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Body overloading in the giant circle on rings

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The results of kinematic measurements of the performance of a forward giant on rings along with the recorded stretching force are presented. The external energy and power during exercise were computed. The results indicate the significance of elastic properties of the athletes' body during extremal overloading, giving insight into the changes of potential, kinetic and elastic energies which are fundamental for the proper performance.

Key words: giant, overloading, elastic forces, gymnastics, rings

1. Introduction

The magnitude and rate of changes of external forces acting on human motor system during execution of giant circle on rings have been presented in some biomechanical studies [1–6]. The program of this exercise consists in performing a full circle from initial to final hand stance forwards or backwards. Difficulty of this trial is connected with an impulse-like overloading of the motor system, which may reach a many-fold value of the gymnast weight in his lowest position from falling to raising.

The physical nature of the exercise consists in an abrupt inhibition of the athlete's centre-of-mass (COM) momentum in the vicinity of his lowest position, and consecutive instantaneous lifting him to the initial hand stance. The changes in the height of the COM are about 2 m, depending on the gymnast's height. The overloading acting on the body at the bottom of the circle constitutes the fundamental technical, psychological and biological problem in gymnastics.

The magnitude of the recorded force was regarded in this paper as the information confirming the overloading acting on the athlete during the exercise. The value of computed total mechanical energy expenditure during the execution of the circle displays the information about the work accomplished by the muscular strength [7].

The purpose of this paper is to investigate the value of the overloading that acts on the gymnast during execution of the forward giant circle on rings, which may be of significance in technical and strength preparation of the athlete and, more importantly, in the prevention of injuries resulting from overloading.

2. Material and methods

The results are based on the performance of a gymnast from NTS Nysa, Poland (age 19 years; body mass 74 kg; height 180 cm) representing the first sport class. He has been trained for 10 years. After the warm-up, the athlete executed the forward giant twice. The trial, which was better scored by the referees (according to the FIG regulations), was selected to the further analysis. During the trials the forces acting on the cables were recorded. These signals were measured with sampling rate of 500 Hz by means of strain gauges amplified and fed to the computer via A/C converter for later analysis.

The performance of the gymnast was additionally recorded by video camera perpendicularly to the sagittal plane of the subject. This required gluing of markers to the joints' axes at places routinely accepted in biomechanics. The purpose of kinematic analysis was to assess the dynamic parameters of the COM displacements of the individual body segments. Proper synchronisation of the force and kinematic data recordings was achieved by a system based on BioWare™ software. The kinematic analysis was performed by the Vidana™ system, which allowed us to compute velocities and accelerations of the COM displacements of all body segments as well as the accomplished work from the formula [7]:

$$T + V = Q,$$

where: T – kinetic energy, V – potential energy connected with the gravity, Q – energy added to the system (effect of muscular work).

Mechanical work W generated into the system from t_1 to t_k time instants satisfies the equation:

$$W = \sum_{i=1}^{k-1} |Q_{i+1} - Q_i| = \sum_{i=1}^{k-1} |T_{i+1} + V_{i+1} - T_i - V_i|,$$

where: $Q_i = T_i + V_i$ – mechanical energy of the system in an instant t_i; t_i – time instant corresponding to the i-th video frame; k – number of samples (video frames).

After each trial the static vertical co-ordinates of the gymnast in a maximally stretched hanging position were recorded. This was done in order to evaluate an expected elongation of the cables and the body.

3. Results

The experimental and computational procedures allowed us to obtain biomechanical data about the overloading phase of giant circle. The following data vs. time were computed: force acting on the body $F(t)$, total mechanical energy introduced into the system *Q*(*t*), potential energy *V*(*t*), kinetic energy *T*(*t*), and external mechanical work *W*(*t*) (Fig. 1). Additionally, the body lengths of the gymnast under static and dynamic conditions, while hanging, were evaluated between two markers placed at the palm (metecarpale – III) and the ankle (malleolus). The point just below the ceiling, where the right cable was attached, was assumed as a fixed reference for the distance-related computations. The assessment of the error of this measurement for ten-fold reading in the Vidana system is presented in the Table.

Table. The length of the gymnast–cables system [m] and the gymnast alone under static (*Ls*) and dynamic condition (*Ld*) along with the system length change $\Delta L = Ld - Ls$

Segmental length	Cables + gymnast $\overline{X} \pm SD$	Gymnast $\overline{X} \pm SD$
Ls	5.135 ± 0.0061	2.296 ± 0.0078
Ld	5.222 ± 0.0078	2.375 ± 0.0185
ΔL	0.087	0.079

4. Discussion

The energetic state *Q*(*t*) of the system allowed us to find a characteristic transient and abrupt decrease in *Q*, followed by an immediate recovery with a visible energy loss of 150–200 J (Fig.1). This abrupt loss in *Q* takes place in the position that eliminates the body curvature, under the force 10 to 13 times as large as the body weight [5]. The drop in *Q* testifies to the execution of a negative mechanical work (decrease in *Q*) and a positive work (partial release of the energy). The shape of the *W*(*t*) curve shows that under the short-term overloading the gymnast accomplishes about 50% of the mechanical work spent on the execution of the whole circle emphasising the significance of this phase in the completing of the full giant circle. This issue suggests that the most substantial part of the work during the overloading phase be accomplished thanks to elastic properties of the whole kinematic chain involving the gymnast and the cables. The observed body stretch of about 8 cm caused by a shock impulse of force may be explained by significant mobility of the shoulder girdle as well as elastic straightening and elongation [8] of the spine.

