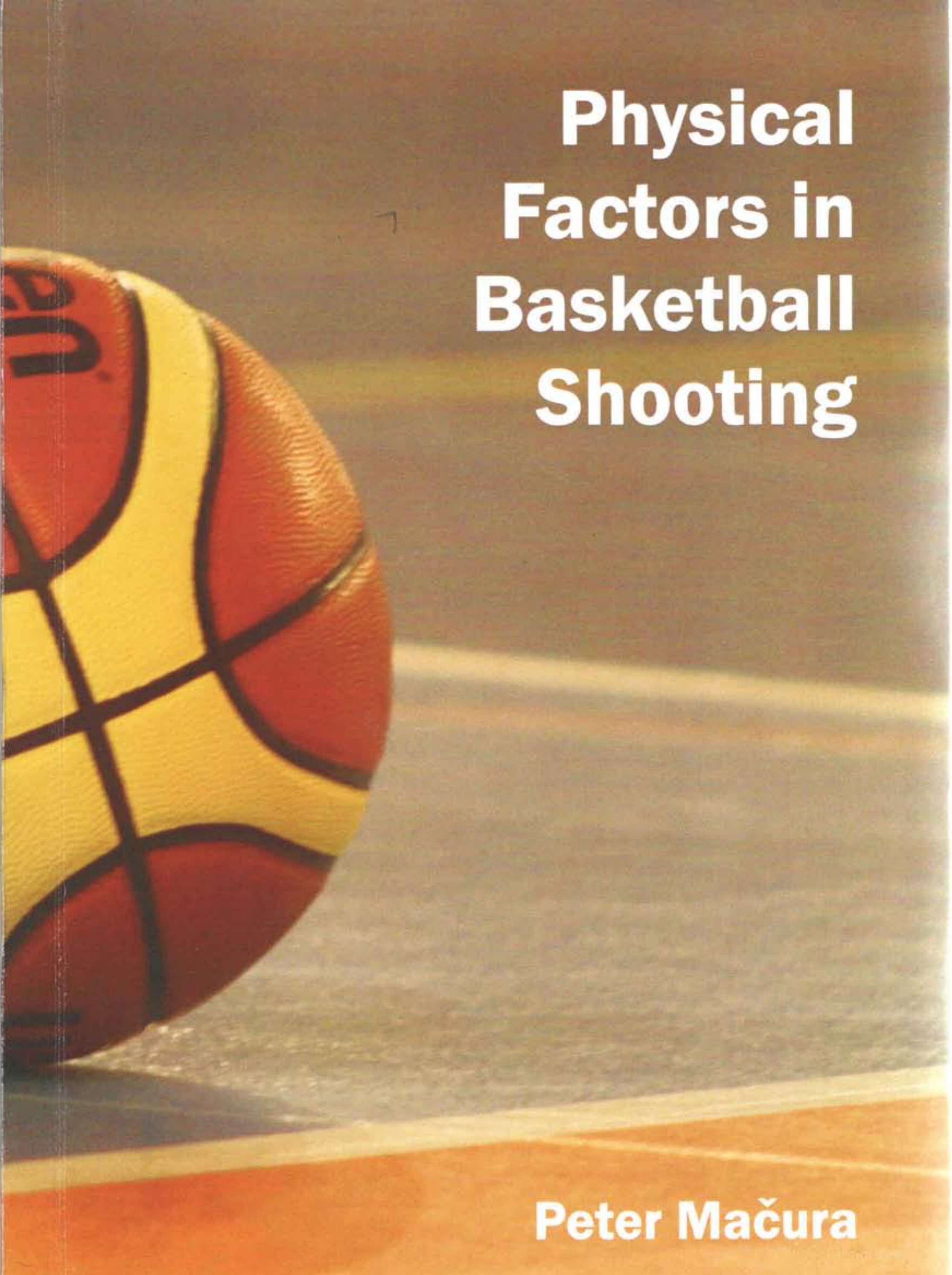
Physical Factors in Basketball Shooting



Peter Mačura

Physical Factors in Basketball Shooting

Peter Mačura

Reviewers

Uldis Grāvītis
Latvijas Sporta pedagoģijas acadēmija
Latvia, Riga

Rudolf Hajossy
Slovak Academy of Sciences, Mathematical Institute
Slovakia, Bratislava

Vladimír Psalman
Masaryk University, Faculty of Sport Studies
Department of Athletics, Swimming and Outdoor Sports
Czech republic, Brno

Physical Factors in Basketball Shooting

UDK 796.3
Ma 167

Comenius University in Bratislava, Faculty of Physical Education and Sports,
Department of Sport Games, Slovak republic

Publisher Latvijas Sporta pedagoģijas acadēmija, Latvia, Riga
Published in 2013. Number of pages 110. Edition 1

English translation:
Mgr. Martin Mačura, PhD.
Constantine the Philosopher University in Nitra, Faculty of Arts, Nitra, Slovakia

ISBN 978-9934-520-03-7

Contents

Preface

My interest in basketball shooting began after enrolling in the Faculty of Physical Education and Sports, Comenius University in Bratislava, Slovakia in 1975. This is when I started taking the first steps as a basketball coach and I had a first-hand experience with many factors associated with basketball shooting, which could be observed and examined in the training process.

I asked myself multiple questions and I was eagerly looking for the answers in myself, in the available literature from all around the world and later in the research results from various "basketball-developed" countries, particularly the USA and USSR.

My interest is mainly focusing on finding the answers to the question "Why the shooter hits basket?"

I studied numerous works from the field of psychology, education, biomechanics, physics, statistics and other sciences, exploring the various ways and aspects of basketball shooting.

I have not found a satisfactory answer to the above question to this day. I have just learned a lot of new information.

Some of it I have included in this little book...

Author

Introduction

The ball trajectory is determined by the shooter's shooting motion at a particular time and place and his/her aim is to score a basket. As a result of this endeavor, the ball is shot at the basket.

The direction and initial speed of the shot determines whether the ball flies into the hoop or not.

The location and position of the point of release of the ball from the shooter's hand allows for a certain set of initial speeds and directions of the ball, which result either in a direct pass through the hoop or a rebound from the board.

Self-evidently, the initial intention of the shooter is to shoot the ball into the basket. This intention is irrevocable.

Whether we want or not, basketball shooting is all about ejecting a material object - the basketball - toward another material object - the basket. This is also the focus of mechanics as part of physics, and it is also what this little book is about...

Physical Factors in Basketball Shooting

Floor

In the past, the term “wooden decking” was used. This was when the basketball courts were still made of quality wood; the term was probably transferred from marine terminology.

For the purpose of focusing on the material the court is made of and its various properties, we will use the term “floor”.

At present the floor material used in the production of basketball courts is not precisely defined. It can be made of wood but also artificial materials.

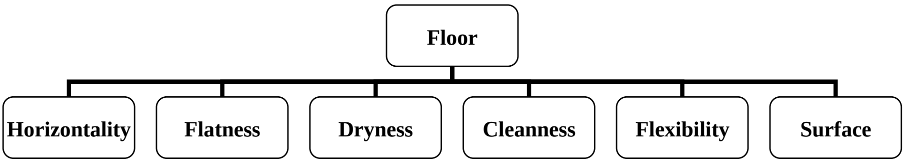


Figure 1: Floor properties affecting the execution of shooting motion.

The floor must be level, matte, made of wood or synthetic materials and at least 7 m below the ceiling.

The following floor properties are important:

- Hardness
- Surface

Floor hardness significantly affects the rebound characteristics before jump shooting. The floor surface influences the shooter's certainty while stopping to take a shot.

Experience also suggests that any moisture and dirt on the floor influences the player's ability to move around the basketball court.

Moisture and cleanness affect the stopping motion before a shot and accelera-tion/deceleration of any motion requiring floor support.

Court

The term “court” indicates the basketball playing area. It is marked with lines, areas and positions where the player stands, moves, shoots from etc. **(Figure 2)**.

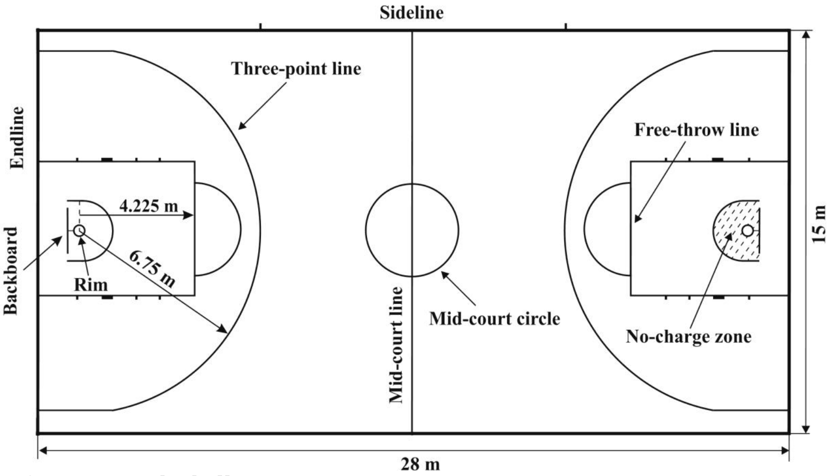


Figure 2: Basketball court.

The dimensions of a basketball court in top world competitions are 28 x 15 m. National competitions can also be played on smaller courts (26 x 14 m).

The court area represents a full set of shooting positions the players can use for shooting at the hoop on the opponent's basket.

The most frequent shooting position in the court is the area in front of the basket at the distance of up to 7–8 meters.

The dimensions of the dedicated court sections within the distance of 6.75 meters[1] in the three–point territory must not change pursuant to the rules of basketball.

The distance of hoop and board from the end line, free throw line from the hoop and three-point area lines are also constant.

[1] The distance of the three-point arc was 6.25 m till the end of Season 2009/2010.

The length and width of the basketball court can be modified. The change in the court length does not affect any circumstances related to basketball shooting.

The change in the court width only affects the size of the area for three–point shots from the field corners and consequently the shooting success from this location.

All youth competitions are played on the same courts as the adult ones.

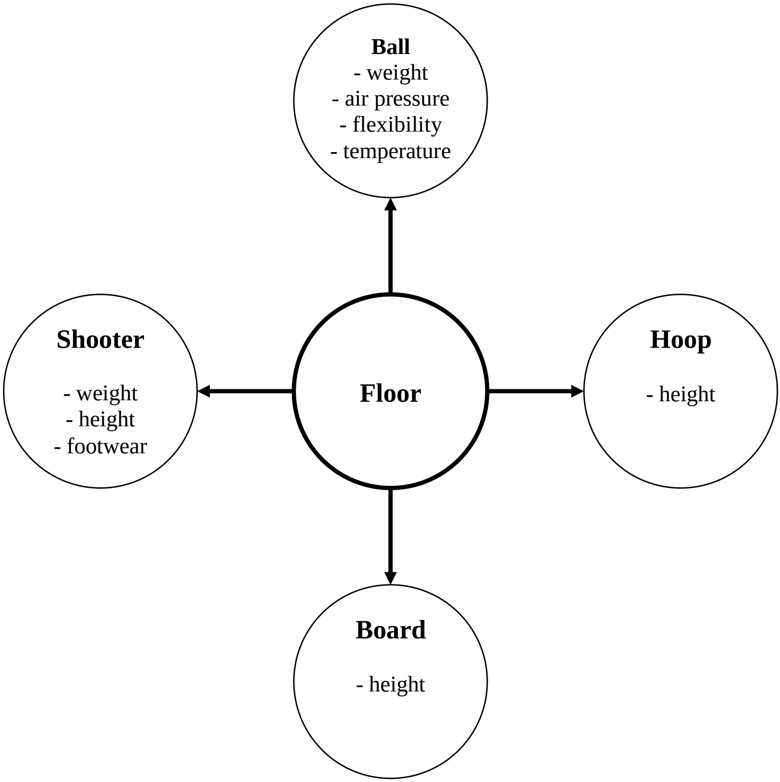


Figure 3: Relation of floor to other important factors in basketball shooting.

Backboard Support Structure

The backboard support structure is in place to fix the basket in position above the playground. It should be sufficiently rigid and motionless. The following parts of the basket structure are important when analyzing basketball shooting:

- Basket
- Board

Sometimes, the structure moves and shakes as a result of players and ball touching the hoop and/or board. The rules stipulate very clearly that any visible vibrations of the structure must end within 4 seconds.

The intention is that the hoop be stationary at the moment the shooter aims and releases the ball.

Basket

The basket consists of the hoop and net. Together, these two are termed a 'basket'.

The net must be made of white cord. The purpose of the net is to provide better visual feedback to the shooter in case of a successful shot, especially when the ball does not touch the hoop.

The basketball hoop and basket are often treated as a synonym, which is not quite appropriate for the purpose of further analysis.

Hoop

The hoop is the target area where the shooter is supposed to deliver the ball.

The hoop piping with a diameter of 1.6 to 2.0 cm has a circular shape. The basketball rules require the hoop to be made of solid steel with an internal diameter of 0.450 to 0.459 m (Figure 4) and painted orange.

The tolerance values for hoop piping (0.004 m) and hoop internal diameter (0.007 m) affect the variability and stability of proper throwing angles and throwing velocity when shooting at the hoops of these various sizes.

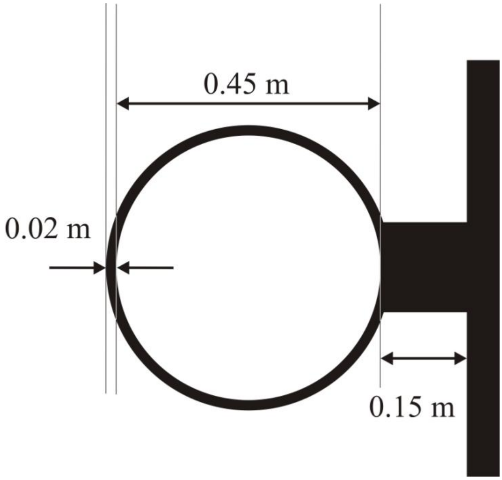


Figure 4: Basketball hoop – inner diameter (0.45 m), hoop piping diameter (0.02 m) and distance (0.15 m) from the board (Official basketball rules, 2012)[2].

Pressure release hoop must meet the rebound characteristics set out for solid hoops.

Both hoops used in a competitive match must have identical rebound properties.

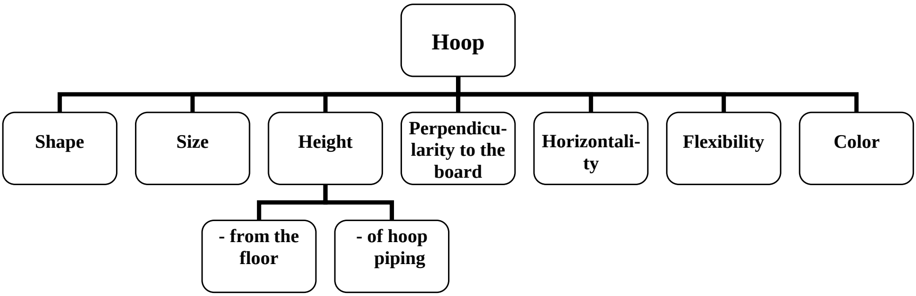


Figure 5: Hoop factors affecting basketball shooting.

2 http://www.fiba.com (Official basketball rules 2012)

The hoop fixture must not create a direct link between the hoop and the board, which is often the case in lower divisions; as it affects the ball rebound characteristics from the hoop (Kondrašin 1973).

Especially the transition from soft to hard hoops results in lower shooting success.

Hoop and floor

The relation between the hoop and floor is given by their parallelism and distance, generally referred to as hoop height (Figure 5).

Hoop height is the shortest distance between the plane on the upper edge of the hoop assembly and the floor.

The hoop height from the floor is constant. It is stipulated in the rules that the upper edge of the hoop is placed horizontally 3.05 m above the floor with the maximum deviation of ± 6 mm.

Saleh Satti (2004; p. 2) states in his experimental work that the measured hoop height is 3.05 ± 0.013 m using a digital meter and analysis. This is the only time a researcher measured the actual hoop distance from the floor in a research work related to basketball shooting. In other works, researchers are likely to base their findings on the assumption that the hoop height is exactly by the rules, i.e. 3.05 m.

Comparing the values of the required hoop height of 3.05 m and the real measured hoop height of 3.05 ± 0.013 m in the above analysis, the difference oscillates around 4 mm.

In minibasketball competitions, the top edge of the hoop is 2.60 m above the floor.

The rules do not permit any deviation from the horizontal angle of the hoop.

Hoop and board

The hoop is attached to the structure so that no force applied to the hoop has a direct effect on the board. There should be no direct contact between the hoop and the board.

The nearest distance between the internal wall on the hoop and the front surface of the board is 0.15 m with a 0.002 m (2 mm) deviation.

The perpendicular distance between the front wall on the board and the hoop center is 0.375 m and it can vary by ± 5.5 mm maximum.

The perpendicular projection of the hoop center on the board must be on the hoop axis perpendicular to the ground.

Board perpendicularity to the hoop

The angle between the hoop plane and the front surface of the board is constant. The basketball rules state that it is perpendicular and they permit no deviation.

This stabilizes the range of angles the shooter can attain when shooting at the board from any respective position on the court with the intention to hit the hoop from the top.

Hoop and ball

Under normal circumstances, the hoop size is not modified depending on the player's sex or age in basketball trainings and matches.

Also, the ball size is constant for a given group of basketball players and the training and competition seasons.

The change in ball size used by a given group of players in trainings and matches is connected with their transition to higher age categories.

Minibasketball players use smaller balls compared to just a few years older basketball players.

The clearance between the hoop and the ball (Figure 6) changes only by changing the ball size since the hoop size is constant (Table 1).

It is generally assumed that the greater the ball size, the smaller the clearance between the hoop and ball.

Adult females train and play with a smaller female ball (circumference = 0.7305 m, diameter = 0.2326 m) resulting in a greater clearance (0.2174 m) between the ball and hoop when compared to men (0.2066 m).

With a constant–sized hoop, the change in ball size results in modifying the hoop – ball relation (Table 1).

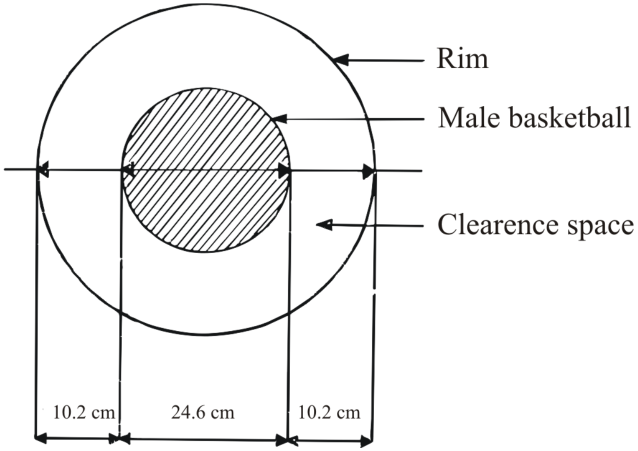


Figure 6: Clearance space between the hoop and male basketball (Herrmann 1976; p. 164).

