

ERGONOMIC ASPECT OF BIOMECHANICS OF IMPACT INTERACTIONS IN SPORTS

IVANOVA, G.
Lesgaft Institute of Physical Culture
Leningrad
USSR

INTRODUCTION

The effectiveness of strokes in sports is considerably influenced by the quality of implements and equipment [raquets, balls, etc.]. The advantages of new models of sport implements were repeatedly pointed out [Groppel et al, 1987]. However, the majority of experimental investigations were devoted to the study of raquet and ball processes without any correlation with human being and beyond the process of human activity, which sufficiently restrains the quality and properties of sport implements.

For example, tennis raquets were studied in laboratory conditions being freely, rigidly or pneumatically clamped [Baker et al, 1979; Elliot, 1982; Grabiner et al, 1983; Djarkov, 1973; Watanabe et al, 1979] while the ball rebounds were determined by the string type and tension.

We consider the quality of sport apparatus and implements [i.e. raquets, hockey sticks, balls, flounces] should be investigated under the natural conditions, coinciding the ergonomic properties with human biomechanical characteristics in the united whole biomechanical system. During the interaction of subject of impact [hand, foot, raquets holding in hand] with ball one can not ignore the changings of mechanical properties of system due to the another reduced mass, contact duration time and energy transfer among bodies. In this paper new approach of biomechanical study of impacts based on a new system "human body - sport implement - sport apparatus - medium" is discussed and experimentally investigated. The mentioned system is more complicated than simple "human body" system itself but at the same time it is more deterministic and hence, it more adequately describes the sport techniques, which variations accompany implement modernization.

Works dealing with tennis provide considerations that raquet rigidly clamped in mechanic frame and raquet gripped by hand show different reactions to ball impact of the same velocity [Balakshin et al, 1987; Hatze, 1976]. Previously it was mentioned [Katznelson et al, 1979] that human hand is affected by deflecting raquet oscillations at 83 Hz frequency, which is close to that obtained with cantilever racket tightening on bench, but later Balakshin et al [1987] pointed out that dumped raquet and raquet gripped by hand possess different dynamic responses to ball impact, which, according to Minaev [1988], depend on rigidity and mass of impact subject. The investigations carried out by Balakshin et al [1987] showed that undesirable frequencies, at which raquet resonances may appear, are determined not only by raquet characteristics [i.e. elasticity of material, cross-section dimensions, mass, length] but also by parameters of sportsman hand itself - its rigidity coefficient and mass. Moreover, Hatze [1976] discussed the model and experimental evidence of forces and contact duration dependence on grip firmness. On the contrary, Grabiner et al [1983] opposed Elliot [1982] and Watanabe et al [1979] that intersegment rigidity of biomechanical chain does not influence on impact mass and post-impact velocity of ball.

THEORETICAL MODEL

The classical theory of impacts does not consider the deformation of bodies during the impact relying on contact duration $\tau \rightarrow 0$ and body displacement $a \rightarrow 0$. In reality contact duration and joint displacement of bodies in sport impacts have finite values [Ivanova, 1978; Bartonietz, 1975]. While investigation of impacts nature the modern theory of impacts besides the classical speculations often uses methods of theory of elasticity and wave mechanics [Alexandrov et al, 1963].

Let us consider the collision of two perfectly rigid bodies with elastic intermediate element, which resistance force is proportional to compression: $F = c \cdot a$, where c is stiffness of equivalent spring or packing and a is compressive strain of spring. Substituting F into the expression for the kinetic energy A_k , which is transferring into the potential energy A_p one obtains

$$A_p = \int c a da = c \cdot a_{\max}^2 / 2.$$

therefore the maximum compression is :

$$a_{\max} = v_0 \left[\frac{m_1 m_2}{c (m_1 + m_2)} \right]^{1/2} \quad (1)$$

where v_0 is the relative impact velocity of bodies, m_1 and m_2 are body masses. The maximum impact force is

$$F_{\max} = c a_{\max} = v_0 \left[\frac{c m_1 m_2}{m_1 + m_2} \right]^{1/2} \quad (2)$$

The contact duration is

$$\tau = \tau \left[\frac{m_1 m_2}{c (m_1 + m_2)} \right]^{1/2} \quad (3)$$

and body displacement during contact is

$$x_{m1} = x_{m2} = \tau v_0 \frac{m_1}{m_1 + m_2} \left[\frac{m_1 m_2}{c (m_1 + m_2)} \right]^{1/2} \quad (4)$$

The time dependence of force of impact interaction is described by sinusoidal function:

$$F = F_{\max} \sin \left(\frac{c v_0}{F_{\max}} t \right) \quad (5)$$

THE AIM OF THE EXPERIMENT AND EXPERIMENTAL METHODIC

The experiment was carried out to prove the necessity of introduction of non-impact forces into the impact model besides the damper component. This modification was first noted by Agashin(1977), but he reached this idea from the another way. The experimental facts, allowing to describe the behavior of human system within the impact phase, are rather insufficient. Due to this the aim of the experiments was to find any experimental factors proving the involvement of muscle system in the dynamics of ball and hand interaction.

