REPULSION OF THE SOCCER BALL DEPENDING ON THE FREE FALL HEIGHT

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Abstract
Within the program of physical development games play a dominant part, and the most important of all games are games with ball. In our environment soccer has a leading role as a ball game. The only object which leads the dynamics of the game is a soccer ball. The interest in this form of sport is very large and can be seen globally. Tens of thousands direct observers are watching the matches that take place in large stadiums. Tens of millions viewers are watching soccer matches indirectly over television screens. Hundreds of millions of viewers are watching soccer matches replay. Financial balance sheets around the soccer outweight the balance of many multinational corporations. Researches related to the elastic properties of the ball basically fall under the area of kinematic survey. Since maximum strikes of the ball are rarely used, the game content is mostly composed of technical and tactical maneuvering. Measured strikes of the ball are prevailing in technical and tactical maneuvering. Acquiring habit of measured strike of the ball takes place within condition preparations, which will be explained in detail in the discussion of the study.

Key words*: repulsion, ball, football, fall*

Introduction

Within the program of physical development games play a dominant part, and the most important of all games are games with ball. In our environment soccer has a leading role as a ball game. The only object which leads the dynamics of the game is a soccer ball. The interest in this form of sport is very large and can be seen globally. Tens of thousands direct observers are watching the matches that take place in large stadiums. Tens of millions viewers are watching soccer matches indirectly over television screens. Hundreds of millions of viewers are watching soccer matches replay. Financial balance sheets around the soccer outweight the balance of many multinational corporations. What are the reasons that a round body, weighing less than a pound with a diameter of about eight inches, physically and emotionally engages millions of the masses? Soccer is a conflicting game with limited space. Each player can occupy any space on the court. Basically a soccer match is, expressed by strategic language, a battle for space and time, and in such maneuvers it often leads to direct contact with the opponent. During a good game, each player in the court makes about two and a half million natural muscle contractions, creating a series of complex developments in a fight to take possession of the ball before opponent does that, to get into the zone from which he can score before being distracted by the opponent. Since such maneuvering takes place continuously and takes a long time, besides the modern maneuvering where there are already well coordinated combinations, it is performed to the highest speed and maximum fatigue condition, so all the players in the court are exhaust to the maximum by every good soccer match. The result of matches is not evaluated by the level of bio-motoric performance, who had a longer run, or who was running faster, or who jumped higher, but by number of scored goals. Therefore, all the maneuvering movements are governed by the ball movement. Ball is the machine, which properties must be well known to each player! Overall, at average game ball is rarely hit with maximum impulse, while hitting ball with measured impulse is occurring most frequently. This is primary reason why each player must be fully aware of the nature of the elastic properties of the soccer ball.

Methods

Researches related to the elastic properties of the ball basically fall under the area of kinematic survey. Since maximum strikes of the ball are rarely used, the game content is mostly composed of technical and tactical maneuvering. Measured strikes of the ball are prevailing in technical and tactical maneuvering. Acquiring habit of measured strike of the ball takes place within condition preparations, which will be explained in detail in the discussion of the study. The research conducted in this study primarily refers to the standard soccer ball for seniors with the following performance (table 1). The aim of the study was to determine repulsive features of the soccer ball, primarily depending on the initial velocity after a collision with a solid surface. The experiment consisted of recording balls dropped from different heights (2 meters, 4 meters) by rapid camera and of computational identification of spatil-temporal relations, both individual and comparative. In the first phase of the research paths of the soccer ball were established in the first four rejections from the solid surface (charts 1 and 2). Trajectory of a soccer ball, released from a height of two meters in the first four rejections of solid surfaces. Vertical: points of culmination for each rejection of the soil, measured in meters. Horizontally: the duration of each rejection of the soil (in seconds).

