ENERGY TRANSFER EVALUATION IN THE "STRIKER-BALL" SYSTEM DURING IMPACT

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Classical Newton's model has been used to analyze the energy transfer mechanisms in the "striker-ball" system during impact. The velocity restitution coefficient and velocity transfer index were determined from the laboratory experiments and in natural sports playing conditions (volleyball, football, tennis). It was found that a living system controls the energy transfer in the impact phase depending on the motion task of the stroke.

KEY WORDS: energy transformation, impact forces, velocity restitution coefficient, contact phase, rigidity analysis

INTRODUCTION: The energy efficiency of motion is one of the key indicators of improved sport technique. The accuracy and stability of strokes in sport are mainly dependent on the quantity of energy transfer during impact of bodies. The transient of this process causes its complexity. Impact interaction with a ball basically lasts from 5 to 20 ms and during this period a living system has to provide control over the speed, rotation and precision of the emerging ball.

The main problem for a coach and a sportsman in analyzing the impact process is that the latter is absolutely indistinguishable by unaided eye and could not be described by a determined language due to its short duration. On the other hand, the clear understanding of the contact phase of a striker with a ball is very important.

In order to evaluate the energy characteristics of a human being during the impact phase with a ball a classical Newton's theory of collision was used. It permits to consider the contact as a "black box" thus ignoring all processes within the period of body interaction. The main postulate of Newton's theory is based on the absence of deformation of bodies involved in the impact; zero value of impact period; lack of joint displacement of interacting bodies and energy dissipation. In reality, the restitution coefficient *K* reflects at least three dissimilar phenomena:

1. Material elasticity;
2. Spring properties of bodies;
3. Changes of general body motion, for instance the initiation of rotation.

All of the above factors may be accounted for in the restitution coefficient, but only in case the energy approach is applied for its determination. The square of *K* is equal to the ratio of post-impact kinetic energy (A_2) to its pre-impact value (A_1) provided the body energy is calculated with respect to the centre of masses of both bodies:

$$K = \sqrt{\frac{A_2}{A_1}} = \frac{|U_2 - U_1|}{|V_2 - V_1|} \qquad (1)$$

where U_1 and U_2 are velocities of bodies after the impact and V_1 and V_2 are velocities before the impact; *1* represents the striker and *2* represents the ball. Energy transfer from the striker to the ball can be evaluated from the ratio of ball velocity after the stroke to the pre-impact velocity of the striker. We call this parameter the *velocity transfer index R*:

$$R = \frac{U_2}{V_1} \tag{2}$$

METHODS: Two types of experiments were carried out:

1 - A model experiment, where in laboratory conditions the restitution coefficient (K) of the ball velocity was determined after the impact with: 1) hand, 2) foot, and 3) string surface of the tennis racket gripped in hand. The following conditions were observed:

- any transition of striker's sections in the contact phase was not allowed;
- the rigidity of striker-ball biomechanical system during impact was controlled;
- a player has followed the instructions either to relax muscles or to provide muscle tension as if in real stroke.

Wrists of volleyball and tennis players were located on a table of 1.35 m height covered by soft fabric. Fingers and palm were fixed by supports on the table. A tennis racket remained free in the air, but its head was rested at the support. Football players sat on a chair and put heels of the straight feet in boots on an earth surface with fixed toe. A ball was dumped to the middle of instep. Totally 22 sportsmen took part in the experiments. The initial ball height (H) and rebound height (h) were measured by ruler placed in the plain of ball motion. Video recording was carried out for objectivity. All rebounding heights were averaged over 5 successful attempts. The restitution coefficient (K) was determined as follows:

$$K = \frac{U_2}{V_1} = \sqrt{\frac{h}{H}}$$

2 - A natural experiment, where body velocities before and after impact were measured at natural playing conditions. Football, volleyball, and tennis ball strokes were accomplished by professional players. The experimental 1-D registration was done by pulse filming technique on a professional camera (f=360mm) "Pentacet-35" at 700 fps with a built-in electronic timer. Optical axis of the camera was set at the assumed rebounding height perpendicular to the stroke direction. Film-comparator "AK-1" was used for taking the readings from the film with the accuracy of 0.16 mm by co-ordinate, which makes less than 1% of the ball size (Ivanova,1991). The processing of spatio-temporal dependencies from the film allowed to calculate the velocities before and after the impact, which were used for determination of K and R according to (1)-(2).±

RESULTS AND DISCUSSION: The velocity restitution coefficient of a ball (K) after the contact with hand or foot depends on the striker's rigidity (see Table 1). Higher values of *K* were obtained for tennis biomechanical system "ball-grip-racket" with the string contact surface, whereas a living system controlled the rigidity of the grip. It is known (Groppel, Shin, & Tomas, 1987), that *K* is close to 0.6 for tennis rackets completely fixed in a frame.