The following interpretation of the observed events can be assumed: A ramp input of external force applied at the bottom position of the swing causes an immediate reaction of the kinematic chain. Mechanical analysis of such a system implies the inverse proportionality between the length change and the intrinsic stiffness of its segments. The assumed hypothesis is supported by an experiment with an iron frame having similar geometrical quantities to the gymnast body except a many times higher stiffness. This frame, after releasing from the 90° position with respect to the cables, broke the cables indicating a much larger overloading as compared to the gymnast [9].

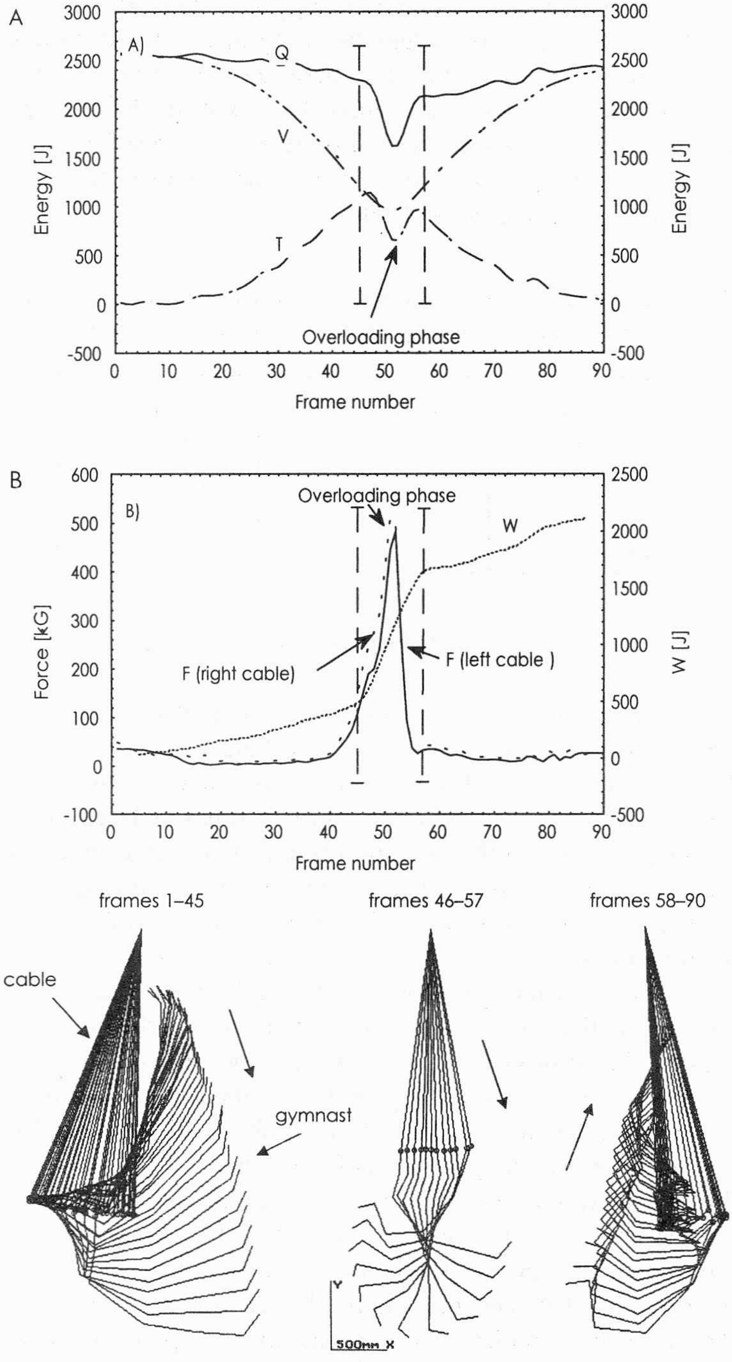

Fig.1. Overloading phase in giant circle (frames 46–57); symbols' meaning: A) $Q(t)$ – total mechanical energy introduced into the system, $T(t)$ – potential energy, $V(t)$ – kinetic energy. B) $F(t)$ – reaction force of cables, $W(t)$ – external mechanical work accomplished during the execution of giant circle

The recorded dissipation of 28% of the energy Q (Fig.1) during the time of body elongation and recuperation indicates that the cable–gymnast system displays plain viscoelastic properties. The results allow us to accept the following model of the circle at its bottom position:

$$\frac{E_1}{E_2} = \frac{K_2}{K_1}, \qquad K_1 > K_2,$$

where: E_1 – elastic energy stored up in the cables, K_1 – cable stiffness, E_2 – elastic energy stored up in the skeleto-muscular system, K_2 – body stiffness.

5. Conclusions

- The peak value of the overloading acting on the body takes place at the bottom of the falling phase amounting to 13-fold the body weight.
- The overloading results in accumulation and immediate recoil of the elastic energy of the gymnast's body. Utilisation of this energy to the effective lifting of the athlete is possible only within the time limits of the maximal overloading phase.

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