In basketball shooting, the hoop – ball relations can be divided into two groups:

- Relations without the ball touching the hoop
- Relations with the ball touching the hoop

The first group includes the relations affecting the success of basketball shooting:

- Ball size – hoop size
- Ball shape (roundness) – hoop shape (circularity)

The relations in the second group of the hoop – ball relations are determined by hoop – ball properties such as:

- Ball and hoop flexibility and weight
- Ball and hoop coefficient of friction
- Internal air pressure in the ball

Table 1: Clearance[3] percentage (%) between the balls of different sizes and the inner edge of nominal sized hoop with the internal diameter of 0.45 m.

Size[4]	**Ball name**	**Ball circumference (m)**	**Ball diameter (m)**	**Clearance in the hoop (m)**	**% of ball diameter[5]**
7	men	0.7645	0.2434	0.2066	84.88
6[6]	women	0.7305	0.2326	0.2174	93.47
5[7]	minibasketball	0.7050	0.2246	0.2254	100.36

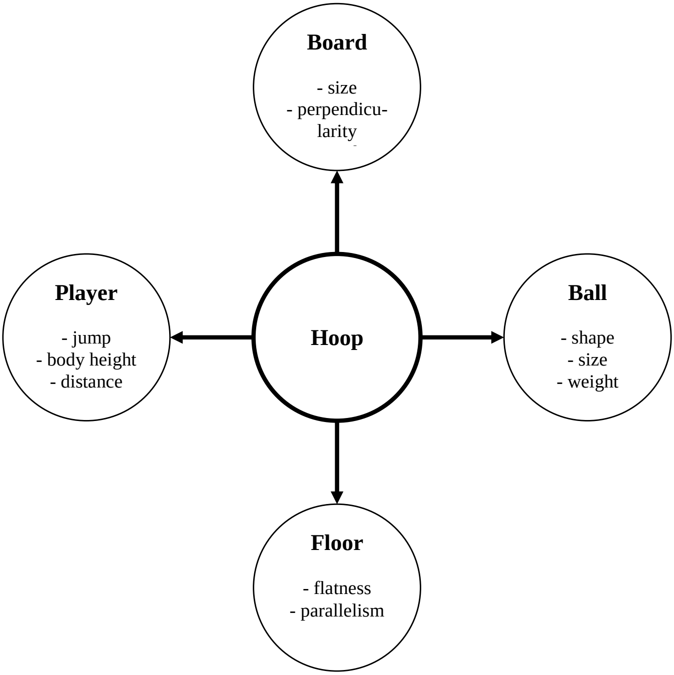


Figure 7: Relation of hoop to other key factors in basketball shooting.

---

[3] Clearance means the difference between the internal diameter of the hoop and the outer diameter of the ball.
[4] The numbers from 5 to 7 represent the conventional identification of basketballs of different sizes.
[5] This is the ratio between the clearance and the hoop diameter.
[6] http://encarta.msn.com/encyclopedia_761571883/Basketball.html (11.06.2007)
[7] Minibasktebal. Pravidlá. (Minibaskteball. Rules). Bratislava, Slovenská basketbalová asociácia, Združenie minibasketbalu Slovenska PEEM 2003. p. 10.   ISBN 80-88901-71-5

Rolling ball on the hoop

Sometimes, the ball rolls on the hoop and subsequently either falls into the basket or outside. The rolling of the ball can be described as a spherical object rotating around its axis with a variable angle of rotation in relation to the hoop plane. When the ball loses contact with the hoop, the ball ceases to roll on the hoop and the rolling motion changes to a spin flight.

The rolling of the ball in relation to shooting occurs as:

- A result of the first contact with the hoop directly after the flight phase toward the basket without previously touching the hoop or board
- Subsequent contact with the hoop after the previous contact or rebound from the hoop and/or board

Board

The basketball board is flat and perpendicular to the floor. Its hardness and flexibility must be comparable with other basketball boards used.

This is important when the ball rebounds from the board, which is considered a principal function of the basketball board.

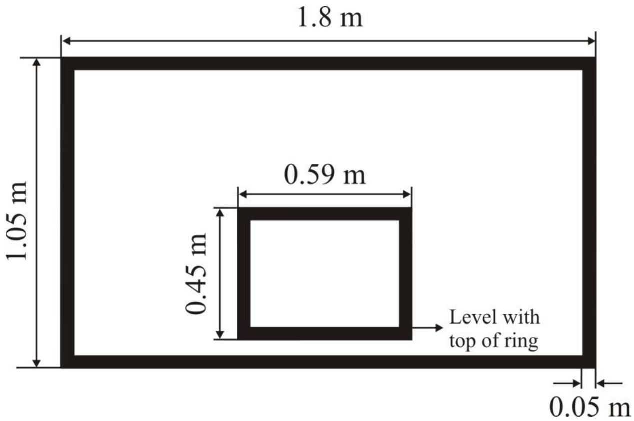


Figure 8: Basketball board with border lines and additional rectangle for official FIBA competitions.

With its orientation towards the hoop, most of the court area and shooting positions, the basketball board usually prevents the ball from bouncing off into the playing field toward the endline. It bounces the ball back into the court.

The basketball board has a rectangular shape with the height of 1.05 meters, width of 1.8 meters and unspecified depth (Figure 8). The front panel of the board has a rectangular shape and it represents a full set of possible rebound points for the ball to bounce off toward the hoop.

The boards are made of transparent or opaque material. The front surface of the board must be smooth and non–reflective. In case of boards made of an opaque material, such boards must be white.

The lines of the board are white on transparent ones or black on white opaque boards. Their width is 0.05 m.

The board has border lines around its perimeter and an additional rectangle in the center area where the hoop is attached.

The boards are mounted on the backboard support structure perpendicular to the ground and parallel to the endline.

A board made of tempered safety glass must meet the strength test.

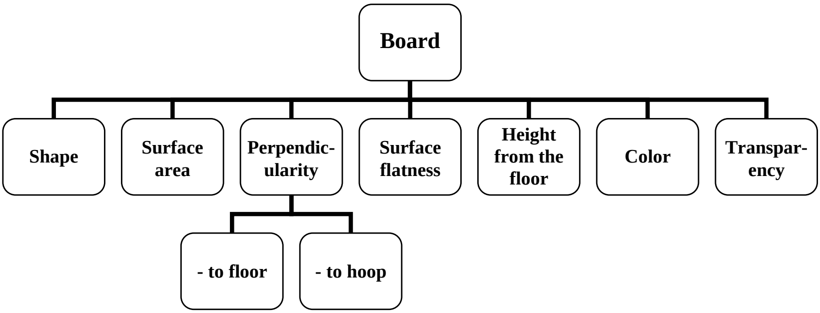


Figure 9: Board factors affecting basketball shooting.

There are two heights on the board in relation to ground level. These are:

- Bottom edge height – 2.90 m from the floor
- Top edge height – 3.95 m from the floor

These determine the lowest and highest possible theoretical rebound points from the board at the hoop.

The rules do not permit any deviation of the board front panel angle from the plane perpendicular to the floor.

Ball

A basketball is a round and flexible object filled with air and it is used by basketball players in dribbling, passing and shooting.

Ball shape

The ball has a spherical shape. It is dyed orange or a combination of orange/light brown (Figure 10).

Figure 10: A two–color basketball approved by FIBA.

Ball size

The basketball size can be understood as its circumference, diameter, volume and surface area.

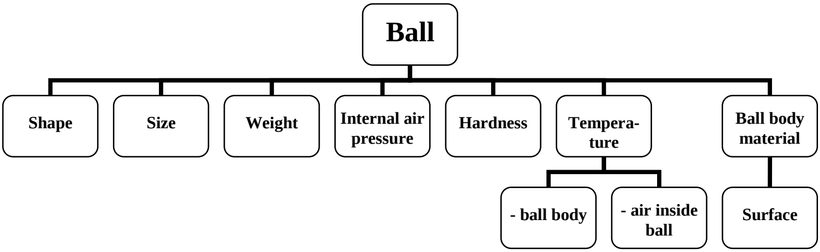


Figure 11: Ball factors affecting basketball shooting.

The basketball rules determine the ball size by its circumference (Table 2).

Ball weight

The basketball rules define the ball weight and size as follows:

Table 2: Weight and size of most commonly used basketballs.

Size	Ball name	Weight[8] (kg)	Ball circumference (m)
7	men	0.57–0.61	0.75–0.78
6[9]	women	0.50–0.54	0.72–0.74
5[10]	minibasketball	0.47–0.50	0.69–0.71

Ball volume

The internal volume of a ball with outer radius r = 0.12 m is 6.37 l (Brancazio – Brody 1987)[11].

Table 3: Ball circumference, diameter, internal volume and outer surface.

Size	Ball name	Ball circumference (m)	Ball diameter (m)	Ball volume (m^3)	Ball surface area (m^2)
7	men	0.7645	0.2434	0.0075340	0.1860
6	women	0.7305	0.2326	0.0065751	0.1699
5	minibasketball	0.7050	0.2246	0.0059197	0.1584

[8] http://www.molten.sk/basketbal.php (29.09.2007)
[9] http://www.slovakbasket.sk/download/OficialnePravidlaBasketbalu2004.pdf (14.06.2007) p. 12.
[10] Minibasktebal. Pravidlá. (Minibaskteball. Rules). Bratislava, Slovenská basketbalová asociácia, Združenie minibasketbalu Slovenska – Peter Mačura, PEEM 2003. p. 10. ISBN 80-88901-71-5
[11] The method of calculating the ball volume is introduced in Hajossy-Mačura (2011), p. 24, formula (1.7).

Ball surface

The outer surface of the ball must be made of leather or artificial leather. In some competitions, basketballs with rubber surface can also be used.

The ball surface has eight or twelve black dividing lines, the width of which cannot exceed 0.00635 m (6.35 mm). The ball surface area is described in Table 3.

Ball hardness

The ball hardness is determined by its pressure. It is defined in relation to the floor – how high the ball needs to jump after bouncing off the floor.

The reason why the internal air pressure in the ball is not precisely determined lies in the fact that, given the effects of temperature, temperature changes during the game mainly due to dribbling, ambient temperature fluctuations and pressure, altitude (factors determining atmospheric pressure), the ball rebound characteristics change at a constant internal pressure.

In order to stabilize the shooting conditions in hoop shots or bank shots, it is more suitable to determine the ball hardness using the rebound characteristics from the board and not from the floor.

In one experiment focusing on the effects of ball softness on basketball shooting, ball softness was analyzed on purpose. Softness was not altered by changing the internal pressure, but by ball type, material and filler material (sponge ball for children) (Ajd 1985).

Due to organizational reasons, the basketball rules do not stipulate exactly what the basketball properties such as shape, surface, size, weight and hardness should be.

Ball and air

Despite its invisibility, air is a material substance. Air impedes objects moving in it, including a flying basketball.

There exist two basic variables in the ball – air relation:

- Ball and air outside the ball
- Ball and air inside the ball (Figure 12).

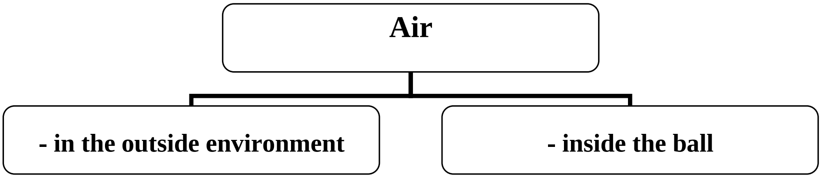


Figure 12: Air affecting basketball shooting.

The resistance of the aerial environment mostly depends on the basketball speed and size characteristics.

To maintain its rebound characteristics and shooter's grip, the inside pressure is a crucial property.

Ball and outside air

There are several forces affecting the flying rotating ball:

Gravitational force
Air resistance force
Magnus force as a result of ball rotation
Archimedes (buoyancy) force

The most commonly considered force is the largest one - gravitational force. The effects of other forces are usually neglected (Tan - Miller 1981, Satti Saleh-2004). The ball moves along a parabolic trajectory as a result of this force. The parabolic trajectory changes into the ballistic one under the influence of air resistance and it is shortened. With the standard backspin, the Magnus force extends the ball flight path. The Archimedes force provides the ball with extra buoyancy and it also extends its flight path.

A concrete idea of what the impact of these forces is on the flight path is provided in Example 5.6 (Hajossy - Mačura 2011), whose aim was to calculate the ballistic trajectory of a rotating ball in an optimum shooting distance of 6 meters.

In the simplified scheme of numerical computational shooting from the distance of 6 m at the hoop 3 m high, the following parameter values were used:

- Initial optimum ball speed V_0 = 8.3 m s^{-1} and angle $\alpha_0 = 49.7^0$
- Angular ball velocity $\omega_x = \omega_y = 0$, ω_z = 6.283185 sequence s^{-1} at the revolution frequency f = 1 s^{-1}
- Ball weight and diameter m_L = 0.6 kg, D = 0.24 m
- Density and drag coefficient ρ = 1.15 kg m^{-3}, C = 0.49
- Gravitational acceleration g = 9.81 m s^{-2}

Forces under consideration	**Horizontal distance of the point of release from the hoop center** x (m)	**Difference** 6,0 – x (m)
Parabolic trajectory		
Gravitational[12]	6.00	0
Gravitational and Archimedes	6.11	–0.11
Ballistic trajectory		
Gravitational and air resistance	5.36	0.74
Non-rotating ball		
Gravitational, air resistance and Archimedes	5.47	0.53
Rotating ball		
Gravitational, air resistance, Archimedes and Magnus	5.56	0.44

The table indicatively shows that:

- The Archimedes (buoyancy) force extends the parabolic path of a 6 m flight path by about 0.1 m
- The air resistance force shortens the path of the ball by about 0.75 m
- The Magnus force extends the total distance the rotating ball by about 0.1 m

[12] The gravitational force is a result of Earth's gravity and the centrifugal force caused by its daily rotation. The Earth has an ellipsoidal shape. The distance of the Earth's poles to its center is approximately 21 km smaller than the distance of the equator, which means the gravitational force on the poles is larger than on the equator. The magnitude of the centrifugal force is proportional to the distance from the Earth's axis of rotation. Therefore, it is the largest on the equator. It follows from the above that the gravitational force is the smallest on the equator, therefore a ball fired from a distance of 6 m at the basket on the equator will fly about 6 cm farther than the ball fired on the Earth's poles.

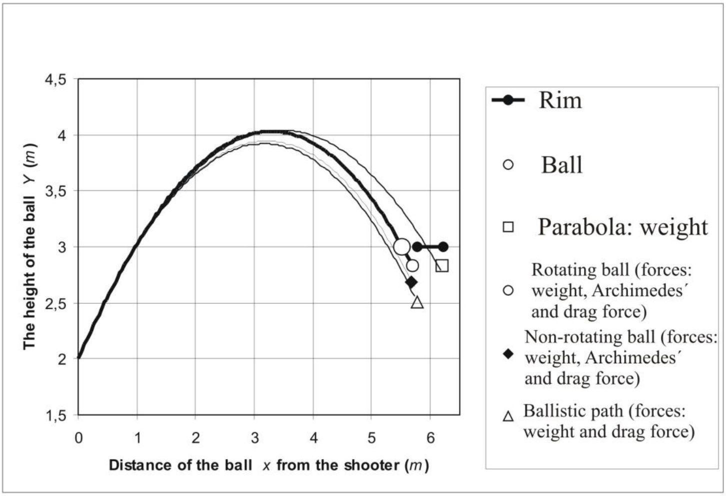


Figure 13: The optimum ball trajectory of a shot at the basket at the height of 3 m from the presumed horizontal distance of 6 meters and the height of the point of release of 2 m depending on the impact of various forces and their combinations.

Similar values of the individual forces on the flight path of a rotating ball were also identified by Fontanella (2006).

Ball and inside air in the ball

The factors affecting the air inside the ball include pressure, temperature and partially weight. The weight of air in the ball is determined by the pressure and temperature (see Example 1.1 and 1.2 in Hajossy - Mačura 2011).

Internal air pressure in the ball

One of the key factors affecting successful basketball shooting is the dependence of board and hoop rebound characteristics on internal air pressure in the ball.

The experimental work by Lindeburg – Hewitt (1965) is one of the few works tackling the issue of air pressure in a basketball, stating that the internal air pressure in a basketball used in the experiment equals 9 lbs, which corresponds to about 35 kPa.

Molten (ball manufacturer) shows a uniform air pressure for balls sized 7, 6, 5 and 3 in the range of 49–63 kPa (the sizes and weights are presented in Table 3). The size 1 mascott ball has an internal overpressure of 40–60 kPa (Molten For The Real Game. Catalog 2007/2008; p. 31).

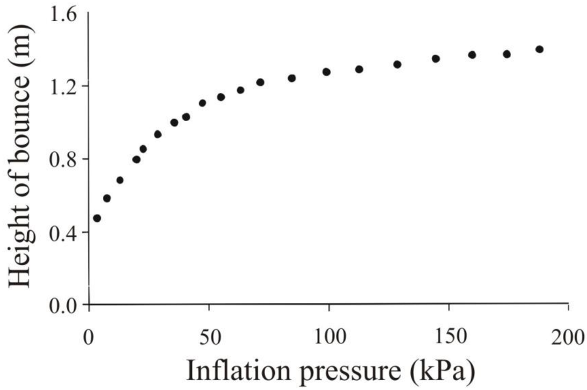


Figure 14: The basketball rebound height with varying internal absolute pressure when dropped from 1.8 m on a concrete floor (Fontanela 2006; p. 111).

We see that the manufacturers recommend the "pressure" of approximately 50-60 kPa. Since the environment around the ball has the atmospheric pressure of 100 kPa, smaller air pressure in the ball (50 kPa) would cause it to deflate. This means that the recommended pressure in the ball should be understood as excess pressure (overpressure) of 50 kPa vis-a-vis the ambient atmospheric pressure. Therefore, the absolute pressure in the ball is 150 kPa.

Apart from the above work by Lindeburg – Hewitt (1965), even Skleryk – Bedenfield (1985; p. 95) state that the air pressure in the balls in their experiments equals about 35 kPa and/or 47 kPa as an experimental factor causing the changes in the performance of control skills tests.

Air temperature in the ball

It has been determined through experimentation that the overall number of rebounds of a basketball from the floor depends on the air temperature in the ball (Figure 15).

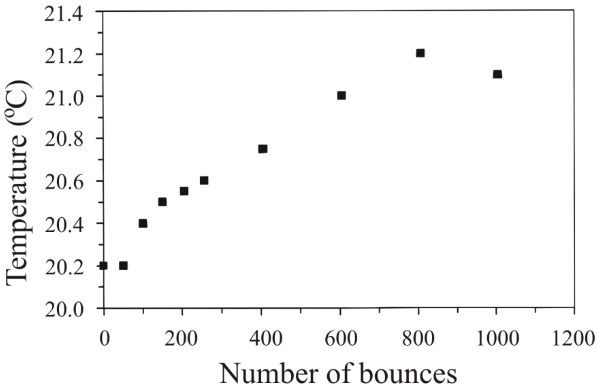


Figure 15: Relation of air temperature in the basketball and the number of bounces from the floor **(Fontanella 2006; p. 112).**

The inside pressure in the ball rises with the rising temperature and conversely, the cooler the air, the lower the air pressure in the ball (Corcoran – Rackstraw 1999).