Table 1 Velocity Restitution Coefficient *K* at Different Biosystem Rigidities

Sport, n - number of players under test	Striker's section, degree of rigidity	Ball fall height H, m	Rebound height h±δh, m	K ±δK
Volleyball*, n=5	Wrist, relaxed	5.5	0.055±0.003	0.10±0.01
	Wrist, strained	5.5	0.107±0.002	0.14±0.01
	Wrist, clenched fist	5.5	0.159±0.001	0.17±0.01
Football, n=10	Foot, relaxed	3.0	0.13±0.01	0.21±0.01
	Foot, strained	3.0	0.17±0.01	0.24±0.01
Tennis, n=7	Hand, light grip	3.0	0.14±0.01	0.21±0.01
	Hand, stiff grip	3.0	0.21±0.02	0.26±0.01

* experiment conducted together with S. Fetisova.

Obtained data from the natural experiments were processed and compared with that on body velocities in the impact phase taken in the literature (see Table 2).

Table 2 Average Velocity Restitution Coefficient *K* and Velocity Transfer Index *R* at Different Natural Strokes in Tennis, Volleyball and Football

Sport	Source	Type of stroke	Number of strokes	K ± δK	R± δR
Tennis	Author, (Ivanova, 1991)	Service	9	0.68±0.03	1.23±0.02
	(Plagenhoef, 1971)	Service	2	0.60±0.05	1.33±0.02
	(Chelume, Van & Hebbelink, 1974)	Service	3	0.59±0.02	1.19±0.03
	(Zaitcheva, 1974)	Service	3	0.80±0.07	1.22±0.05
	(Elliot & Marth, 1989)	Ground	28	0.31±0.54	1.4 - 1.6
	(Zaitcheva, 1974)	Volley	4	0.33±0.06	1.00±0.05
Volleyball	Author, (Ivanova, 1991)	Attack	12	0.69±0.03	1.19±0.08
	(Fetisova, 1974)	Service	30	0.45±0.02	1.16±0.05
	(Plagenhoef, 1971)	Service	1	0.41	1.11
Football	Author, (Ivanova, 1991)	Ball at rest	18	0.49±0.08	1.27±0.03

The comparative analysis of the restitution coefficient *K* in the model and natural experiments showed, that in natural playing conditions the energy exchange between the living system and the ball occurs considerably more extensively. This suggests the partial presence of some additional energy in the interaction phase. The energy has to be of a non-impact origin as it appears only in the living "striker-ball" system, when the striker's translation takes place. It is worthy to note, that the velocity transfer index (R) appeared to be nearly the same and equal to 1.2. This is regardless of stroke types, velocities, balls and type of natural experiment. The study of correlation between *K* and *R* has revealed a very weak relationship (correlation coefficient equal to 0.07 for volleyball and 0.28 for tennis, all being statistically unauthentic). This all proves that energy transfer within the impact phase is not governed by pure mechanical regularities, but is a controlled process depending on the motion task of the stroke.

CONCLUSION: The application of Newton's theory to the impact analysis in sports allows to:

1 - estimate quantitatively the difference in energy transfer between special stroke in sports and ordinary mechanical one;
2 - consider the velocity transfer index in biomechanical systems as a controlled parameter;
3 - obtain similar magnitudes of the velocity transfer indices (Rλ1.2) in strokes of professional players regardless of stroke type;
4 - prove, that despite its transient nature the impact phase in sport strokes appears to be a well internally controlled process;
5 - select the restitution coefficient *K* and energy transfer index *R* as the most informative parameters for energy transfer evaluation in the impact phase.

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