Table 1 Performance of the standard soccer ball

Dimensions of the ball	For seniors
Mass (kg)	0.4245
Radius (m)	0.1105
Circumference (m)	0.6943
Cross-Section (m2)	0.03936
Suface (m2)	0.1534
Volume (m3)	0.00565

Table 2: Height of Refusal from the Ground

The vertical projection of rejection in meters	H_{max} = 2m	H_{max} = 4m
h_1	1.65	2.88
h_2	1025	2.25
h_3	0.95	1.70
h_4	0.75	1.25

Table 3 Time of Refusal from the Ground

The horisontal projection of rejection in secundas	H_{max} = 2m	H_{max} = 4m
t_1	2.64	3.52
t_2	2.18	2.88
t_3	1.84	2.44
t_4	1.60	2.00

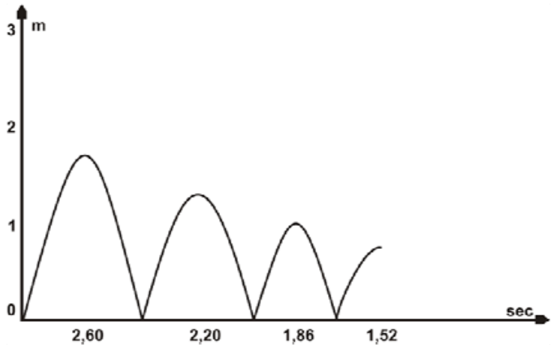

Figure 1 Trajectory of a soccer ball

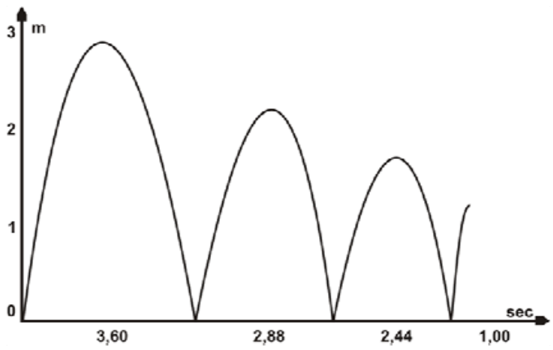

Figure 2 Trajectory of a soccer ball (2 meters)

Trajectory of a soccer ball, released from a height of four meters in the first four rejections of solid surfaces. Vertical: points of culmination for each rejection of the soil, measured in meters. Horizontally: the duration of each rejection of the soil, shown in seconds.

The raw results of the spatial and temporal values for every rejection from the soil are presented in tables (Table 2 and 3). Interpolation of the points of culmination was performed in the second phase for every rejection from the soil (charts 3 and 4).

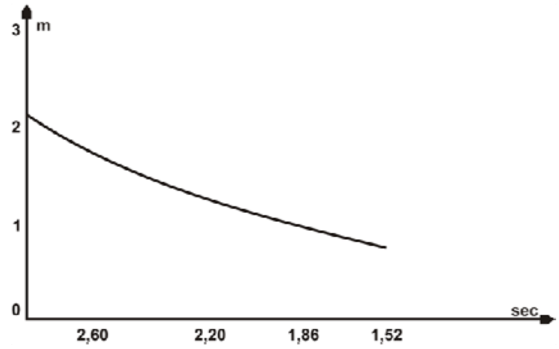

Figure 3 Interpolation of the points of culmination

Chart of interpolated points of culmination after free fall from a two meters height.

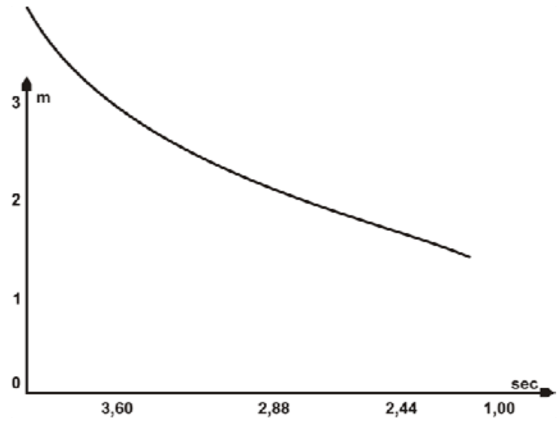

Figure 4 Interpolation of the points of culmination (2 meters)

Chart of interpolated points of culmination after free fall from a four meters height.