Air weight in the ball

According to the basketball rules, the air weight in an inflated ball is 11.8 g (Brancazio - Brody 1987). This value is downright insignificant vis–a–vis the admissible weight variations of basketballs in the basketball rules. Therefore, no clear indication is given of whether the balls are inflated or deflated accurately.

Internal air pressure in the ball and shooting techniques

Apart from the ball size and the shooter's hand, the shooting technique in basketball is also influenced by the internal air pressure in the ball, which affects the way the shooter holds the ball.

A more inflated ball is easier to handle for some shooters and, conversely, others prefer using less inflated balls.

The grip also depends on the ball surface structure and the material the ball surface layer is made of.

There are players who cannot grip the ball when shooting and they have to lay it on their fingers and/or fingertips, while others can grip the ball with one single hand without dropping it even when held from the top.

Ball and floor

The basketball rules[13] stipulate that the basketball has to have such pressure so as to rebound from the floor to the height of 1.2 to 1.4 m (measured from the ball top) when dropped from 1.8 m (measured from the ball bottom).

The floor and its properties are important in basketball shooting mainly when dribling and bouncing the ball off the floor before the shot.

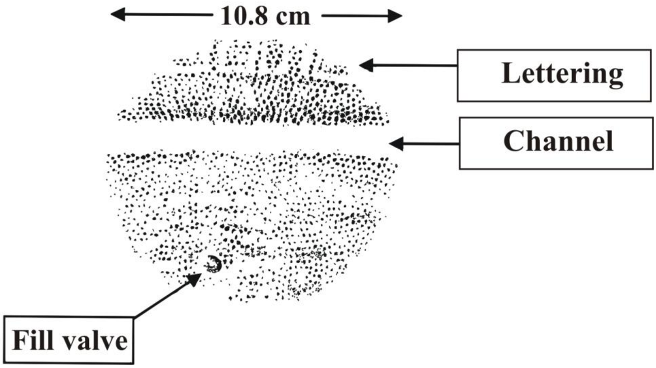


Figure 16: An imprint of a male basketball dropped from 1.3 m on a carbon copy paper placed on a horizontal dynamographic board with zero rotation (Fontanella 2006; p. 104)[14].

[13] http://www.slovakbasket.sk/download/OficialnePravidlaBasketbalu2004.pdf (14.06.2007) p. 12.
[14] The calculations of ball deformation are presented by Hajossy - Mačura (2011) in Example 6.1

The experiments performed by Hay (1973), Isaacs – Karpman (1981) and Mathes – Flatten (1982) all deal with perpendicular rebounds of a basketball made of various materials from a flat floor of various types.

An important finding to consider is that under certain experimental conditions, leather balls bounced by 4.9 cm higher than balls made of plastic on all tested surfaces: tartan, asphalt, glass, concrete and hardwood (Mathes–Flatten 1982).

Ball rebound

The basketball rules clearly state what kind of ball can be used in the game depending on the perpendicular bounce from the floor the match is to be played on.

The basketball rebounds can be generally divided into rebounds from:

- Floor
- Backboard support structure
  - – Hoop
  - – Board (Figure 17)

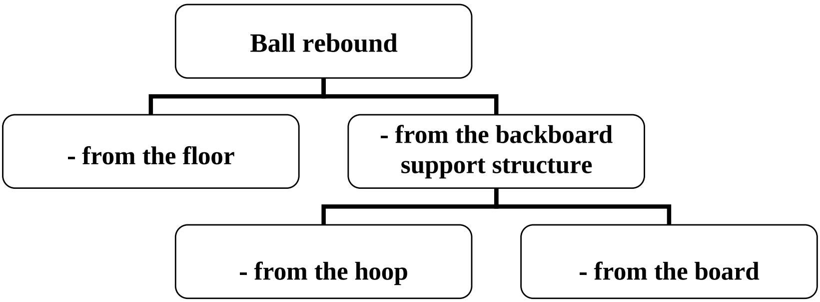


Figure 17: Types of rebounds in basketball.

Ball rebound mechanism

The ball is filled with compressed and further compressible air. The ball body is made of flexible material. The compressibility and expansibility of air inside the basketball and its flexibility are some of the key factors influencing the ball rebound.

When hitting another object, the ball is squeezed, which raises the internal air pressure. At the same time, the flexible ball body is warped.

The increase of inner pressure in the ball causes a subsequent expansion of the ball body into its original non–deformed shape.

The return of the ball to the original spherical shape happens in a very short time. The ball will then bounce off the object it hits.

Ball rebound in basketball shooting

In basketball shooting, we distinguish the following types of ball rebound:

- Rebound from the hoop
- Rebound from the board (Figure 18)
- Combinations of rebounds from the board and hoop, or vice versa, in various sequences
- Random and intentional rebounds from the shooter's hand/s

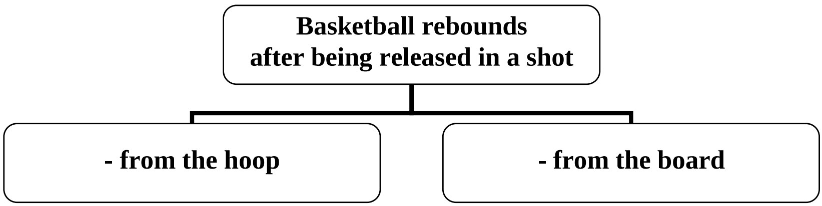


Figure 18: Types of basketball rebounds after the shot.

With the usual air pressure range inside the basketball, the higher the air temperature in the ball, the more it bounces off (Corcoran – Rackstraw 1999).

The extreme air pressure inside the ball causes the rebound height to drop when the ball bounces off a hard surface because the overpressure decreases the deformation of the ball.[15]

[15] The theory of ball bouncing off the floor is explained in Hajossy – Mačura (2011), Example 1.8., p. 37.

Ball rebound from the floor

In relation to the basketball and the floor, the important factors affecting its rebound characteristics in the last rebound before the shot are: ball weight and shape, ball size, internal air pressure and temperature, material the ball is made of, rotational characteristics of the ball the moment it touches the floor, the angle of impact of the ball the moment it touches the floor, floor flexibility etc.

Ball rebound and angle of impact on the floor

We know several kinds of ball rebounds from the floor depending on its angle of impact. Typically, the ball hits the ground at an angle which is not perpendicular.

Despite the above, the biggest attention is paid to the perpendicular ball rebounds from the floor (Hay 1973, Brancazio 1981, Fontanella 2006).

Rebound from the floor and ball size and weight

Isaacs – Karpman (1981) released basketballs of different sizes and weights from the height of 2.44 m on the floor: the biggest with the circumference of 0.749 m and weight of 0.595 kg, the medium–sized with the circumference of 0.699 m and the weight of 0.496 kg and the smallest with the circumference of 0.632 m and the weight of 0.255 kg.

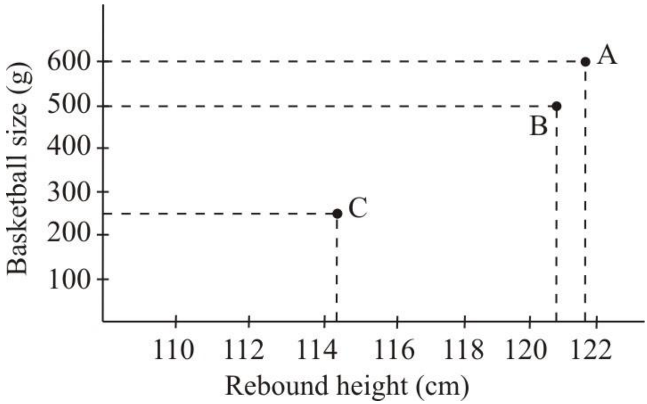


Figure 19: The relation of rebound height and basketball size. Ball sizes: A – large, B – medium, C – small (Isaacs – Karpman 1981).

The rebound height changes depending on the basketball size and weight: the biggest ball bounced to the height of 1.217 m, the medium ball bounced to the height of 1.209 m and the smallest to the height of 1.143 m (Figure 19).

The future measurements will shed more light on whether the rebound height is more a function of ball weight than ball size provided the other variables remain constant.[16]

Rebound from the floor and ball rotation

The ball rebound from the floor can be divided into the following two categories depending on the ball spin the moment it hits the floor:

- Zero spin
- Non–zero spin

of the ball before it hits the floor.

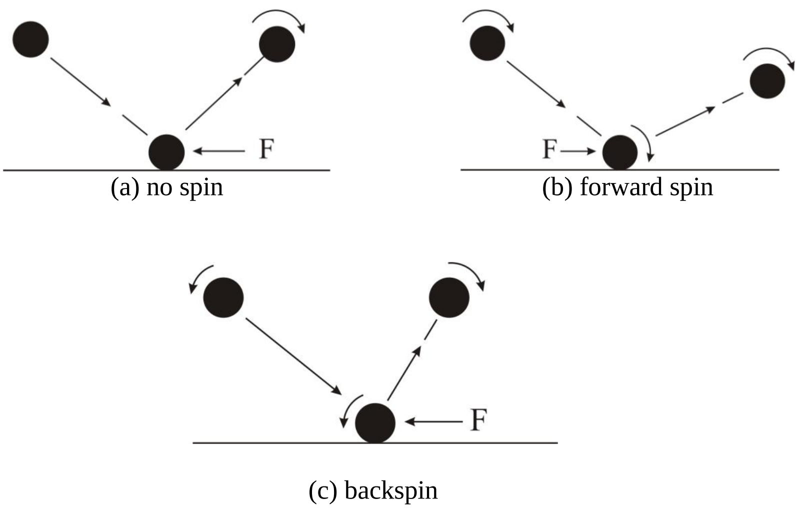


Figure 20: Rebound of a basketball hitting the floor at an acute angle with varying spin.

[16] The theory of a bouncing ball with no spin is explained in Hajossy – Mačura (2011), Example 3.4., p. 142.

Brancazio (1981) compared the differences between the rebound of a ball hitting the floor at an angle and having a horizontal rotational axis (Figure 20) with zero spin (a), forward spin (b) and backspin (c).

The rebounds of a flying spinning basketball can be divided into:

- Rebounds of a flying ball with a backspin
- Rebounds of a flying ball with a forward spin

A ball hitting the floor at an acute angle having zero spin will receive a forward spin in the direction of flight.

A spinning ball hitting the floor perpendicularly will bounce off in the direction of spin (Figure 21).

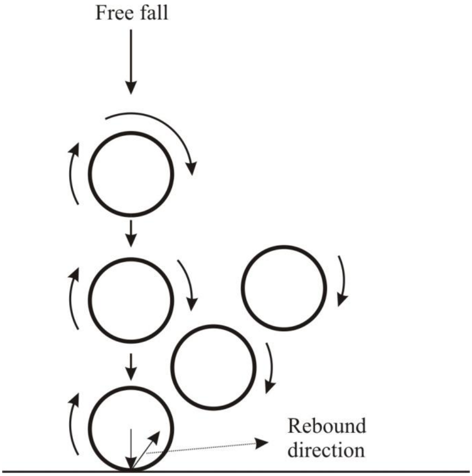


Figure 21: Rebound direction of a spinning ball hitting the ground perpendicularly[17].

[17] Chapter III, Part 1.4 in Hajossy – Mačura (2011) explains the bounce of ball from the floor and backboard (p. 127 et seq.)

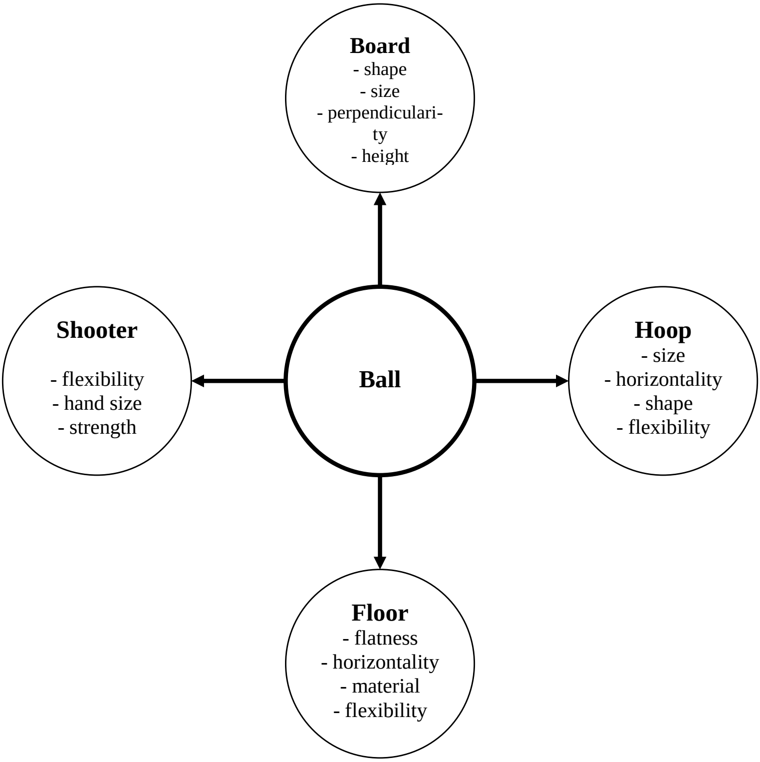


Figure 22: Relation of the ball to other key factors in basketball shooting.

Ball rebound from the hoop and board[18]

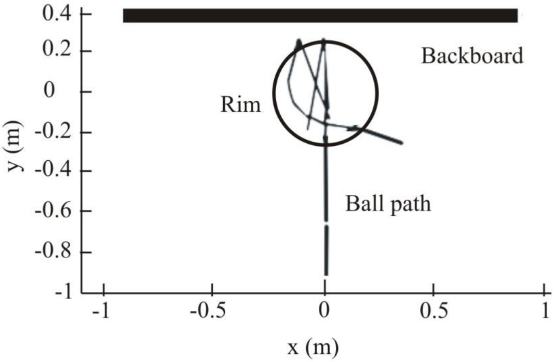
The examination of ball rebound from the board and hoop is also important in terms of determining the player motion in defensive and offensive rebounding.

In addition to shooting the ball through the hoop and through the basket, there is probably only one other situation in basketball in which the rebound of a ball from the hoop is used on purpose:

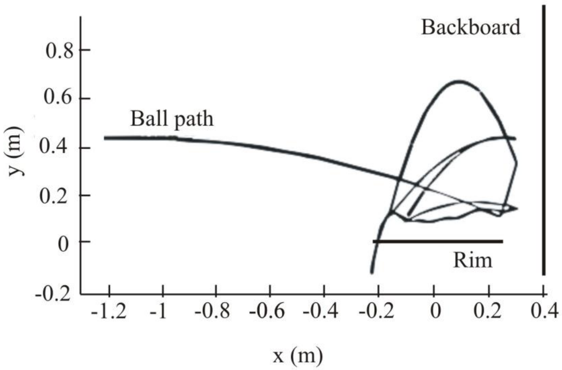
[18] Example 3.7 (Hajossy – Mačura 2011) shows the difference of a rebound from a smooth and rough board of a spinning and non-spinning ball.

- In the last seconds of a competitive match as part of the last free throw, the shooter in the team losing by one or two points intentionally shoots the ball at the metal hoop so it bounces to one of his/her teammates who in turn, due to time constraints, immediately shoots into the hoop. This way, they attempt to score two points by shooting from the field as opposed to one point by scoring the last free throw.

It requires a high degree of skill to rebound the ball toward a teammate who is in turn expected to dominate it and overcome his/her opponents.



a



b

Figure 23: Trajectories of a basketball rebounding from the hoop and backboard – top view (a) and side view (b) (Okubo – Hubbard 2006; p. 1307).

Shooter

Shooter and floor

The relation between the floor and shooter is influenced by various circumstances. Among others, we can name floor flexibility, type, surface and cleanliness, shooter's sports shoes and their softness and shoe surface material grip to the floor surface.

The floor cleanliness and wetness affect the friction between the shooter's shoes and the floor when stopping before the shot.

These affect the shooter's stability and certainty before stopping and the jump height in jump shooting.

Low coefficient of friction between the soles of shooter's sports shoes and the floor causes an occasional slip when stopping, which in turn affects the shooter's certainty in carrying out the shooting motion and any other kinematic and dynamic parameters in shooting.

The player must dynamically compensate the above biomechanical parameters. This above all concerns the initial throwing angle in three–dimensional space and the ball velocity.

We see that the relation between the player and the floor has a huge impact on the success of a particular shot and, from a long–term viewpoint, on shooting as an activity.

Shooter's base of support on the floor

Different shooting methods are accompanied by different sizes of shooter's base of support. Set shots in free throws are performed with the support of both legs. The area supporting the shooter on the floor is larger than shooting after a step–out and turn in which the only support is the tread surface of the supporting leg, and/or the front outer sole of the sneaker.

In modern basketball, it is also quite frequent for the player to release the ball from his/her hand in the flight phase – in the jump. In this case we cannot talk about a base of support on the floor at the time of release; it can be more properly labeled as the support area at the moment of take-off.

An example here is one–handed hook shot after a lay–up or a hook shot while jumping.

Generally, the size of the support area and the position of center of gravity while shooting determine the shooter's balance.

A hitherto unique work exploring the relation of friction and hardness of different surfaces on basketball shoes and three types of playing surfaces was presented by Rheinstein – Morehouse – Niebel (1978).

They discovered higher friction values in rotational forces with soft surface soles on hard oak, maple and plastic flooring compared to hard surface soles.

The interaction with footwear was also determined by the flooring surface and player weight. Plastic floor surfaces showed more resistance to lateral forces than hardwood flooring when in contact with basketball shoes.

Heavier players had a disadvantage compared to lighter players when playing on dirty floors. Lateral friction on a dusty surface was smaller with heavier players than with lighter players.

Shooter and court

If free throws are not taken into consideration, the court area can be divided into sectors (Figure 24) and it is used unevenly in shooting (Figure 25).

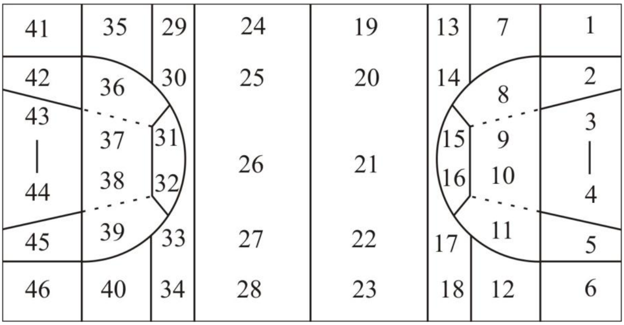


Figure 24: Basketball court division into sectors (Hagedorn – Lorenz – Meseck 1981; p. 444).

A dominance of shooting in relation to the board from the sides and near the basket (Sectors 3 and 4 and 43 and 44) was found.

