Minimal cable tension sets positive conditions for releasing moments of muscle force and switching from one exercise to another.

An overload of the gymnast's motor system occurs in positions 8-13. The overload reaches its maximal value during a hang (positions 10-11). In this position the musculoskeletal system constitutes a natural extension of the cables, and therefore, similarly to the cables, it undergoes an overload resulting from a force several times greater than that of the gymnast's body weight. The overload increments within 0.17 s and decrements within 0.07–0.08 s. The motor system's reaction results in a series of stretching forces in joints, especially in the upper limbs and spinal column. The sense of the forces depends on the swing direction. Two repeatable patterns of reaction force were acquired. One pattern corresponds to the forward swing, while the other one to the backward swing. A lower value of the maximal force and a lower force gradient were obtained in case of the forward movement, whereas a higher value of the maximal force and a higher force gradient, along with a double peak in the force increment phase, were obtained during the backward swing.

The biomechanical parameters of cyclic swings are presented in a phase diagram of the gymnast's momentum of COM's. The phase characteristics of the momentum proves that the gymnast achieves very similar kinematic parameters during the execution of both backward and forward swings (Fig. 3). Irrespective of the direction and range of the swing, the obtained COM momentum is always in the same position (0Y=±1.3 m) and attains similar maximal value. It may, therefore, be stated that varying force reaction patterns for forward and backward swings do not necessarily result from the 7% difference in swing range, but are rather connected to the body shape assumed by the gymnast. It should be pointed out that the gymnast resembles a solid in the backward movement more than in the forward movement. This is the consequence of anatomic conditioning of the movement of upper and lower limbs in respect to the trunk.

Discussion

The maximal force and rate of change of force is 15% greater for the backward than the forward swing, momentum is 37% greater, although the kinematic parameters of both swings differ by only about 4%. The difference between the swing direction and the reaction force may result from a functional asymmetry of the motor system in the sagittal plane as well as attenuation of backward body excursion, as noted in earlier research [19]. This point of view was confirmed in the analysis of swings dynamics and giant circles, where a tendency to obtain higher values of reaction force in backward rather than forward swings and giant circles was noted.

Generally, it should be underlined that the maximal range of cyclic swings may attain an amplitude of 273 degrees. Such range is, therefore, close to the execution of a giant swing. An unexpected property of cyclic swings is a relatively large scope of the horizontal oscillation of the COM. This oscillation might be a factor in reduction of reaction force, although no substantial evidence was presented. During cyclic swings a much smaller external overload was obtained in comparison with giant circles, which is beneficial to the gymnast. Assuming an average overload of 11 BW for a giant circle, in accordance with the published data [2,11,12,21,22], the maximal overload affecting the gymnast during cyclic swings is up to 45% lower with a 24% swing range difference. A theoretical model of this exercise [20], which does not take into consideration the COM's horizontal oscillation, assumes a reaction force of 12.5 BW for the maximal backward swing range and 10.5 for the maximal forward swing range. For these reasons, ignoring the fact that cyclic swings allow to adjust swing amplitude to the gymnast's technical abilities, cyclic swings should be recommended as a means of training, which favors overload reduction affecting the musculoskeletal system, as well as a means of adapting the gymnast to higher overloads.

Overloads of the motor system in swing exercises is a complex dynamic process. Some researchers suggest that the elasticity of the equipment is an overload reduction factor [3], but recent research does not reach that conclusion. However, an elastic reaction of the linkage in a human-cable system is inversely proportional to the stiffness of both elements of the system [17,18]. Assuming an arc-like body shape promptly to attaining maximal cable reaction force may lessen longitudinal stiffness of the gymnast. Research done on a dummy model [21,22] concluded that an upright silhouette of the gymnast, as opposed to an arch-shaped silhouette, triples cable reaction force in the lower phase of the swing. As a consequence of a 3D model research [1,26] four factors, which reduce force applied to shoulder joints, were found. These comprise: body shape, movement technique, lateral arm movement, and gymnast's elasticity. The significance of cable elasticity in reducing joint overload was not confirmed [24].

Concluding, all four factors leading to the reduction of the rection force constitute a whole and form a system. The lack of any of them leads to a change in quantity parameters and in consequence a change in quality parameters. From a practical point of view, both parameters increasing and decreasing the force that affects the gymnast are important. Such parameters manifest themselves in backward swings with a greater reaction force than in forward swings. This is a result of a higher susceptibility of the motor system to forward bending rather than backward bending. Presented overload mechanisms were not discussed in scientific literature in this context.

Conclusion

Reaction force and force gradient affecting the gymnast while executing maximal swings are greater in backward than in forward swings.

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