Planimetric comparison of soccer ball trajectories when released from two and four meters height was performed at the third phase (chart 5):

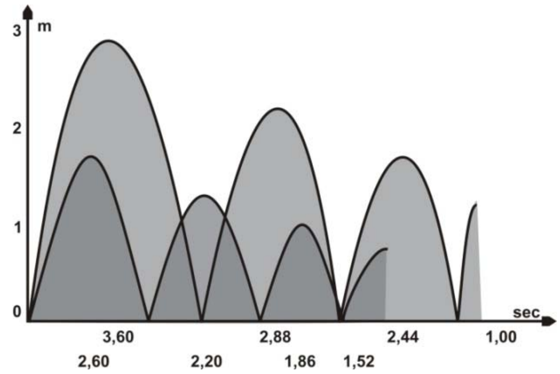

Figure 5 Planimetric comparison of soccer ball trajectories (2 and 4 meters)

Comparative representation of the space covered by trajectories of the soccer balls released from two (darker shading) and four (lighter shading) meters height. Comparative representation of integrated surface was performed at the fourth phase with upper lines representing interpolated points of culmination.

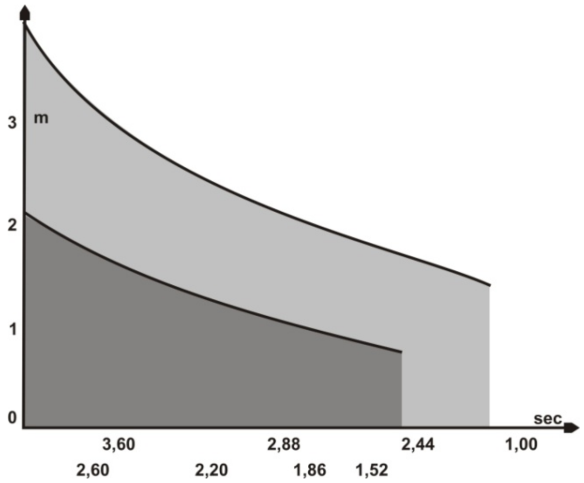

Chart 6: Comparative representation of integrated surface (upper lines representing interpolated points of culmination)

Comparative representation of the space covered by trajectories of the soccer balls released from two (darker shading) and four (lighter shading) meters height, where (i) are integral elements, with dx pointing that function f(x) consists of multiplying with differentiated values. f(x) = chart of natural occurrence (integrand). Differences in time and meters between successive rejections from solid surface were measured in the fifth phase, after falling from 2 and 4 meters height (table 4 and 5).

Table 4 The height difference of the individual rejection of the ground (in meters)

Mathematical operations = subtraction	The starting height = 2 meters		The starting height = 4 meters	
	Spatial variations	%	Spatial variations	%
$h_1 - h_2$	0.40	75.75	0.63	78.13
$h_2 - h_3$	0.30	76.00	0.55	75.55
$h_3 - h_4$	0.20	78.00	0.45	73.53

Table 5 The timing difference of the individual rejection of the ground (in seconds)

Mathematical operations = subtraction	The starting height = 2 meters		The starting height = 4 meters	
	Timing variations	%	Timing variations	%
$t_1 - t_2$	0.46	82.60	0.64	81.81
$t_2 - t_3$	0.34	83.00	0.44	84.72
$t_3 - t_4$	0.18	87.00	0.45	81.96

Ratios of meters and time between successive rejections from solid surface were measured in the sixth phase, after falling from 2 and 4 meters height (table 6 and 7).