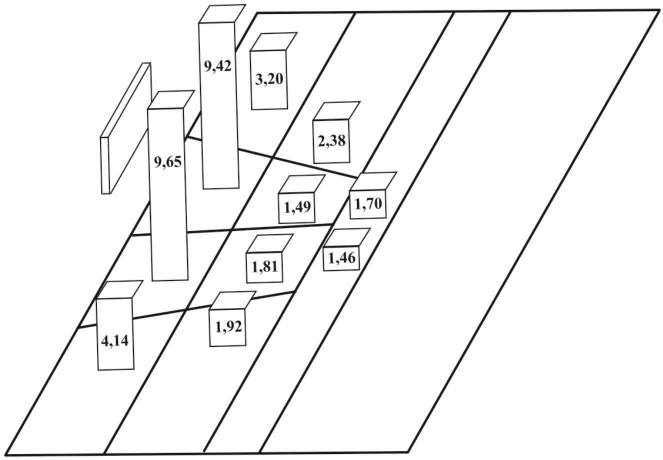


Figure 25: Small and medium distance shooting in basketball games (Hegedorn – Lorenz – Meseck 1981; p. 446). The values express the mean average number of shots from the respective sector per game.

These were followed by areas near the basket from the medium distance at the endline (sectors 2 and 5 and 42 and 45).

The frequency of shooting from a small and long distance differed significantly. The right and left sides of the offensive half of the basketball court is used indiscriminately.

In case of individual teams or particular matches, digressions from the presented results can be expected.

In another research study Tavarez – Gomez (2003) originating at the World Junior Championships, the highest frequency of shooting positions on the court was found in the area in front of the board (45.45%), followed by zone 8 (9.8%) (Figure 26). The smallest number of shots was fired from zone 4 and 7 (1.25% and 3.3%).

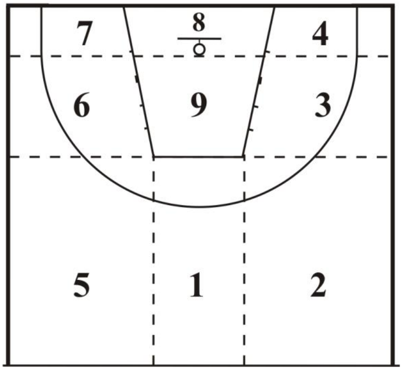


Figure 26: Division of basketball court into sectors (Tavares – Gomes 2003).

It appears that the highest incidence of shooting in basketball competitions is right in front of the board and on the sides under the hoop.

Shooter and ball

The human body can assume a variety of shapes. In particular, the hand is capable of great changes and modifications in its shape. In basketball shooting, the hand can adapt to the spherical shape of the ball and to its size. This adaptation constitutes the relation between the hand and the ball.

The shooter – ball relation can also be determined by their weight and size characteristics.

Shooter's weight and ball weight

Experience suggests that the shooter's ability to shoot in basketball is also limited by his/her weight.

Apart from the player's skeletal system, the total body weight also includes the digestive tract and residuals, the muscle system, which contributes significantly to the "power" factor necessary to complete the shot and/or to shoot without a significant deviation from optimal shooting technique.

Table 4: The weight ratio of a young basketball male player and the ball (%).

	Age (years)					
	11	12	13	14	15	16
Shooter weight (kg) *	38.28	47.83	58.91	64.96	76.75	81.36
Ball size no. 5 – 0.609 kg **	1.59	1.27	1.03	0.94	0.79	0.75
Ball size no. 6 – 0.539 kg	1.41	1.13	0.92	0.83	0.70	0.66
Ball size no. 7 – 0.475 kg	1.24	0.99	0.81	0.73	0.62	0.58

* Mačura (1987) b
** Average value according to the Basketball Rules

The ball–to–player weight ratio is decreasing (Table 4).

It is subjectively assumed that the older and heavier the shooter, the lighter the ball relative to his body weight. The values differ for men's ball No. 7 from 1.24% of shooter's body weight with 11–year–olds to 0.58% with 16–year–olds.

Ball size and shooter´s select body parts

The most important size relations include the ball size and hand size. The hand size is determined by finger length and palm size and it determines the ball grabbing and holding technique and its adaptation when shooting.

Table 5: The ratio of maximum finger span on a flat surface to the ball circumference (%).

	Age (years) - boys					
	11	**12**	**13**	**14**	**15**	**16**
Finger span (m) *	0.182	0.195	0.212	0.218	0.236	0.235
Ball no. 5 circumference – 0.705 (m)**	25.82	27.66	30.07	30.92	33.48	33.33
Ball no. 6 circumference – 0.731 (m)	24.90	26.68	29.00	29.82	32.28	31.15
Ball no. 7 circumference – 0.765 (m)	23.79	25.49	27.71	27.50	30.89	30.72

* Mačura (1987) b
** Average value according to the Basketball Rules

Table 6: Success rate in set shots and hand size characteristics of boys on a flat surface and on a basketball (Mačura 1991).

	Younger pupils (n=18)	Older pupils (n=25)	Cadets (n=16)	Juniors (n=11)
Decimal age (years)	11.96 ± 0.55	14.14 ± 0.63	16.16 ± 0.58	18.18 ± 0.60
% shooting 2 m	10.17 ± 2.94	14.72 ± 2.23	15.94 ± 1.29	16.09 ± 1.78
% shooting 3 m	7.83 ± 2.47	13.24 ± 3.15	14.88 ± 2.47	15.45 ± 1.67
% shooting 4 m	4.06 ± 2.17	11.08 ± 3.46	13.81 ± 3.46	14.00 ± 1.27
Maximum finger splay on a flat surface (m)	0.189 ± 0.012	0.215 ± 0.014	0.235 ± 0.013	0.223 ± 0.014
Finger splay on a ball (m)*	0.162 ± 0.014	0.190 ± 0.016	0.207 ± 0.17	0.207 ± 0.018
Hand surface contour a flat surface (m^2)	0.0118 ± 0.0020	0.0153 ± 0.0014	0.0173 ± 0.0011	0.0166 ± 0.0013

* Ball no. 7 size

The relation of ball size (expressed by its circumference) to hand size (expressed in maximum finger splay) indicates that the younger and smaller the player, the smaller the circumference of a basketball he can effectively grab regardless of its size (Table 5).

The analysis shows that the players of a certain age can hold the smaller ball more effectively, for example, the maximum finger splay in 11 year old players results in a 25.82% surface grab of the minibasketball no. 5, but only 23.79% of the male basketball no. 7. This decreases the grab size of the ball.

In shooting, the ball grab increases with the increasing size of the shooter's hand. The maximum finger splay on the preferred hand in ages 11–18 indirectly reflects the size characteristics of the hand involved in grabbing the ball.

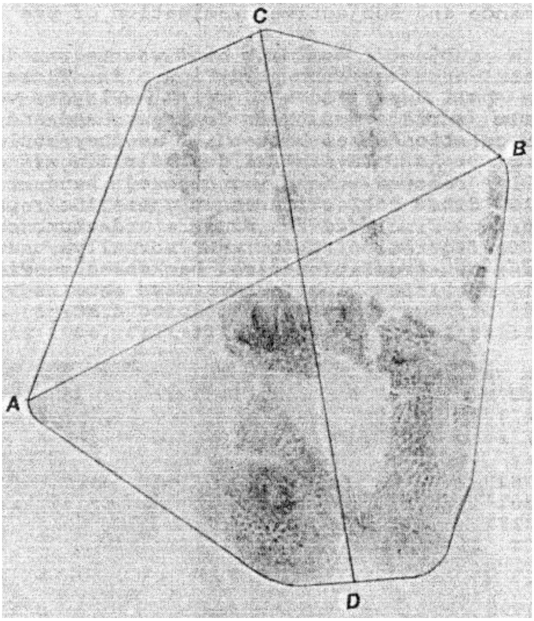


Figure 28: Hand imprint on a flat surface. The distance between points A – B = hand width, C – D = hand length (Skleryk – Bedingfield 1985; p. 92).

High correlation between the maximum finger splay on the flat surface, ball and flat surface hand contour and the success of set shots from the distance of 2, 3 and 4 m shot (Table 6) perpendicularly to board with ball size no. 7 was discovered in laboratory conditions using pupils as test subjects (Mačura 1991).

Liu – Burton (1999; p. 835) introduced the index ratio of average width of the basketball to the finger splay on the shooting hand from the little finger to thumb. In men, the experimental value was 1.16 (men´s basketball ball had circumference 76.2 cm, diameter 24.4 cm) and in women the value was 1.26 (women´s basketball ball had circumference 74.7 cm, diameter 23.4 cm).

Ball grip with the shooting hand

We can assume that the shooter's hand size, finger splay and ball size are the parameters determining the ball grab in the shooting hand.

In a competitive match, the rules clearly define the ball size. Therefore the ball grab of a particular player and his/her shooting hand remains constant throughout the match. Its size varies with finger splay (Figure 28).

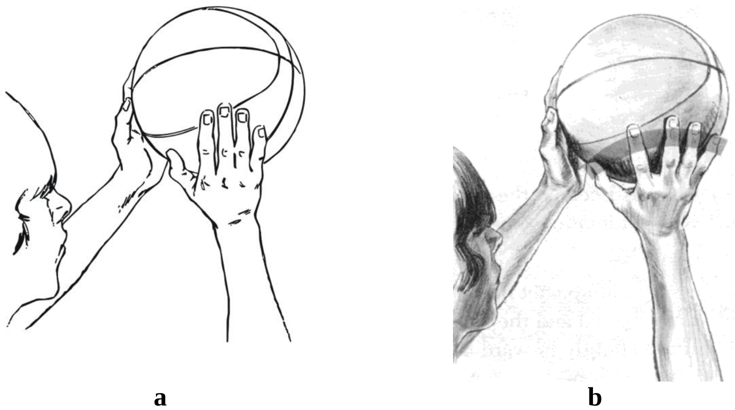


Figure 29: Splayed hand on the ball: a – wrong, fingers are too close to each other, b – correct, fingers are comfortably stretched (Wooden–Sharman–Seizer 1975; p. 65).

In shooting, the balls grab increases with the increasing size of shooter's hand.

The maximum finger splay on the preferred hand in ages 11–18 can indirectly reflect the size characteristics of the shooting hand that supports the ball with its surface area.

The ratio of ball grab with the shooting hand to ball circumference varies with hand size and ball size (Table 6).

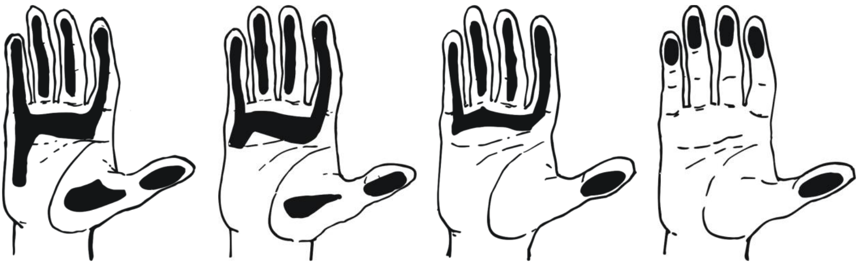
Contact surfaces areas between the hand and the ball

The hand size determines the contact area with the ball of a certain size.

Individual techniques in holding the ball while shooting reflect the location and size of contact areas on the fingers and palm.

Long–term experience shows that the ball is not supposed to contact the central section of shooter's palm during the shooting motion (Figure 30, Illustration 1). Another extreme is to hold the ball with the fingertips only (ibid. Illustration 4).

It is said that the ball should be touching the callous sections of the shooting hand.



1 2 3 4

Figure 30: Contact areas of the shooting hand and the basketball (Anderle 1977; p. 8). Legend: 1 – maximum contact area, 2 – medium contact area, 3 – minimum contact area, 4 – insufficient contact area.

Shooter and hoop

Perhaps the most important factor determining the shooter–hoop relation is that the hoop is elevated relative to the shooter and if he/she wants to score points by shooting the ball within the meaning of basketball rules, the ball must enter the hoop from the top.

This causes most of the points to be scored by shooting the ball on a relatively parabolic trajectory. Dunking is an exception: the ball does not fly through space, but is smashed directly into the hoop by a jumping shooter.

The shooter usually sees the hoop from the bottom. This is a peculiarity in comparison with other sports games where most of the targets the players aim at are not elevated and they see them in plain sight in the direction of the target they are supposed to hit by the respective rules.

Body height and hoop height

Body height is directly proportional to the release point of the ball from the shooter's hand at the moment of shooting.

With constant hoop height, the ball release height determines the vertical distance of the release point from the hoop plane. With constant hoop height, the changes in this vertical distance are relatively small for individual shooters in particular moments.

It is generally assumed that the shooter's height indirectly and significantly determines the strength requirements for a particular shot.

It is assumed that the taller the shooter, the less strength there is necessary to shoot the ball into the hoop from a particular horizontal distance from the hoop.

Table 7: The difference between body height and hoop height (a constant of 3.05 m) = vertical distance between the release point and hoop plane.

	Age (years) - boys					
	11	**12**	**13**	**14**	**15**	**16**
Body height* (m)	1.52	1.67	1.74	1.80	1.88	1.88
Difference (m)**	1.53	1.38	1.31	1.25	1.17	1.17

* Mačura (1987) b
** hoop height 3.05 m minus the body height

Shooter's strength and hoop height

Regarding ball weight and shooter's vertical, horizontal and linear distance from the hoop, a certain strength potential is required in the given throwing angle to impart the necessary speed to the ball.

It is said that a stronger hand helps the shooter to successfully shoot the basketball into the basket, whereby the validity of such claims increases with increasing the distance between the shooter and the hoop and decreasing his/her age (Table 8).

Table 8: Values of maximum grip force in the shooting hand (Mačura 1987).

	Age (years) - boys					
	11.5	**12.4**	**13.5**	**14.7**	**15.7**	**16.7**
Maximum hand grip strength (N)	21.5	23.2	32.0	37.9	44.5	49.1

The shooter's strength prerequisites increase with his/her age, natural growth and focused training activities.

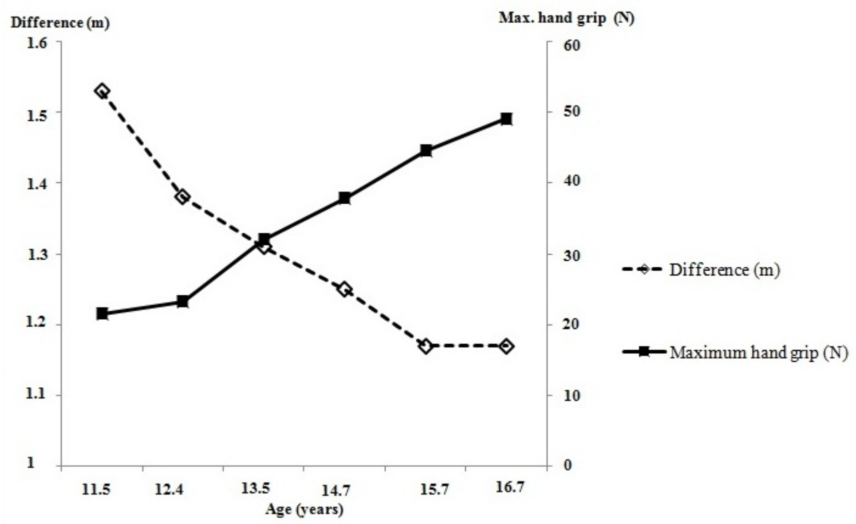


Figure 31: Opposing maximum strength vector of shooting hand grip of boys and the difference between the shooter's height and the constant hoop height of 3.05 m (Mačura 1987 b).

Increasing the player's body height, the vertical distance of the release point from the hoop plane is reduced, thus minimizing the shooter's strength prerequisites when shooting from particular locations on the court.

A paradoxically opposite downward course of the general strength prerequisites in individual development stages of young shooters to decreasing the vertical distance between the release point and the hoop plane was recorded (Figure 31). It is paradoxical that a younger and less skilled shooter needs more strength to overcome the difference between the height of the hoop plane and the point of release.

The course of differential values between the constant hoop height of 3.05 m and the height of young basketball players (11 to 19 years) was contradictory in relation to the values of maximum grip of the shooting hand.

The older the player and the stronger the grip in the shooting hand, the smaller the vertical distance the ball has to travel from the given horizontal distance from the hoop.

Shooter and board

The board is elevated in relation to the shooter. The vast majority of shooting is carried out in a way that the release point of the ball happens to be below the hoop plane.

The fact that the hoop is mounted in the bottom of the board determines the initial throwing angle when shooting at the board. The shooter generally shoots the ball upwards.

If he/she shot the ball downwards at the board into the hoop, the ball release point would have to be located above the hoop level.

Not every shooting position on the court allows for shooting the ball with a rebound from the board. One cannot shoot at the board when shooting from behind it and in cases when the angle between the ball trajectory and the board and the angle of rebound from the board are too small – only a couple of degrees.

In terms of intentionality, the use of the board in basketball shooting can be divided into intentional and unintentional. The unintentional use of the board can also be labeled as random.

The shooters purposely shoot the ball using the rebound technique although sometimes a ball shot inaccurately at the hoop bounces off the board and falls into the basket.

Experience suggests under what conditions to shoot at the board or directly at the hoop.

The most common reason to shoot at the board is the shooter's position in the court.

The board is shot at depending on where the shooting player is located in the court relative to the board (Figures 32 and 33) and how far he/she is from the hoop. It is recommended to shoot at the hoop from smaller distances[19].

[19] Hajossy – Mačura (2011) present the calculation of the point rebound off the backboard when shooting a successful shot on the ballistic trajectory (pp. 226-235).

Board surface as shooter´s visual support

The shooter's view of the hoop is less influenced by his/her shooting position on the court compared to the shooter's view of the board. In most normal shooting positions, we can say the hoop is viewed the same way in the shooter's field of vision.

What visibly changes in the shooter's field of vision depending on his/her location on the court is the board size.

The more perpendicular the position of the shooter to the board, the larger the surface area the board occupies in his/her field of vision. Moving the shooting positions towards the sides of the board, the size of the board gets smaller in the shooter's field of vision.

Similarly, the farther the shooter from the board, the smaller the board appears to be a possible reason why shooting at the board tends to be less frequent with the shooter moving away from the board.

Moving closer under the board, the area of the front side of the board appears to be shrinking in the shooter's field of view.

Shooter´s position relative to the board

The front surface of the board is a complete theoretical set of points the ball can hit and bounce into the hoop.

The position of the release point relative to the board can be viewed in two ways:

- Orthogonal point of release on the floor relative to the front surface of the board (Figures 32 and 33) is termed as angle relative to the board
- Height of the release point above the floor, and/or, location of the orthogonal release point on the board plane

Although no complete unity in the angular distribution of shooter positions on the field against the basketball board was reached (Figures 32 and 33), advice and experience focuses on the first area.

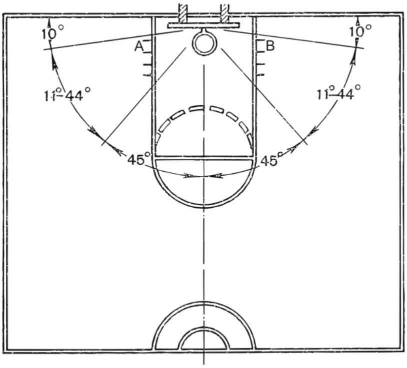


Figure 32: Distribution of shooter positions the player is (11–44°) or is not supposed to shoot from (other angles) when shooting at the board (Cetlin 1955; p. 80).