EXPERIMENTAL RESULTS

High-speed filming, accelerograms, tensodynamograms, EMG of strokes allowed to correct the given model.

The dependence $\Delta l = f(F)$ for soccer ball with static loading is shown in Fig.1 and gives evidence for linear behavior of c . The ball deformation during impacts in volleyball for near (a) and far (b) field shots as a function of contact duration with hand are given in Fig.2 (Ivanova et al, 1975). The difference of loading and unloading pulses is clearly seen from Fig.2. The more the initial velocity of ball (b), the greater the area of unloading pulse: $k > 1$. Biomechanical characteristics of motion of experienced volleyball players in impact phase during the attack shot are represented in Table 1 and correlation of certain mechanical parameters of impact with EMG of *m. flexor carpi ulnaris* are given in Table 2.

Based on the model and experimental results one may work out certain practical recommendations.

1. Maximum value of compression (1), for example for string surface deflection or ball deformation, is increasing with increasing of impact subject velocity and decreasing while growing of implement or ball stiffness. This parameter is connected with ball ruling and "feeling" of ball or racket. At the primary stage of training in strokes it is useful to regulate the degree of stiffness of sport implement in accordance with physical condition of player by increasing of compliance of racket or ball for better improvement of its elasticity and better "tracking" of ball in the phase of its joint motion with racket.

2. Maximum impact force (2) grows with relative impact velocity growing and increasing of masses of interacting bodies and its stiffnesses. For players in poor physical or technical conditions it is sensible to

use implements with more soft intermediate element to escape injuries but in this case one must follow the sequence of dynamic structure of impact at the primary stage of training and that for master stroke.

#3. Impact duration (3) is decreasing with increasing of packing rigidity and is increasing with increasing of body masses but is independent on the velocity of impact subject. Contact duration is less than 20 ms being the time of motion system reaction to response, this means that no corrections are possible in this phase. There the motion control program is based on previously acquired skill of player. The reduction of stiffness or mass of ball will lead to the increase of contact duration but at the same time to the increase of mechanical energy losses in impact phase and will contribute to formation of another motion program with different recoil forces and different trajectory of joint motion of bodies.

#4. Body displacement during impact (4) grows with relative impact velocity growing and increasing of mass of impact subject. The higher the rigidity of intermediate element the smaller the body displacement during impact.

#5. In case $k=1$ the impact force is varying according to sinusoidal law (5). In reality all mechanical systems possess the greater loading pulse than unloading one as the restitution coefficient is always less than 1. Experimental study of impact pulses (Fig.2) showed that interaction of biomechanical chain with elastic body (ball, for instance) manifested by electrical activity of muscles (Table 2) and restoration pulse is greater than loading pulse. Restitution coefficient becomes greater than unity that is impossible for mechanical systems. "Human body - sport implement - sport apparatus - medium" system being the open biomechanical system allows both the supply and loss of energy during the impact and joint motion of bodies.

The investigation of controlled parameters of impact provides data for coaches for aimful individual optimization of stroking techniques. Post-impact ball energy is defined in contact phase and is affected by number of factors, among which besides the mentioned ones is the loss of potential energy of elastic deformations which failed to transfer into the kinetic energy due to the discrepancy between the impact duration and natural period of body oscillations. For 100% transfer of energy of elastic deformations from one body to another the impact duration τ is to be 3-5 times higher than the period of natural body oscillations. In sports, tennis for instance, the natural frequency for free racket and racket gripped by hand differs. To increase the transfer coefficient of energy to ball players often weaken the grip for the strokes at high racket velocities, but while prevailing of non-impact force component in motion program they, on the opposite, usually tend to increase the impact mass by tightening the grip. The above mentioned contradictions in the viewpoint of authors and their misunderstandings about the value of k (Groppel, 1987) are explained by their considerations of impacts in living systems as purely mechanical one ignoring the energy contribution of non-impact forces on the trajectory "a" during the time interval τ . These influences are programmably caused and proved by high degree of correlation between mechanical motion parameters and EMG activity of muscles within the impact phase.

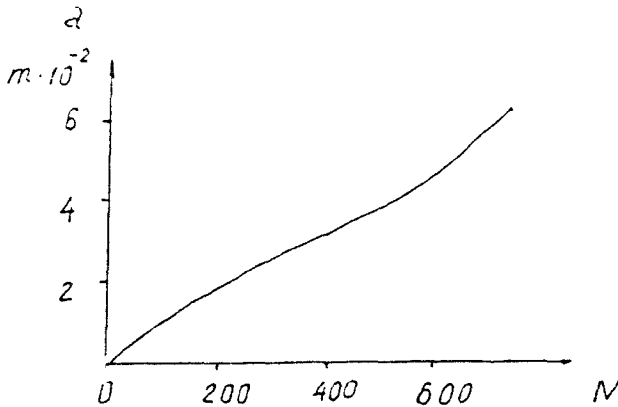


Figure 1: The dependence of soccer ball deformation on force.