Table 6 Quotient of the height of individual rejection of the ground (in meters)

Mathematical operations = divide	The starting height = 2 meters		The starting height = 4 meters	
	Quotient	%	Quotient	%
$h_1 : h_2$	1.33	75.75	1.29	78.13
$h_2 : h_3$	1.30	76.00	1.28	75.55
$h_3 : h_4$	1.27	78.00	1.27	73.53

Table 7 Quotient of the timing intervals of individual rejection of the ground (in seconds)

Mathematical operations = divide	The starting height = 2 meters		The starting height = 4 meters	
	Quotient	%	Quotient	%
$t_1 : t_2$	1.21	74.00	1.22	81.81
$t_2 : t_3$	1.18	83.00	1.18	84.72
$t_3 : t_4$	1.15	84.00	1.15	81.96

(Reciprocal) ratio coefficients for repulsions of the soccer ball dropped from height of 2 and 4 meters were calculated in the seventh phase.

Table 8 Quotient of the height of individual rejection of the ground (in meters)

Mathematical operations = divide, square root	The starting height = 2 meters		The starting height = 4 meters	
	Quotient h_{x+1} / h_x	Coeficient of Repulsion k= $\sqrt{h/H}$	Quotient h_x / h_{x+1}	Coeficient of Repulsion k= $\sqrt{h/H}$
h2: h1	1.32	0.87	1.28	0.88
h3 : h2	1.32	0.87	1.32	0.87
h4: h3	1.23	0.89	1.36	0.86

Table 9 Quotient of the timing intervals of individual rejection of the ground (in seconds)

Mathematical operations = divide, square root	The starting height = 2 meters		The starting height = 4 meters	
	Quotient h_{x+1} / h_x	Coeficient of Repulsion k= $\sqrt{h/H}$	Quotient h_x / h_{x+1}	Coeficient of Repulsion k= $\sqrt{h/H}$
t2 : t1	1.21	0.91	1.22	0.90
t3: t2	1.18	0.92	1.18	0.92
t4: t3	1.15	0.93	1.15	0.91

Result and discussion

During the collision of the elastic bodies with spherical structures, that is occurring during ultra short time, consequences are deformations over the entire surface, and mostly over limited surface of direct contact. In the first phase (compression), elastic material, from which the ball is made, is being compressed so in that phase mater has a smaller volume, although the globular (spherical) structure is geometric body which rounds the same amount of mater with the smallest surface. In the second phase (restitution), molecules of the compressed mater are returning in the previous state which is manifested through repulsion between the collided bodies. Unlike soccer ball, compact material bodies of spherical structure and with elastic properties don't have high coefficient of elasticity.

With sport's balls which have increased internal pressure, coefficient of elasticity is much higher because air (gaseous fluid) can be much more compressed then solid material bodies. Compositions of sport's balls with increased internal pressure are making measuring of its dynamic properties much harder. Not one sport's ball, released in free fall, will repulse in the opposite direction following the same trajectory because the core of the ball is never located in the ideal center of the ball. Asymmetrical bouncing of the soccer ball creates a condition for contact surface between the ball and the ground, after every repeated fall, to uncontrollably moves more or less always, left, right, forth or back.

Every such shift is making ball closer or away from the camera, which causes change of proportion, so all of the sizes calculated by proportion, must be accepted in interpolated form, although the interpolation does not give the most accurate values. The experiment was conducted under natural conditions. In theory, the top speed of the free fall from two meters height is () 6.26 m/sec, and from four meters height it is 8.86 m/sec. In practice, with the existence of the gaseous fluid resistance, the top speed of free fall from two meters height is 6.09 m/sec, and from the 4 meters height is 8.36 m/sec. Speed during the free fall with air resistance is calculated by the formula: Based on the elementary data (tables 1, 2, and charts 1, 2, 3, 4, 5, 6) it can be noted that due to air resistance, friction inside the ball and the coefficient of repulsion, bouncing height an time intervals are proportionally reducing over the chart of natural phenomena. Integral surfaces which form the chart of points of culmination are in the same relation as the heights from which balls are dropped. Percentage ratios, differences and ratios are modified after correcting basic values, due to deviation from the vertical trajectory of the ball. The differences between the previous and the next heights, as well as the differences between the durations of the previous and next bounces are shrinking proportionally in time and space, while increasing in percentages (table 4, 5). Ratios between the previous and the next heights, as well as the ratios between the durations of the previous and next bounces are shrinking proportionally in time and space, while increasing in percentages (table 6, 7). Coefficients of the repulsion have identical value, which is for the soccer ball around 0.87, regardless of the drop height or initial speed.