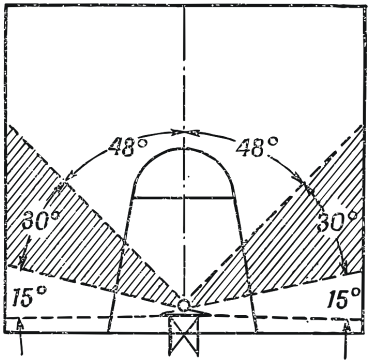


Figure 33: The distribution of shooter positions the player is (shaded 30°) or is not supposed to shoot from (other angles) when shooting at the board (Semaško 1976; p. 38).

The dependence of shooting success on the horizontal distance of the shooter from the hoop is affected by the shooter's position in the court in relation to the basketball board (Figure 40).

In all shooting modes and horizontal distances the shooter can assume in relation to the hoop, the closer the shooter is to the area in front of the hoop, the higher the success rate of shooting.

Shooter and ball release point

The release point of the ball is the place of last contact between the shooter's hand and the ball.

The height of the release point is the perpendicular distance of the point of shooter's last contact with the ball from the floor.

The release point is important in evaluating the ball release, considering the respective values of initial ball velocity and throwing angle.

It specifies the vertical, horizontal (Figure 35) and direct (Figure 36) distance from the center of the hoop.

The release point of the ball from the hands happens to be under the hoop in most shooting attempts (Figure 34). Occasionally, there are shots with extremely high jumps.

The height of the release point in a set shot is determined by the height of the rotation axis of the shoulder joint, length and straightness of the shooting hand in the elbow joint, angle of the longitudinal axis of the shooting hand, or incline of the longitudinal axis of the shooter's body to the floor.

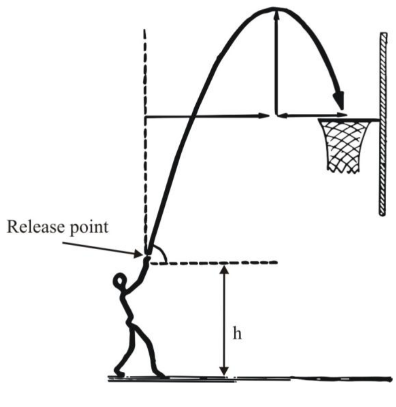


Figure 34: Position of the release point under the hoop (Tehnica si tactica individuala a jocului de basket 1952; p. 96). The angular value is illustrative; h – height of the release point from the floor.

When jump shooting, the above factors influencing the height of the release point are also affected by the shooter's jump height.

The height of the release point relative to the basketball board was not paid much attention to in the available (mostly professional) sources.

Southard – Miracle (1993; p. 288) determined the height of the release point from the floor in women (n = 8) when shooting free throws (4 series of 15 throws) ranging from 2.19 to 2.30 m from the floor.

The range of different experimentally observed height levels of the release point of the ball when shooting from different distances is shown in Table 9.

Inexperienced shooters released the ball from the hand higher above the floor than the experienced ones. The reason could be the longer trajectory on which the hand has an effect on the ball, potentially resulting in higher points of release of the ball from the floor. Another possible explanation is that in the two closer distances, the less skilled shooters were shooting not only from higher points of release, but also with a greater throwing angle (see Table 14).

By increasing the shooter's distance from the hoop, the vertical throwing angle decreased along with the release point height.

Table 9: Height of the release point when shooting from different distances from the hoop (Toyoshima – Hoshikawa – Ikegami 1979; p. 527).

	Shooter's distance from the hoop (m)		
	2.425	**4.225**	**6.25**
Skilled shooter	2.00 ± 0.02	2.04 ± 0.03	2.00 ± 0.04
Inexperienced shooter	2.14 ± 0.03	2.07 ± 0.05	2.06 ± 0.05

Shooter and distance from the hoop

For accurate analysis, the shooter's distance from the basket must be construed as the distance of the release point from the center of the hoop in the following scenarios:

- Horizontal distance of the release point from the hoop center *x*:
  – Distance between the orthogonal release point of the ball and the hoop center on the floor (Figure 35)
- Vertical distance of the release point from the hoop center *y*:

– Height difference between the upper edge of the metal hoop and the release point height from the floor

- Direct distance of the release point from the hoop center:
  – This is the shortest line between the release point and the hoop center (Figure 36)

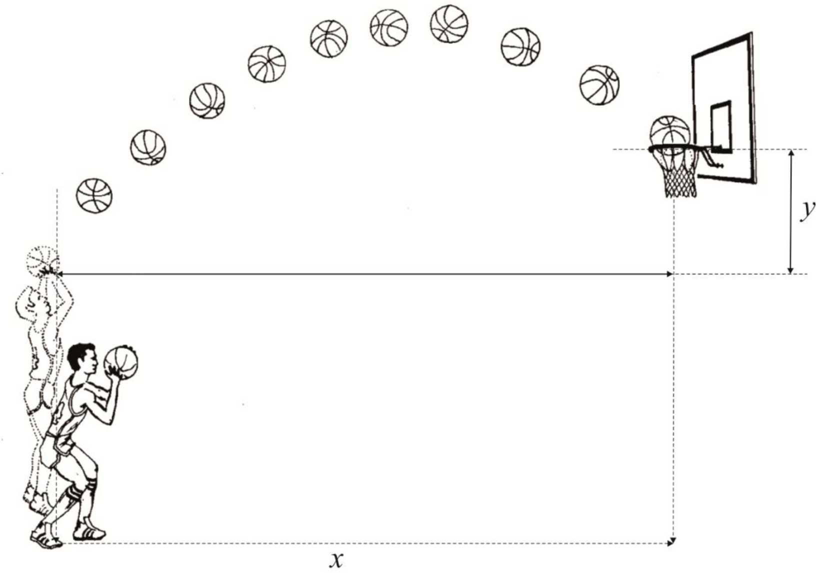


Figure 35: Horizontal *x* and vertical *y* distance of the point of release from the hoop center.

When shooting set shots in training and competitive matches, the shooter's distance from the basket is understood as the position of the nearest point of his/her nearer foot from the orthogonal projection of the hoop center on the floor.

It appears that the important factor in the analysis of shooter's exact distance from the basket is not the distance of shooter's feet from the orthogonal projection of the hoop center on the floor, but the direct distance (Figure 36).

It is assumed that the shooter's direct distance from the hoop is smaller than the traditionally perceived distance.

This is due to the fact that when shooting, the shooter normally pushes the ball into his/her hand even to the point of a slight arm stretch, whereby the projection of the release point gets closer to the hoop in comparison with the closest point on the front foot.

In free throws, the values of the horizontal distance of the release point from the center of the hoop ranged from 3.471 to 3.731 ± 0.003 m (3 mm) (Saleh Satti, 2004; p. 5).

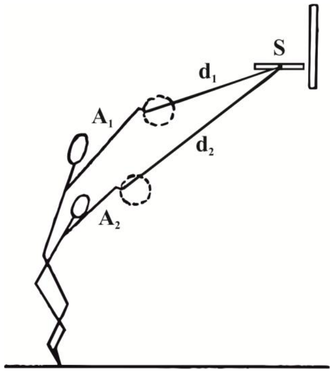


Figure 36: Schematic representation of the direct distances (d_1, d_2) between the release points (A_1, A_2) and the hoop center (S) in an identical horizontal distance of two shooters with varying tallness: A_1 – tall player, and A_2 – small player, $d_1 < d_2$ (Mačura 1988).

Shooter´s distance from the hoop and shooting success

Shooter's distance from the hoop is one of the most important factors influencing the success of shooting.

When shooting, the relation between accuracy and target distance is very simple: the greater the distance from the target, the less likely the target is engaged (Ivojlov – Ginzburg – Breger, 1976). This shooter–target dependence (Figure 37) was discovered even earlier by Bunn (1963).

Petrov (1968) documents the strong relation between the shooter's distance from the hoop and shooting success (Table 10). He is one of the first researchers who noted not only the horizontal distance of the shooter from the hoop, but also the shooter's height. He is mentioning the height of the shooter's eyes (1.80 m) as a key factor in adjusting the shooter's viewing angle at the hoop in relation with the horizontal distance from the hoop (Figure 38).

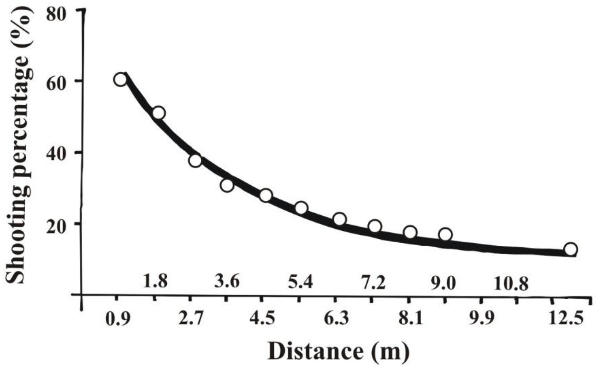


Figure 37: Shooting success in basketball match depending on the distance from the hoop (Bunn 1963; p. 217).

The dependence of shooting success on the horizontal distance of the shooter from the hoop is affected by the shooter's position in the court in relation to the basketball board (Figure 40).

On the one hand, Bunn (1963) found a relatively smooth development of the rate of success in competitive shooting matches (Figure 37), on the other hand Liu – Burton (1999; p. 837) identified a significant decrease of shooting success in noncompetitive women shooters from beyond the threshold distance of 6.10 m (Figure 39).

We expect similar trending among young basketball players, while the critical value will be closer to the hoop depending on age, gender and mastery of the shooting technique.

By increasing the shooter's distance from the hoop, the success rate dropped in all age groups (Table 11 shows the successful shots from 20 attempts). The shots were made with a basketball No. 7 for adult men.

The average trending of deviations showed a decrease from older pupils to older cadets. This demonstrates that shooting accuracy increases with age.

Table 10: Basketball shooting accuracy depending on the distance from the hoop and hoop viewing angle (Petrov 1968; p. 71).

Shooter distance from the hoop (m)	**Shooting accuracy (%)**	**Viewing angle (°)**
0.9	62	22.02
1.8	52	15.20
2.7	40	11.32
3.6	32	9.00
4.5	28	7.20
5.4	24	6.12
6.3	21	5.34
7.2	19.5	4.42
8.1	18	4.12
9.0	17	3.40
12.0	13	2.50

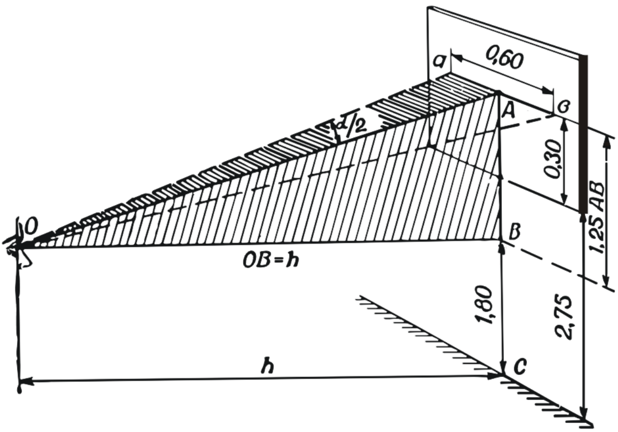


Figure 38: Graphical representation of shooter's view of the hoop and board (Petrov 1968; p. 71).

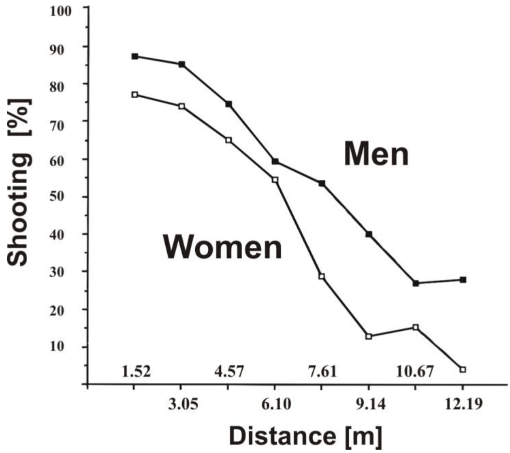


Figure 39: Success of non–competitive shooting in non–basketball players depending on the shooter's distance from the hoop (Liu – Burton 1999) (empty tags – women, black tags – men).

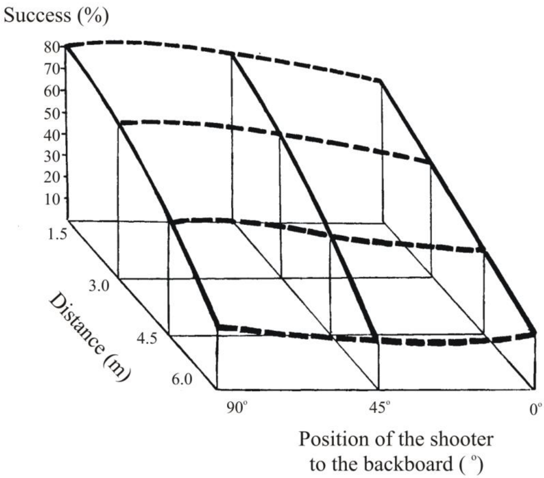


Figure 40: Dependence of shooting success from distance and position of the shooter in the court (Smirnov – Belov – Poljakova 1973; p. 14).

The decrease of deviations in shooting success in younger pupils and older cadets when moving away from the hoop can be explained in two ways.

Table 11: Success of set shots in young basketball players (Mačura 1991).

	Younger pupils		**Older pupils**		**Cadets**		**Juniors**	
n	**18**		**25**		**16**		**11**	
	x	**s_d**	**x**	**s_d**	**x**	**s_d**	**x**	**s_d**
Age	11.96	0.55	14.14	0.63	16.16	0.58	18.18	0.60
2 m	10.17	2.94	14.72	2.23	15.94	1.29	16.09	1.78
3 m	7.83	2.47	13.24	3.15	14.88	2.47	15.45	1.67
4 m	4.06	2.17	11.8	3.46	13.81	3.46	14.00	1.27
		x = 2.52		x = 2.94		x = 2.40		x = 1.57

In younger pupils aged 11.96±0.55 year, the gradual change of distance from the hoop from two to four meters caused a high degree of shot randomness.

Juniors (age=18.18±0.6 year) shot high numbers of shots from medium and long distances in training, which may be reflected in a greater stability of shooting from the greater experimental shooting distance. Another possible explanation is the fact that the experimental distance of 4 m is a distance close to distance when shooting free throws; older cadets had a huge experience with free throws in their basketball career. This might also have been reflected in a greater shooting stability from the distance of 4 m compared to smaller distances of 2 and 3 m.

By moving away from the basket, the shooting stability generally decreased. The values of average standard deviation of shooting success were 2 m=2.06, 3 m=2.44, 4 m=2.59.

Permissible horizontal distance error in basketball shooting

Based on the variability of permissible throwing angles and ball velocity in the respective points of release, there also a certain permissible range of horizontal distance exists in which the ball falls into the hoop without touching it when flying through the hoop center plane perpendicular to the floor.

The permissible horizontal distance error in basketball shooting is determined by the following formula:

$$\Delta L = \frac{1}{2}\left(D_0 - \frac{D_L}{\sin\alpha}\right) \qquad (1)$$

in which	ΔL =	Extreme values of permissible error in horizontal distance L from the hoop center S in which the ball still enters the hoop without touching its front or back part [m]
	D_0 =	Hoop inside diameter [m]
	D_L =	Ball outside diameter [m]
	α =	Entry angle of the ball into the hoop [^{o}], whereby the angle must be at least 32^o for the male ball (Brancazio 1981; p. 360)

In respect of (1), which determines the allowable margin of horizontal distance error in successful basketball shooting, there is an obvious dependence on the ball and hoop size.

In the future it will be necessary to define the permissible error of horizontal distance as a function of the horizontal throwing angle in basketball shooting, which we assume depends on the ball and hoop size, also.

Shooter and throwing angle

From the shooter's perspective, the ball can be given the following directions simultaneously:

- Bottom up – vertical throwing angle (side view)
- Left right – horizontal throwing angle (top view)

The combination of these two throwing directions results in creating a three–dimensional throwing angle.

When shooting directly at the hoop, the ball can be shot so that:

- The plane perpendicular to the floor the ball flies in also crosses the center of the ball and the hoop center. We say the ball flies up with a zero horizontal throwing angle and misses the right and left side of the hoop from the inside.

- The plane perpendicular to the floor the ball flies on only crosses the center of the ball and not the hoop center. Three possibilities arise:

    1) The horizontal throwing angle may have a value greater than zero, however, it does ensure the ball falls through the hoop, be it in contact with the hoop or not
    2) The horizontal throwing angle has a value greater than zero and the ball, after bouncing off the hoop, is deflected away from the hoop, or into/toward the hoop center, however, it won't enter it
    3) The horizontal throwing angle has a value which causes the ball to miss the hoop body from the outside

When shooting directly at the hoop, the throwing angle determines the angle of entry into the hoop.

We base our assumptions on the insignificance of air resistance in usual ball flight scenarios and speeds and minimum effect of ball rotation on the ball trajectory.

Vertical throwing angle

An example of mathematically calculated effects of changing the vertical throwing angle on the distance of the ball's entry relative to the hoop center at a 1^{o} deviation from the given angle at the distance of 3.658 m is shown in Table 12. The release point height was 1.524 m.

Based on the release point height we assume it was a well–established practice to shoot free throws with two hands from below. Unfortunately, the work did not specify the shooting method.

If the release point of the ball happens to be on the hoop plane, the size of the entry angle into the hoop would have to be very close if not identical to the vertical throwing angle at which the ball is shot at the hoop.

The relevant vertical throwing angle values increase with the player approaching the basket and by decreasing the release point height from the floor.

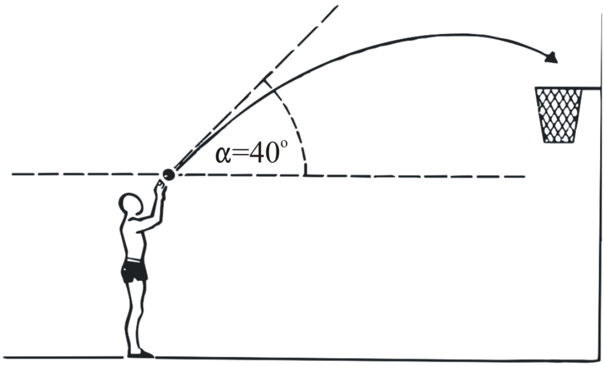


Figure 41: Vertical throwing angle in basketball shooting (Herrmann 1976; p. 164). The value of 40° is illustrative.

Table 12: The effect of 1° deviation from the given vertical throwing angle on the ball's entry into the hoop (Mortimer (1951).