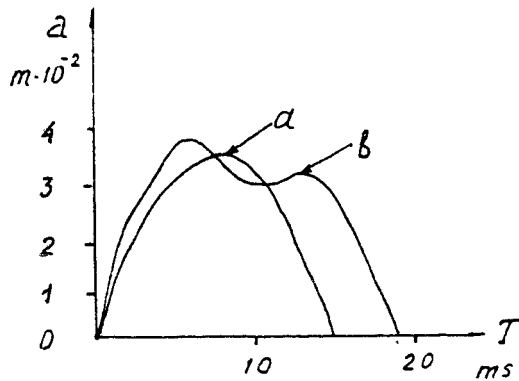


Figure 2: Deformation of ball in natural volleyball shot

TABLE 1

Characteristics	Value	Units
1. Linear velocity of ball at the time of rebound	18.75±0.6	m.s ⁻¹
2. Linear velocity of articulatio radiocarpea joint at the impact phase	15.1±0.7	m.s ⁻¹
3. Pre-impact angular velocity of forearm	32.2±1.2	rad.s ⁻¹
4. Angular velocity of carpus	263±13.3	rad.s ⁻¹
5. Linear stiffness	2.1 · 10 ⁺⁴	N.m ⁻¹
6. Angular stiffness of articulatio radiocarpea joint	645±12.2	N.m.rad ⁻¹
7. Average resistance force	1375±41	N
8. Joint displacement	0.09±0.007	m
9. Duration of impact phase with ball	8.4±0.5	m.s
10. Period of m. flexor carpi ulnaris activity	0.126±0.05	s

TABLE 2

Correlation matrix of mechanical characteristics (A) for impact phase and electromyography of *m. flexor carpi ulnaris* (B)

Feature content	1	2	3	4	5	6	7
1 Pre-impact hand acceleration							
2 Post-impact hand acceleration	0.89						(A)
3 Maximum reaction force	0.87	0.67					
4 Area under chain acceleration curve	0.91	0.56	0.84				
5 Period of activity	0	0	-	-			
6 Maximum amplitude	-0.72	0	-0.54	0.8	0		(B)
7 Integral activity	-0.73	0	0.54	0.8	0.36	0.73	
8 Oscillation frequency	0.58	0	0.60	0.57	-0.39	-0.39	-0.43

REFERENCES

- AGASHIN, F. (1977) Biomechanics of stroke motions. *Physical Culture & Sport (USSR)*
- ALEXANDROV, E., SOKOLINSKY V. (1969) *Applied theory and calculations of impact systems. Nauka (USSR)*
- BALAKSHIN, O., ZAITZEV, V., MINAEV, A. (1987) The investigation of natural frequency properties of tennis rackets. Theory and practice of physical culture (USSR), 53-55.
- BARTONHETZ, K. (1975) Biomechanical analysis of stroking actions in certain kinds of sports. Ph.D. dissertation (USSR)
- DJARKOV, A. (1974) Study and design of sport implements made from wood for impact actions. Ph.D. dissertation (USSR)
- IVANOVA, G., FETISOVA, S. (1975) On a construction of biomechanical system of action program for strokes. "Biomechanics" Proceedings of Coaches' Training Workshop. Riga (USSR)
- KATZNELSON, M., ZAITZEV, V., PETROV, V. (1979) The study of force acting upon tennis player during the impact of ball with racket. Theory and practice of physical culture, 11, 32-35
- GROPPEL, J., SHIN, J., TOMAS, J., WELK, G. (1987) The effect of string type and tension on impact in mid-sized and oversized tennis rackets. *Int.J. of Sport Biomechanics*, 3, 40-46.
- GROPPEL, J., SHIN, J., SPOTTS, J., HILL, B. (1987) Effect of different string tension patterns and racket motion on tennis racket-ball impact. *Int.J. of Sport Biomechanics*, 3, 142-158.
- BAKER, J., PUTMAN, C. (1979) Tennis racket and ball responses during impact under dumped and free standing conditions. *Research Quarterly*, 50(2), 164-170.
- GRABINER, M., GROPPPEL, J., CAMPBELL, K. (1983) Resultant tennis ball velocity as a function of off-center impact and grip firmness. *Medicine and science in sports and exercise*, 15, 542-544.
- ELLIOTT, B. (1982) Tennis: the influence of grip tightness on reaction impulse and rebound velocity. *Medicine and science in sports and exercise*, 14, 348-352.
- HATZEL, H. (1976) Forces and duration of impact and grip tightness during the tennis stroke. *Medicine and science in sports and exercise*, 8, 88-95.
- WATANABE, T., JKEGAMI, Y., MIYASHITA, M. (1979) Tennis: the effect of grip firmness on ball velocity after impact. *Medicine and science in sports and exercise*, 11, 359-361.