Conclusion

For more specific information about soccer ball repulsion, it would be necessary to use three cameras for recording, so the deviation from the vertical ball movement can be measured and to correct the scale because of the changes at the place of fall. This pilot study suggests that the habit of measured strike can be acquired only by scientifically created fitness training. Measured strike of the soccer ball has a wide range of both intensity and three-dimensional space. Measured strike of the soccer ball has a special place in the fitness training of soccer players. Conditions for a good soccer match are based on having great durability, great power and great speed. Those are three basic bio-motoric dimensions that are very demanding in respect of the human capacity.

Even a well trained soccer player does not have a sufficient amount of calories to develop all three bio-motoric dimensions to the maximum at the same time. Therefore, fitness preparation in soccer takes place in four phases. In the first phase aerobic capacity (overall endurance) is developing. Overall endurance is just a base for continuing fitness preparations for the second phase. In the second phase anaerobic-lactate capacity (speed endurance) is developing. Gaining speed endurance is a condition for moving to the next phase. In the third phase, anaerobic-alactate capacity (speed in intermittent mode) is developing. Only after developing anaerobic-alactate capacity comes the next phase. The fourth phase or situational training is work with the ball individually and within the group, where dominant technical and tactical skills are practiced within the greatest speed of movement and with the greatest degree of fatigue. In that part of fitness preparations most of the time and the biggest part of energetic reserves is spent on acquiring precision of passing the ball in typical situational conditions.

References

Bjelica, D. (2008). *Sportski trening* [Sports training. In Serbian.]. Nikšić: Fakultet of sport and physical education.
Kašanin, R. (1946). *Viša matematika I*. [Hihger mathematics 1. In Serbian.]. Beograd: Naučna Knjiga.
Opavsky, P. (2004). *Uvod u biomehaniku sporta* [Introduction to sports biomechanics. In Serbian.]. Beograd: Vizartis.
Opavsky, P. (2009). *Fudbal* [Football. In Serbian.]. Sopot: Merkur.
Rašković, D. (1950). *Opšta mehanika* [General mechanics. In Serbian.]. Beograd: Tehnička Knjiga.
Targ, S.M. (1975). *Teorijska mehanika* [Theoretical mechanics. In Serbian.]. Beograd: Građevinska Knjiga.
* * * (2015). *Pravilnik* [Football rules. In Serbian.]. Podgorica: Nogometni savez Crne Gore.

ODBIJANJE NOGOMETNE LOPTE OVISNO O VISINI SLOBODNOG PADA

Sažetak
U sklopu programa fizičkog razvoja igre igraju dominantnu ulogu, a najvažnije od svih igara su igre s loptom. U našem okruženju nogometu ima vodeću ulogu kao igra s loptom. Jedini objekt koji vodi na dinamiku igre je nogometna lopta. Interes za ovaj oblik sporta je vrlo velik i može se vidjeti na globalnoj razini. Deseci tisuća izravnih promatrača gleda utakmice koje se odvijaju na velikim stadionima. Deseci milijuna gledatelja gledaju nogometne utakmice neposredno preko televizijskih ekrana. Stotine milijuna gledatelja gledaju snimke nogometnih utakmica. Financijske bilance oko nogometa pretežu nad financijama mnogih multinacionalnih korporacija. Istraživanja u ovom radu se odnose na elastična svojstva padajuće lopte unutar područja kinemaičke analize. Budući su maksimalni udarci relativno rijetki, sadržaj igra se uglavnom sastoji od tehničkih i taktičkih manevara. Izmjerene štrajkova loptu prevladavaju u tehničkom i taktičkom manevriranje. Stvaranje navika mjereja udarca lopte odvija u uvjetima pripreme, a što je detaljno objašnjeno u raspravi o studiji.

Ključne riječi*: odbijanje, lopta, nogomet, pad*

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