Vertical throwing angle (°)	**Initial throwing velocity (ms^{-1})**	**Distance of ball center from hoop center (m)**	**Distance by which the ball misses the hoop (m)**
57+1	7.336	0.0134	0.0099312
58+1	7.345	0.0235	0.0099058
59+1	7.361	0.0341	0.0087120
60+1	7.384	0.0441	0.0071626
61+1	7.416	0.0533	0.0053846
62+1	7.455	0.0628	0.0027177

With identical values of the throwing velocity and position of the release point relative to the hoop, the change of the relevant vertical throwing angle causes:

- At a greater throwing angle, the ball to strike in front of the hoop center
- At a smaller throwing angle, the ball to strike beyond the hoop center

What are the measured values of the vertical throwing angle? The values of successful and unsuccessful shooting performed from three different distances by a beginner and expert shooter (Zaciorksij – Golomazov 1972) are presented in Table 13.

Regardless of the shooting success and performance, it is clear that the throwing angle values tend to decrease with the shooter moving away from the hoop.

Table 13: Values of vertical throwing angle (^{o}) when shooting from different distances from the hoop (Zaciorskij – Golomazov, 1972; p. 19).

	Distance of shooter from the hoop					
	3 m		5 m		7 m	
	E	B	E	B	E	B
Successful shots	59.50^o	56.80^o	52.50^o	50.60^o	47.40^o	49.00^o
Unsuccessful shots	59.80^o	56.50^o	51.50^o	50.40^o	46.70^o	48.80^o

Legend: E – experienced player, B – beginner

It is probably the lack of strength and coordination that causes the unskilled shooters to shoot the ball from a greater distance (6.25m) with a smaller throwing angle (49.66 ± 2.44) compared to the skilled shooters 53.67 ± 0.51 (Table 14).

The stability of shooting motion from a greater distance was more limited in inexperienced shooters (s_d = 2.44) compared to the skilled ones (s_d = 0.51).

With the aim to create a habit of shooting the ball with a greater vertical throwing angle, it is important to realize that skilled shooters shoot with a greater vertical throwing angle without visual inspection just like with open eyes (ibid.).

Table 14: Values of vertical throwing angle (^{o}) when shooting from different distances from the hoop (Toyoshima – Hoshikawa – Ikegami 1979; p. 527).

	Distance of shooter from the hoop (m)		
	2.425	**4.225**	**6.25**
Skilled shooter	57.00^o ±2.73^o	53.29^o ±1.04^o	53.67^o ±0.51^o
Inexperienced shooter	57.57^o ±1.09^o	53.61^o ±1.09^o	49.66^o ±2.44^o

The throwing angle in young basketball players aged 12.86 ± 0.13 year varied in the free throws depending on the hoop height Satern–Messier–Keller–McNulty (1989; p. 128).

When shooting at the hoop 2.44 m high, the throwing angle was 44.90^o and in the standard height of 3.05 m it reached 50.97^o. The higher hoop forced the younger shooters to stretch their arms upwards compared to shooting at the lower hoop.

Table 15: Values of vertical throwing angle when shooting free throws (Saleh–Satti 2004; p. 4). Attempt 4 was unsuccessful. Other attempts were successful.

Attempt	**Throwing angle (^{o})**
1	53.5 ± 0.2
2	51.3 ± 0.2
3	54.7 ± 0.4
4	52.0 ± 0.2
5	54.8 ± 0.2

The throwing angle was in the range of 57.8±4.2^o to 58.7±3.7^o (Southard – Miracle 1993; p. 288).

When shooting free throws, the measurements showed the value of the vertical throwing angle (Table 15). We see that the values of successful shots varied from 51.3 ± 0.2 to 54.7 ± 0.4 ^{o}. The height of the release point from the floor ranged from 2.2 to 2.4 meters (Saleh – Satti 2004; p. 2).

Minimum vertical throwing angle in basketball shooting

The minimum vertical throwing angle is determined by the minimum angle of entry of the ball into the hoop.

When shooting directly at the hoop, the minimum throwing angle is determined by the smallest possible angle of entry of the ball into the hoop without touching it. If it is lowered in any way, the ball contacts the hoop upon entry.

Taking into account the definition of minimum throwing angle for successful basketball shot (Brancazio 1981)

$$\alpha_{0\ min} = tg\ D_1 / D_0 + 2h/L \qquad (2)$$

in which
- D_1 = Ball outside diameter [m]
- D_0 = Hoop inside diameter [m]
- h = Vertical distance of the release point from the hoop plane [m]
- L = Horizontal distance of the release point from the hoop center [m]

we see that the minimum throwing angle α_{0min} depends on the hoop–ball size relation.

Vertical throwing angle in bank shots

The shooter's decision to shoot directly at the hoop or use a rebound from the board determines his/her choice of the throwing angle.

Cooper – Hamley (1974) found lower throwing angle values when shooting rebound free throws ($51^o14'$), which differed from the calculated value of $55^o29'$ presented by Mortimer (1951) for shooting directly into the basket. The underlying reason may also be a potentially different shooting technique.

Horizontal throwing angle in basketball shooting

In addition to the vertical throwing angle, the horizontal throwing angle is also considered (Figure 42).

When shooting directly into the hoop, the horizontal throwing angle means the deviation from the theoretical line between the ball and hoop center.

When shooting from the distance of 6 m, the horizontal throwing angle deviation of 4^o causes the ball does not touch the hoop. In a 3^o deviation, the ball touches the hoop. In a 2^o deviation, the ball falls through the hoop when the shot is neither too strong nor too weak (Figure 43). We assume the author used men´s no. 7 basketball. No other ball sizes existed at that time.

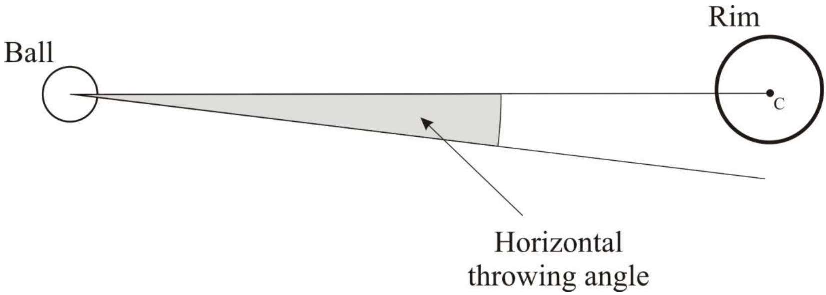


Figure 42: Horizontal throwing angle; C – hoop center, top view.

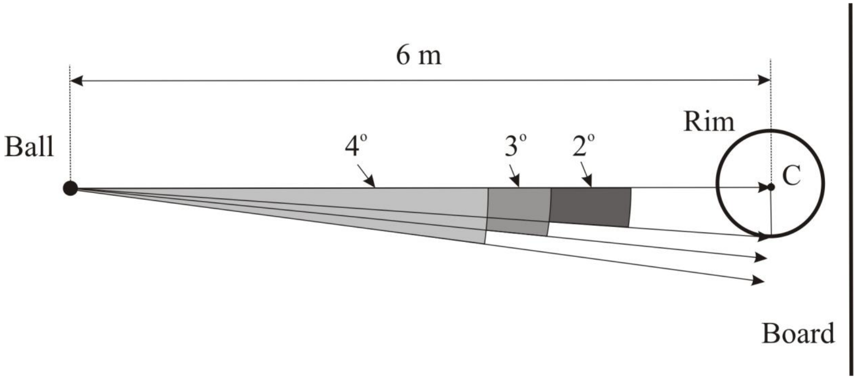


Figure 43: Example of error in horizontal throwing angle in basketball shooting from the distance of 6 m (Bunn 1963; p. 216), top view.

Permissible horizontal throwing angle error in basketball shooting

When determining the admissible margin of error in the horizontal direction of the flight path at the hoop, the respective angle will be measured on the horizontal plane of the court floor. When looking at the flight path from top (Figure 44), the maximum divergence from the hoop center is determined by the conditional angle β, (Hajossy – Mačura, 2011).

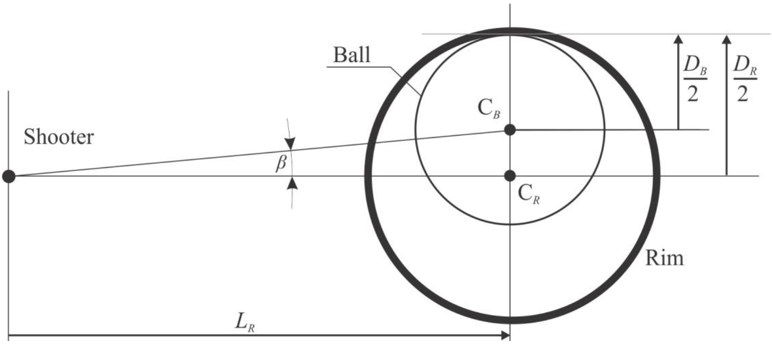


Figure 44: Maximum angular error β on the horizontal plane in a successful shot.

$$tg\beta = \frac{D_R - D_B}{2L_R}, \quad (3)$$

where D_R and D_B are the hoop and ball diameters, L_R is the horizontal distance of the shooter (or the point of release) from the hoop center C_R (L_R is the length of the reflection of the actual distance onto the floor).

According to (3) Hajossy – Mačura (2011) in a successful shot at the distance of 6 m, the maximum deviation of the angle of release on the horizontal plane is determined by the formula

$$tg\beta = \frac{D_R - D_B}{2L_R} = \frac{0.45m - 0.24m}{2.6m} = 0.0175,$$

and the maximum angular error must be smaller than

$$\pm\beta = \pm arctg\,(0.0175) = \pm 1.0^0.$$

Shooter and throwing velocity

For each release point in the court there exists a set of throwing velocities causing the ball to enter the hoop from the top without touching it.

By moving the shooter farther away from the hoop, the throwing velocity increases.

The minimum deviation (greater than 1%) from the mean value of the desired throwing velocity results in the ball bouncing off the hoop.

The range of permissible values of throwing velocity is much smaller than the permissible values of throwing angle.

Saleh Satti (2004) measured the throwing velocity in free throws. The value varied in four successful shots from 6.50±0.70 ms^1 to 6.43±0.70 ms^{-1} in the failed shot.

When shooting bank shots, the throwing velocity value reached 9.68 ms^{-1} (Cooper–Hamley 1974).

Satern–Messier–Keller–McNulty (1989; p. 128) found the throwing velocity value of 7.03 ms^{-1} in young basketball players aged 12.86 ± 0.13 year in free throws shots at the hoop in the standard height of 3.05 m and 7.01 ms^{-1} in the height of 2.44 m. The difference between the throwing velocities was statistically insignificant, which is is in accordance with the theory.

The change in the ball size has an insignificant effect on throwing velocity.

The throwing velocity in free shots in women (n = 8, age 20.5 years) using the women's basketball ranged from 4.34 ± 0.11 to 5.46 ± 1.34 ms^{-1} (Southard – Miracle 1993; p. 288).

The throwing velocity was measured from various distances (Table 16) in successful and unsuccessful shots performed by beginners and expert players.

Much like with the throwing angle, by moving the shooter farther away from the hoop, the throwing velocity values show a uniform trending: they are on the rise both in successful and unsuccessful shots, beginners or experienced shooters (Table 16 and Table 17).

In addition to the above trending, the throwing velocity in unsuccessful shots was higher or identical to the velocity in successful shots. The only exception was a beginner shooting from the distance of 7 m (Table 16), which could be explained by improper technique of the shooting motion or insufficient strength predispositions when shooting from this relatively large distance.

Table 16: Throwing velocity (ms^{-1}) when shooting from different distances from the hoop (Zaciorskij – Golomazov 1972; p. 19).

	Distance of shooter from the hoop					
	3 m		**5 m**		**7 m**	
	E	B	E	B	E	B
Successful shot	5.78	6.55	8.59	8.68	9.90	12.27
Unsuccessful shot	6.09	6.62	8.82	8.82	9.87	12.27

Legend: E – experienced player, B – beginner

Table 17: Throwing velocity (ms^{-1}) when shooting from different distances from the hoop (Toyoshima – Hoshikawa – Ikegami 1979; p. 527).

	Distance of shooter from the hoop (m)		
	2.425	**4.225**	**6.025**
Skilled shooter	6.02 ± 0.18	7.29 ± 0.11	8.37 ± 0.15
Inexperienced shooter	5.83 ± 0.15	7.32 ± 0.23	8.25 ± 0.21

Relation between throwing velocity and throwing angle

The relation between throwing velocity and throwing angle is perhaps most important when analyzed in three dimensional space.

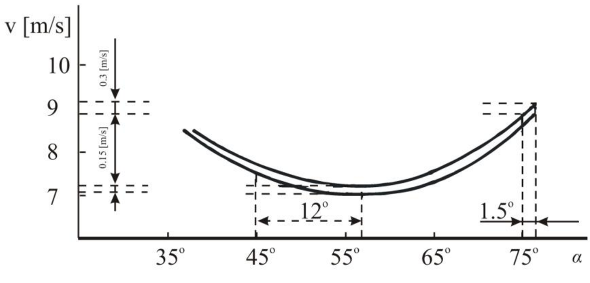


Figure 45: The curve reflecting the relation of the throwing angle and initial throwing velocity in basketball shooting with the ball trajectory into the hoop center (Golomazov 1971; p. 28).

After analyzing speed and throwing angle, it must be assumed that their mutual relation tolerates certain digressions (Figure 45).

In a throw from a certain distance and release point height, the adequate ball velocity is limited by the acceptable margin of throwing angle and vice versa. In other words, for every throwing angle there is a set of throwing velocities resulting in the ball falling into the hoop (Figure 46), and conversely, for every throwing velocity, there is a set of throwing angles resulting in the ball falling into the hoop (Figure 47).

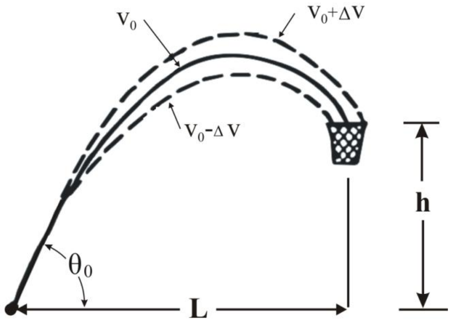


Figure 46: Extreme values of permissible error in throwing velocity and throwing angle. There exists a range of throwing velocities $v_0 \pm \Delta v$, which result in a successful shot (Brancazio 1981; p. 360).

If the shooter throws the ball at the given throwing velocity from the given distance and release point height but with an excessively large throwing angle, the ball trajectory is too arched and the ball hits the front section of the hoop or falls down in front of the hoop ($\theta_0+\Delta\theta_+$) (Figure 48). Conversely, if the shooter throws the ball at the given throwing velocity from the given distance and release point height but with an excessively small throwing angle ($\theta_0-\Delta\theta_-$), the ball trajectory is too flat and the ball hits the back section of the hoop or flies behind the hoop.

The second case applies to intentional bank shots.

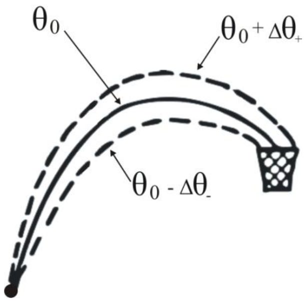


Figure 47: Extreme permissible error of the throwing angle: for any given throwing velocity v_0 every angle in the range from $\theta_0 - \Delta\theta_-$ to $\theta_0 + \Delta\theta_+$ results in a successful shot (Brancazio 1981; p. 361).

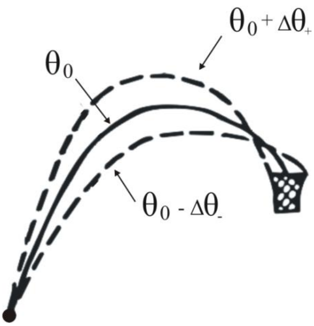


Figure 48: Sample ball trajectory at the respective velocity depending on an excessively large or excessively small throwing angle (Brancazio 1981; p. 361).

It is commonly assumed that for a successful shot into the hoop center, which is determined by the horizontal distance of the center of the hoop from the shooter L and the hoop height H, the shot speed (4) is necessary at the point of release height h, angle of release α_0 and gravitational acceleration g

$$v_0 = \sqrt{\frac{g\left(1 + tg^2\alpha_0\right)L^2}{2\left(h - H + L\, tg\alpha_0\right)}}, \qquad (4)$$

This corelation between the speed and angle of release of the ball (v_0, α_0) and the parameters of the point of release (h) and the target (L, H) applies universally to all trajectories of all balls shot, kicked, fired or served in various sports. Of course, the accuracy of this relation is limited by neglecting the effects of air and ball rotation.

Optimum throwing velocity in basketball shooting

The strength predispositions for a successful basketball shot foreground the idea of optimum throwing velocity (Brancazio 1981).

The 'optimality' criterion focuses on identifying the lowest throwing velocity logically requiring the lowest total muscular strain in the shooting motion while ensuring that the ball falls through the hoop center in the given h, L and α_o.

The v_{0opt} equation is as follows:

$$v_{0\ opt} = \sqrt{gL\ tg\alpha_{0\ opt}} \qquad (5)$$

where

$$\alpha_{0\ opt} = 45^\circ + \frac{1}{2} arctg \frac{h}{L} \qquad (6)$$

in which
- $v_{0\ opt}$ = Optimum throwing velocity [$m.s^{-1}$]
- g = Gravitational acceleration [$m.s^{-2}$]
- L = Horizontal distance of the release point from the hoop center [m]
- $\alpha_{0\ opt}$ = Optimum vertical throwing angle [^{o}]
- h = Vertical distance of the release point from the hoop plane [m]

This approach could serve as a starting point to optimize the shooting conditions especially for young players in pre–adolescent and adolescent age who show limited growth potential and strength.

At the moment of shooting, the player's stature and strength in relation to his/her body weight and jump height are constant.

When shooting the ball with optimum throwing velocity v_{0opt} , the negative effects of lower stature and small strength of young basketball players are minimized.

Results similar to those achieved through the Brancazio relation (6) for an optimum (i.e. minimum) angle of release $\alpha_{0_{opt}}$ in successful shooting at the basket is also expressed in the relation

$$tg\alpha_{0_{opt}} = \frac{H-h}{L_r} + \sqrt{\left(\frac{H-h}{L_r}\right)^2 + 1} > 1, \qquad (7)$$

In a particular estimation of the optimum angles we can assume the point of release height h = 2 m and hoop height H = 3 m. (If the point of release height is inaccurate, one does not need to use the precise hoop height of 3.05 m).
According to **(7)** in a successful three-point shot (indicative value of L_r = 6 m) for an optimum angle of release, the following formula applies:

$$tg\alpha_{0_{opt}} = \frac{H-h}{L_r} + \sqrt{\left(\frac{H-h}{L_r}\right)^2 + 1} = \frac{3-2}{6} + \sqrt{\left(\frac{3-2}{6}\right)^2 + 1} = 1.1804604,$$

a $\alpha_{0_{opt}} = 49.7^0$.

The relation **(7)** for an optimum release angle $\alpha_{0_{opt}}$ has a very simple geometrical interpretation, as illustrated in Figure 49.

The figure shows a simple rule for optimum shooting:

> in an optimum shot, the ball must be shot directly at the point above the hoop whose vertical distance to the hoop center equals the absolute distance (L_{abs}) from the hoop center to the point of release. (The point of release is the location of the last contact of the ball and the player's hand).

Results identical to Brancazio's relation (5) for optimum (i.e. minimum) release speed $v_{k\min}$ in a successful shot are also rendered in the relation

$$v_{k\min} = \sqrt{g\left[H - h + \sqrt{(H-h)^2 + L_k^{\ 2}}\right]}\,, \tag{8}$$

as defined in Hajossy – Mačura (2011), where

g = Gravitational acceleration
H = Hoop height above ground
h = Point of release height above ground
L_k = Horizontal distance of the point of release from the player's hand from the hoop center

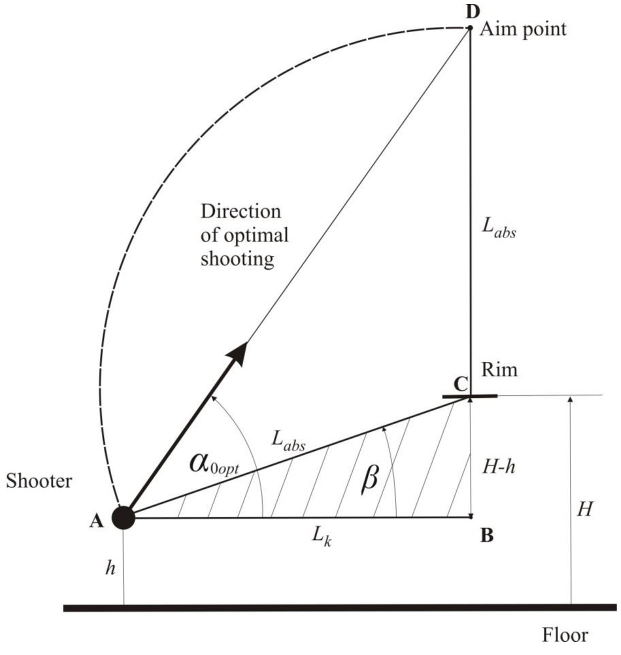


Figure 49: The geometric interpretation of the relation (7) for the optimum angle α_{0opt} of release from the point of release at the height h into the hoop center C at the height H and at the absolute distance L_{abs} (horizontal distance of the hoop center is L_k). In an optimum shot, the ball is flying at the target D in the vertical distance L_{abs} from the hoop center.

It follows from the relation (8) that in a successful three-point basketball shot (the indicative value of L_k = 6 m) the optimum speed is

$$v_{k\,\min} = \sqrt{9.81\left[3-2+\sqrt{(3-2)^2+6^2}\,\right]} = 8.3ms^{-1}$$

When shooting from the distance of 7 m, the optimum speed value should be 8.9 ms^{-1}.

In a successful free throw (the indicative value L_k = 4 m) the optimum release speed is 7.1 ms^{-1}.

Ball acceleration

From the moment it is released from the shooter's hand, the ball decelerates on its ascending trajectory and accelerates on its descending trajectory; both motions are affected by gravitational forces. We assume that the ball flies the slowest in its apex.

The acceleration in the release point is approximately 9.1 ms^{-1} (Saleh Satti 2004; p. 4).

Shooter and ball trajectory

Not only is the hoop above the shooter, it is also horizontal. If the shooter intends to hit the hoop and make the ball fall through the hoop from the top, the ball must be shot on a parabolic trajectory (Figure 50).

Exceptions are bank shots where the parabolic flight path is disrupted by the rebound of the ball from the board and dunking.

Generally there are three possible ball trajectories when shooting the ball directly at the hoop:

- Low
- Medium
- High (Figure 51)

Each trajectory has its advantages and disadvantages. It is just enough to consider the theoretical strength requirements for each ball trajectory and we immediately face a paradox: if the shooter prefers the high trajectory, which is most suitable for its largest and best possible angle of entry into the hoop, he/she needs to exert maximum physical effort, which is not always compatible with his/her physical capabilities.

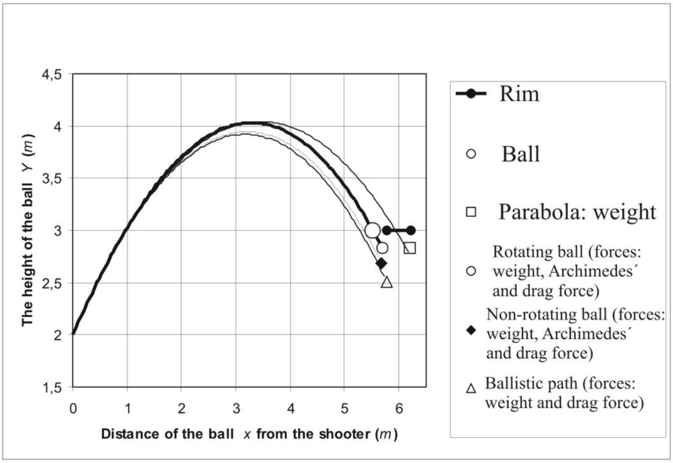


Figure 50: The ball trajectory at an optimum shooting at the basket at the height 3 m, from the presumed horizontal distance 6 meters and the height of the point of ball throwing 2 m, depending on the impact of various forces and their combinations. The trajectories are the results of numerical calculations with the time step 0.02 seconds (Hajossy – Mačura 2011).

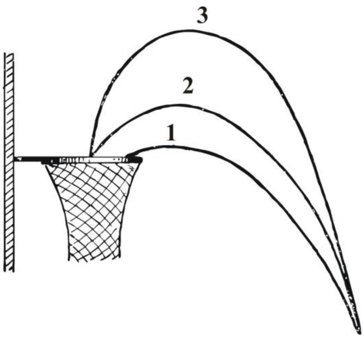


Figure 51: Ball trajectory. 1 – low 2 – medium, 3 – high (Tehnica si tactica individuala a jocului de basket 1952; p. 95). The curves show the path of the ball's center of gravity).

The ball trajectory after it is released from the shooter's hand is governed by the laws of physics.

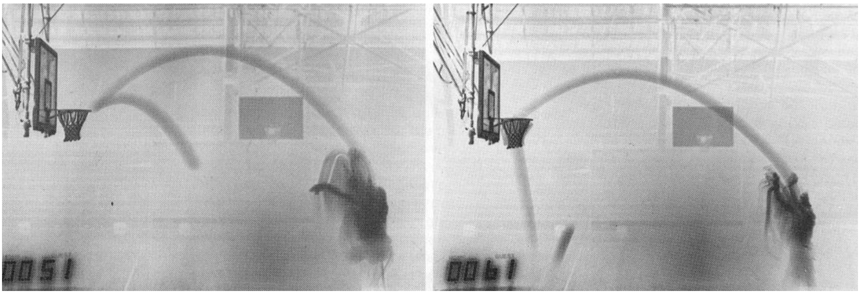
Toyoshima – Hoshikawa – Ikegami (1979) managed to express every point on the trajectory with the following equation:

$$Y = -\frac{gX^2}{2V^2\cos^2\theta} + \frac{\sin\theta X}{\cos\theta} + H$$ [20]

in which Y = Vertical coordinate of the ball (current ball height above ground)
g = Gravitational acceleration
X = Current horizontal coordinate of the ball
V = Initial ball velocity
θ = Throwing angle
H = Height of release point from the floor

We see that the parameters affecting the ball trajectory in basketball shooting depend on initial speed, throwing angle and release point height.

The ball trajectory in basketball shooting directly at the hoop, without using the ball rebound from the board and dunking, is parabolic (Figure 52).



a **b**

Figure 52: Parabolic ball trajectory (Hofer 1979); a – missed shot, b - successful shot.

[20] This relation is identical with the detailed relation 2.10 on page 57 (**Hajossy-Mačura, 2011).** We note that when calculating the trajectory according to**Toyoshima – Hoshikawa – Ikegami (1979)**, only the flight affected by the gravitational force was taken into account.

In a free throw, the flight time from the moment the fingers release the ball until it enters the hoop is 0.94 s (Saleh – Satti 2004; p. 5).

According to Hajossy-Mačura (2011) – Example 2.13, this time is determined by the formula

$$t = \frac{L_k}{V\cos\theta}. \tag{9}$$

If the horizontal distance between the shooter and hoop center is $L_k = 4$ m at the optimum release speed V=7.1 ms^{-1} and optimum release angle θ=52^{o} degrees, the flight furation calculated based on (9) equals 0.92s, which is close to the value in (Saleh – Satti 2004).

The highest point (apex) of the ball, according to Hofer (1978) is located two–thirds the distance of the shooter (free throw) from the hoop and its height is 3.72 m.

The location of the apex point in a successful free throw according to Hajossy-Mačura (2011) – Example 2.12 at the distance

$$X_n = L_k \sin^2\theta_{0opt} = 4m.\sin^2(52^0) = 2.48\,m$$

from the shooter and at the height

$$Y_n = \frac{1}{2} X_n \, tg\,\theta_{0opt} + H = \frac{1}{2}.(2.48\,m)\,tg(52^0) + 2.1\,m = 3.69\,m$$

from the floor.

The shape of the trajectory depends on the initial throwing velocity and throwing angle in three–dimensional space (Figure 53).

In the literature we see two viewpoints on the ball trajectory in basketball shooting.

Following the analysis of ball–hoop relations at the moment the ball flies into the hoop, one group of authors is more inclined to believe in the advantages of the high arc (Mortimer 1951; 1961 Bunn 1963; Vojtov 1967; Hay 1973).

Other authors, basing their arguments on the shooter's physical predispositions for a successful shot, are more cautious in their arguments.

Let us mention Golomazov (1971) who recommends dividing the players into those who are better able to give the ball the right direction and, in effect, should prefer to shoot with the high trajectory, and those who have a greater sense for appropriate throwing velocity so their shots can also have the lower trajectory.

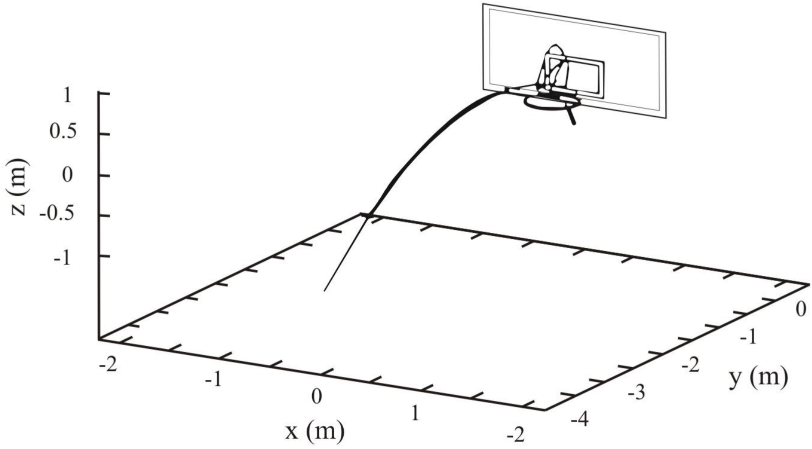


Figure 53: Three–dimensional spatial view of the ball trajectory in basketball shooting (Okubo – Hubbard 2006).

Regarding the above issue, Hay (1973) points out correctly that in a shot with an extremely high trajectory, the shooter ought to have sufficient strength.

This argument is relevant especially in relation to young shooters. The very fact that younger basketball players are smaller forces them to shoot from a lower release point height with a relatively high trajectory and they often fail to meet the theoretical requirements for a proper implementation of the shooting technique.

The basketball spin does not significantly affect the basketball flight path (Saleh Satti 2004; p. 2). In actuality, the backspin of the ball in a three-point shot extends the flight path approximately by 0.1m.

Rotation of a released ball

A ball can be shot with or without spin. The zero spin scenario, however, happens very seldom.

According to the interaction time with other surrounding bodies, there exist two kinds of basketball spin when shooting is taken into consideration:

- Before a rebound from the hoop and/or board
- After a rebound from the hoop and/or board

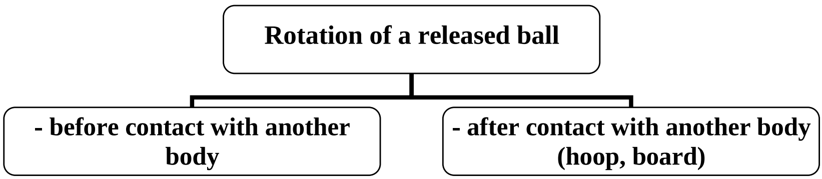


Figure 54: Basketball spin based on the interaction time with other bodies[21].

In basketball shooting, we distinguish:

- Back spin, i.e. the upper part of the ball spins toward the shooter
- Forward spin, i.e. the upper part of the ball spins away from the shooter
- Zero spin (Figure 55)

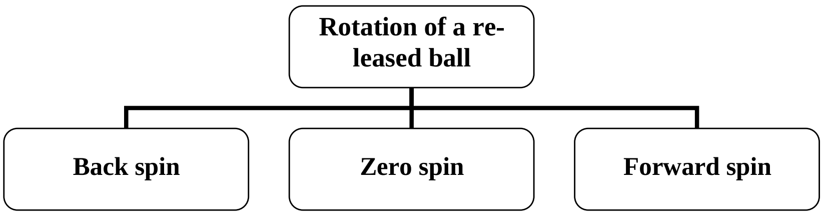


Figure 55: The ball spin direction relative to the shooter.

---

[21] The rotation before the first contact with the hoop or backboard is usually caused by the hands of the shooting player.

The back spin or forward spin of the basketball when shot directly at the basket is mostly discussed when the rotation axis is horizontal or near horizontal.

The spin of the flying ball is caused by a special movement of the player's hand when the ball is shot. This movement is called follow through.

When the ball flies, its rotation is caused only by inertia.

If the ball fails to spin after being shot, it is considered an improper shooting technique, mostly.

The rotation axis relates to basketball shooting both before and after the ball touches the board or hoop. The angle of the spin axis before the ball bounces off the backboard determines its path after the rebound.

Spin speed

Experience shows that the ball can be shot with different spin speeds around its rotation axis. We can detect the following speeds in the ball spin around its rotation axis:

- High
- Medium (Fontanella (2006) discovered that the prevalent frequency is approximately two revolutions per second)
- Low
- Zero

The spin speed has an effect on how fast the ball flies and how it bounces off the board or hoop.

The faster back spin of a flying ball was associated with more accurate jump shooting performed by experienced basketball shooters (Yates – Holt 1982, p. 105–108).

In the theoretical study by Knudson (1993, p. 72) the expectation was that the ball thrown from the free throw distance should rotate 2–3 times on its flight path at the hoop.

By performing measurements, Saleh–Satti (2004, p. 2) determined that when shooting a free throw, the ball rotates approximately 1.25 times around its rotation axis, resulting in a low lift force caused by the ball spin C_L , which has little effect on the ball's trajectory.

The backspin extends the flight path of the ball approximately by 10 cm when the ball is shot from the distance of 6 m (Hajossy – Mačura, 2011).

Spin and rebound in basketball shooting

In each subsequent rebound, the revolution frequency and the angle of the rotation axis change.

On the basketball court, the following objects can spin the basketball when shooting:

- Basketball board
- Basketball hoop
- Player's arms/hands or their parts

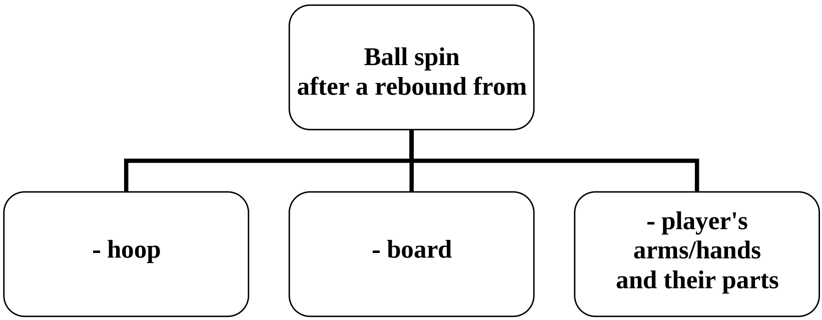


Figure 56: Basketball spin after a rebound from other bodies when shooting.

The only theoretical exception when no rotation is given to the ball is when the ball is dropped freely on the ground. The ball should bounce until it stops on the ground in its initial point of contact with the floor.

This is practically impossible because the ball has no ideal spherical shape and the floor is not ideally flat either.

This case, however, does not apply to basketball shooting.

Rotation axis

The rotation axis is an imaginary line around which the ball spins after being released from the shooter's hand, or after it bounces off the board and/or hoop.

The rotation axis is firmly linked to the ball and it crosses its center. The angular and circumferential speed can be traced on the surface. The angular speed ω is defined by the angle of spin of the ball around its rotation axis per second. Rotation can also be characterized as the frequency f = frequency of revolutions per second, whereby $\omega = 2\pi f$. When describing the rotation of the ball, we can use angular speed since all points of the rotating ball have identical angular speed. Various points in the ball have various circumferential speeds. The most distant points from the rotation axis have the highest circumferential speed.

During the flight, the point of gravity and rotation axis move. The direction of the rotation axis and the angular speed ω does not change in the process.

We distinguish the following rotation axis angles:

- Horizontal
- Vertical
- Oblique (Figure 57)

The horizontal rotation axis of the ball on its flight at the basket means that the rotation axis is parallel to the floor. It most commonly occurs in basketball shooting from the field and in free throws.

Oblique rotation axis is within the range of 0^{o} to 90^{o} relative to the floor.

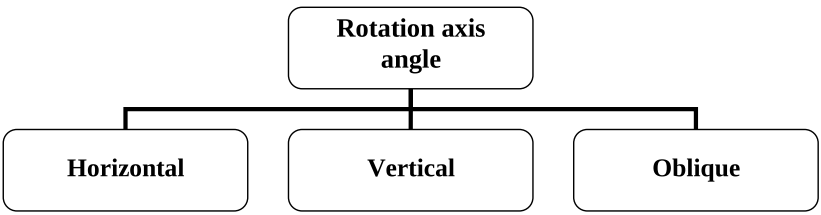


Figure 57: Rotation axis angle of a flying basketball.

The vertical rotation axis of the ball means that the rotation axis is perpendicular to the floor. It occurs sporadically when shooting from underneath the basketball hoop when using the ball rebound from the board.

When discussing the rotation axis angle, we distinguish angles to:

- Floor plane
- Front wall of the basketball board (Figure 58)

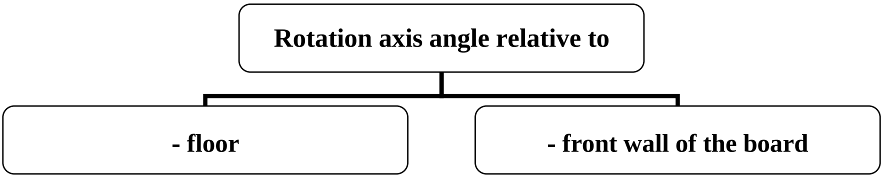


Figure 58: The rotation axis angle of a flying basketball relative to other objects.

Shooter and angle of entry into the hoop

The shooter's action when the ball is thrown directly into the hoop is determined by:

- Ball and hoop size ratio
- Ball and hoop shape
- Difference between hoop height and release point
- Distance between release point and hoop center

The relations between the above ball and hoop characteristics have a detrimental effect on the angle of entry into the hoop.

Theoretically, the most appropriate angle of entry into the hoop is the perpendicular one. It has the largest set of points in the hoop allowing the ball to fly through without contacting its metal rim.

In real life, however, this angle is unattainable. Nevertheless, it serves as a springboard for a common requirement to shoot the ball in a way so it enters the hoop under the largest angle possible, i.e. in an angle approaching the perpendicular one.

For smaller balls, the set of angles of entry into the hoop is more numerous compared to larger balls even in a non–zero horizontal throwing angle.

Hay (1985) ranks the following items as fundamental variables determining the success of shooting:

- Shooter's distance from basket
- Defender's position and posture
- Angle of entry into the hoop

He visualized the change in the ring–shaped area in the plane of entry into the hoop as an ellipse (Figure 59).

He further argues that the ideal angle of entry into the hoop is (90^o), the critical angle is (32.43^o) and the extreme cases are (20^o) where the ball rebounds from the front or back section of the hoop.

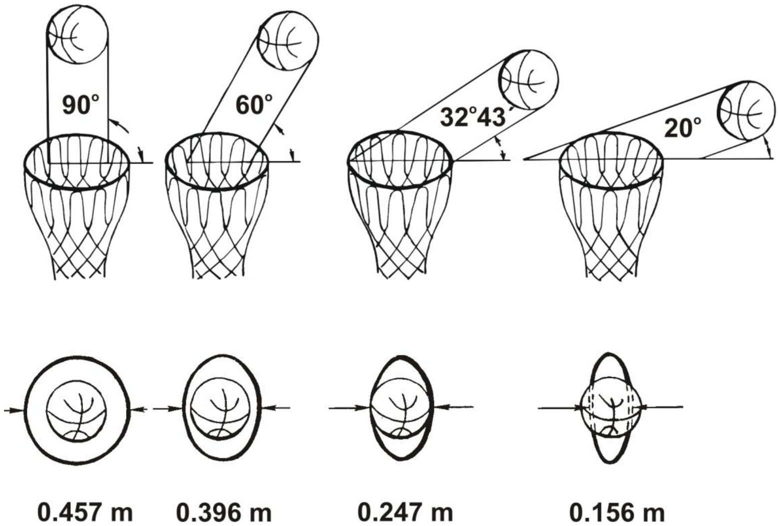


Figure 59: The basketball's "view" of the basketball hoop (bottom) under different angles of entry into the hoop (top) (Hay 1985; p. 218).

When shooting directly into the hoop, the angle of entry is determined by the throwing angle. The moment the ball is thrown with a particular throwing angle, the ball's trajectory is defined.

Sharpe (1975) mentions the conversion of the angle of entry of the ball into the hoop into percentage of effective surface of the basketball hoop (of the usual size) with the internal diameter of 0.45 m (Table 18).

Table 18: The conversion of the angle of entry into the hoop into percentages of effective surface of the hoop (modified from Sharpe 1975; p. 24–25).

Angle	Percentage of effective surface
90^o	100 %
60^o	86.66 %
45^o	70.71 %
less than 32^{o}43′	0 %

Table 19: Difference between the hoop and ball diameter at the given angle α of entry into the hoop[22].

Angle (^{o})	Dsinα (m)	D_L (m)	Dsinα - D_L (mm)
90^o	0.4500	0.2434	207
60^o	0.3897	0.2434	146
45^o	0.3182	0.2434	75
32^{o}44′= 32.74^o	0.2434	0.2434	0
20^o	0.1539	0.2434	-90

The differing trajectory of a flying basketball affects the set of theoretical points in the hoop, causing it either to fly through the hoop, bounce off, or miss it completely (Figure 60).

The values of the angle of entry into the hoop in free throws were measured experimentally (Table 20). We see that the values of successful shots varied from 37.8 ± 1.7^o and 42.0 ± 2.1^o.

[22] Hay's data in Figure 59 (Hay 1985) follow from the internal hoop diameter of 0.457 m and ball diameter of 0.247 m.

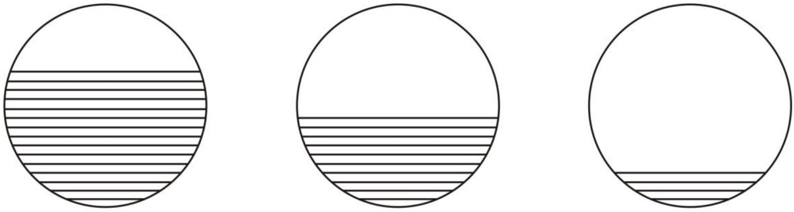


Figure 60: Theoretical set of points on the hoop plane (shaded) ineffective for the ball when shooting at the hoop in the low (a), medium (b) and high (c) trajectory **(**Cetlin 1955; p. 78)[23].

Table 20: Values of angle of entry into the hoop when shooting free throws (Saleh–Satti 2004; p. 5). Attempt 4 was unsuccessful. Other attempts were successful.

Attempt	Angle of entry into the hoop (^{o})
1	38.6 ± 1.7
2	42.0 ± 2.1
3	37.8 ± 1.7
4	39.9 ± 2.1
5	38.5 ± 1.7

Hofer (1978) identified the angle of entry into the hoop when shooting free throws at the level of 40.8^o.

In the average vertical throwing angle of 53^o, the angle of entry into the hoop in free throws ranged from 37.8^o to 42.0^o (Saleh Satti; 2004).

Minimum angle of entry into the hoop

The minimum angle of entry into the hoop is given by the ball size and hoop size. It is commonly held that the smaller the ball, the smaller the value of minimum angle of entry into the hoop.

[23] This figure is qualitative and it states that the sharper the angle of flight to the hoop plane, the smaller the area (white in the picture) suitable for a successful shot. This figure is not an accurate guideline where to shoot to make the ball fly through the hoop.

The ball diameter determines the minimum angle of entry into the hoop. The diameters of basketballs vary depending on their size (Table 1).

It is assumed that balls no. 5 and no. 6 have a smaller minimum angle of entry into the hoop compared to male basketballs no. 7.

Zaciorskij – Golomazov (1972) indicate that the minimum angle of entry into the hoop is $30^{o}41'$ (p. 18, description of Figure 2). Their paper does not specify the size of the basketball used, therefore we assume the study was undertaken with a men's basketball currently known as ball no. 7.[24]

Shooter and ball rebound

Ball rebound related to basketball shooting can be threefold:

- Board
- Hoop

and the combination of board and hoop in differing sequences and count.

Rebound from the board

In a successful basketball shot using the rebound from the hoop, the relation ball – hoop is enriched by a new mediator and the board becomes an integral part of the ball – board – hoop sequence.

The basketball board and its properties, such as production material, perpendicularity to the floor, flexibility, surface friction coefficient etc., all contribute to the relations between the ball and the hoop.

Mainly after the rebound of the ball from the board, the diversity of ball – board – hoop relations significantly broadens.

The most important factors affecting the rebound of a rotating ball from the board include the ball spin speed in the moment of contact and the point of contact on the ball surface and the board in relation to the ball's axis of rotation.

---

[24] Hajossy – Mačura (2011) describe the angles of entry into the hoop in a successful shot on pp. 82-86.

A theoretical analysis of the basketball spin after a rebound from the board was presented by Rovný (1963 a, b – Figure 61) and Brancazio (1981).

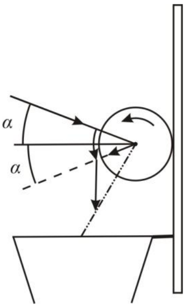


Figure 61: Rebound angle of a spinning ball from the basketball board – side view (Rovný 1963 b).

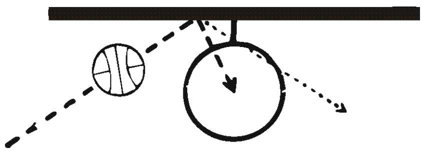


Figure 62: Rebound angle of a ball with zero spin from the basketball board – top view (Dobrý 1963).

Dobrý (1963) rightly notes that the basic rule of physics "angle of reflection equals the angle of attack" is modified when shooting a bank shot (Figure 62). But he incorrectly explains the reason for changes in the parabolic flight path before the rebound. The reason for the difference between the angle of attack and angle of rebound lies in the changing ball rotation during the rebound.

The rebound angle from the board is dependent on the strength, rebound angle and rotation the ball is thrown with.

Although the theoretical studies and research findings on the rebound from horizontal pads are not suitable to study the rebound from the basketball board or hoop, which is perpendicular to the floor, we can make a solid argument that the basketball shots on the board are affected by:

- Ball material
- Board material

Point of contact on the board

We know that when shooting a bank shot, the rebound point on the board depends on the shooter's horizontal distance from the basket, on his/her horizontal position on the court relative to the board (Figure 63), on the height of release point from the floor in the given hoop height and what the speed and direction of the ball is.

When determining where the ball bounces off the board, the following criteria are crucial in the moment of impact:

- Ball velocity
- Ball spin speed, position of the rotation axis
- Position of the rebound point on the board relative to the hoop plane
- Vertical movement on the trajectory (rising or falling)
- Angle of impact on the board in three–dimensional space v plane of impact
- Board surface quality
- Ball surface quality

The last two items greatly affect the friction coefficient T.

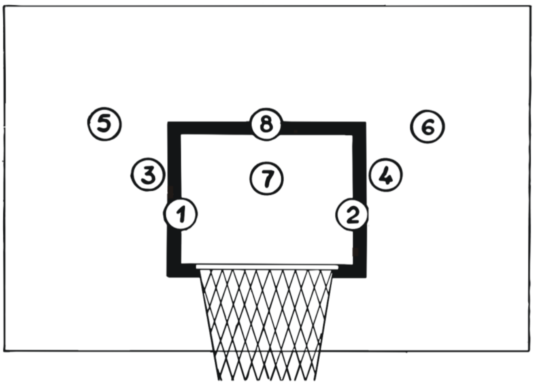


Figure 63: Aiming points when shooting at the board from different positions in the field (Butautas 1954).

Mačura (2007) attempted to identify the points of rebound in successful set shots at a transparent basketball board from various locations in the field (Figure 64) in an experiment with four basketball players (Table 21).

Each location was shot from until the shooter reached 15 successful shots without hitting the hoop – clean shots.

Table 21: Age, body height, and maximum reach with the preferred hand of shooters (Mačura 2007).

Shooter	**Age (years)**	**Body height (m)**	**Maximum reach of the shooting hand (m)**
1	27	1.71	2.35
2	23	1.78	2.43
3	26	1.86	2.50
4	13	1.65	2.18

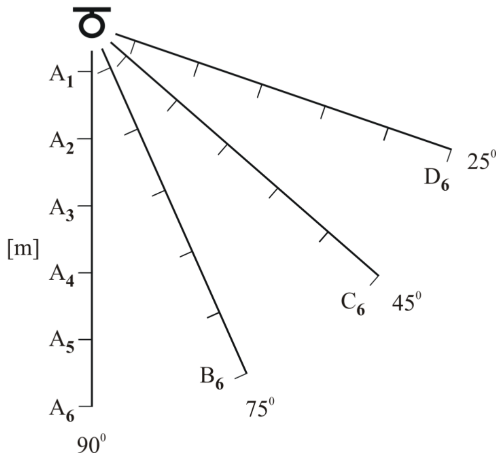


Figure 64: Shooting locations in the experiment.

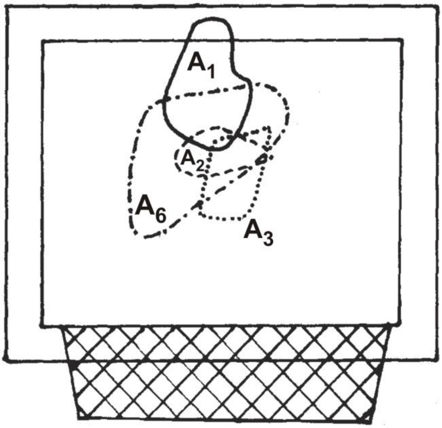


Figure 65: Areas of rebounds from the board from direction A (perpendicular to board) in the distance A_1 (1 m), A_2 (2 m), A_3 (3 m) and A_6 (6 m) from the hoop (Shooter 1).

In the perpendicular direction (90^o), the change in the shooting distance had an insignificant effect on the displacement of the sets of impact points (Shooter 1) (Figure 65). This especially applies to distance A_2 to A_6.

The relatively raised position of the impact points in the distance A_1 (1 m) was probably caused by the fact that, shooting from a closer distance, the shooter must shoot above the hoop, which hinders the ball flight. It forces the (smaller) shooters to shoot with a higher arc.

The shift of the rebound points (Shooter 1) in relation to changing the angle to the board is shown in Figure 66.

We see that by changing the shooter's position relative to the board from the very perpendicular position to the more parallel position, the sets of point for individual positions move toward the outer side of the board and they rise to the upper corner.

As it has been stated previously, we have not identified a uniform trending in the change of sets of impact points when shooting from the position perpendicular to the board (A).

In shots from a 25° angle (D), we identified varying sets of impact points for individual shooters (Figure 67).

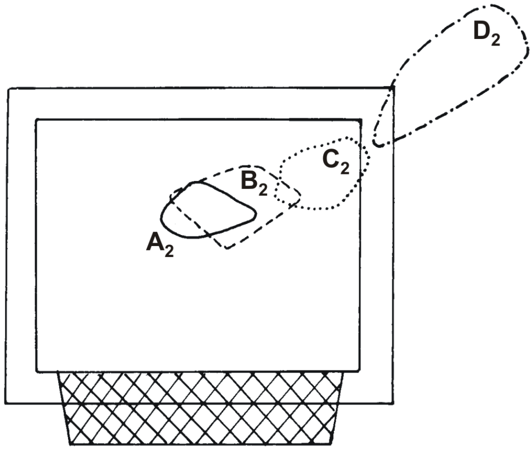


Figure 66: Shift of impact point sets when shooting from 2 m in position A_2 through D_2 (Shooter 1).

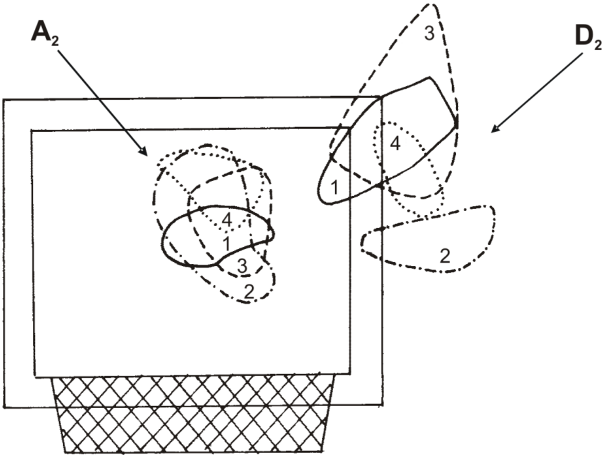


Figure 67: Impact point sets from a 2 m distance, position A_2 and D_2 (Shooters 1, 2, 3, 4).

Figure 67 shows an example for the distance of 2 m. We see no uniform tendency in the shift of impact point sets based on the shooter's maximum reach.

The individual players' impact zones have also to do with the peculiarities of their shooting.

Point of contact on the ball

The point of contact on the ball at the moment it hits the board when shooting using the rebound technique is not identical in character with the point where the ball bounces off the floor.

Ball rotation and rebound from the board

Another peculiarity of bank shots is established by the fact that when shooting from underneath the basket, the rotation axis is not horizontal but oblique relative to the floor.

The ball spin speed combined with the rotation angles in a bank shot result in a far greater amount of rebound angles available compared to the rebound in dribbling and passing the ball against the floor.

Sometimes when the shooter shoots the ball inaccurately, it rebounds from the board without the shooter intending to use it. This phenomenon can be termed an unintentional rebound from the board[25].

Optimum parameters for successful shooting with a rebound from the backboard

In order to calculate the Optimum parameters for successful shooting with a rebound from the backboard, analogical rules are applied to those used in determining the optimum parameters for successful shooting at the hoop, which were described in the previous sections.

[25] The rebounds of a spinning ball from the board of varying quality and trajectory affected by all forces (gravitational, air resistance, Magnus and buoyancy) are analyzed in detail in Hajossy-Mačura (2011) on pp. 32-48, 98-153 and 226-236.

When calculating the shots with a rebound from the backboard, one needs to realize that the backboard behaves like a mirror, i.e. the shooter should aim at the mirror image of the hoop behind the backboard in the horizontal distance L (see Figure 68).

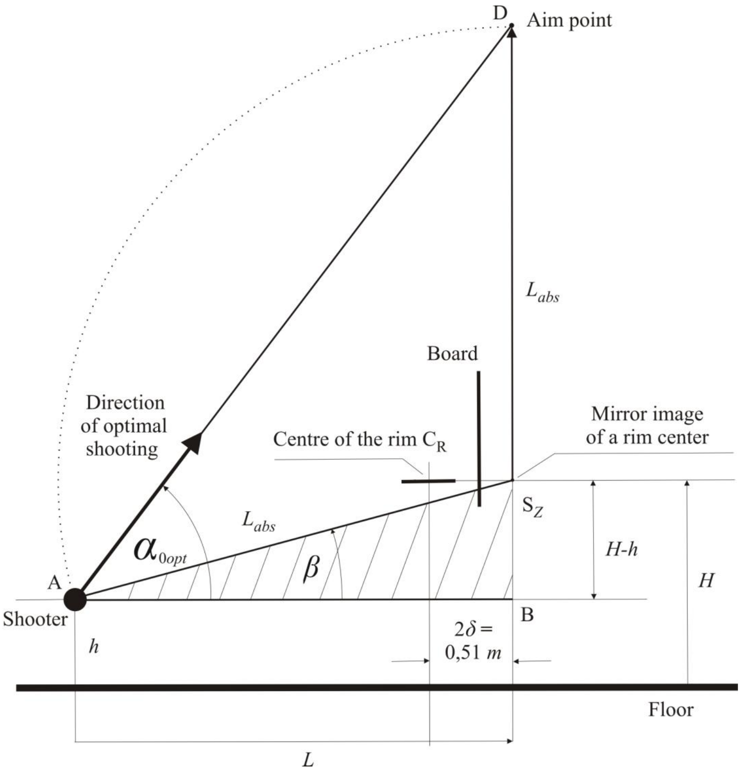


Figure 68: Geometrical interpretation of the relationship **(6)** for the optimum angle α_{opt} of a successful bank shot. The point of release is at the height h. The hoop center C_R as well as its mirror image S_z are at the height H above the floor. The absolute distance from the point of release A to the mirror image of the hoop center S_z is L_{abs} (the corresponding horizontal distance is L). In an optimum shot, it is necessary to shoot the ball in the direction of point D, which is located at the distance L_{abs} above the mirror center of the hoop.

The optimum release angle for a successful shot with a rebound from the backboard as well as for a direct shot at the hoop is defined by the relation (7), which stipulates that to achieve the optimum angle the most crucial parameter is height h of the point of release and the horizontal distance L of this place from the mirror image of the hoop center.

The following simple rule applies for a successful shot with an optimum angle of release $\alpha_{0_{opt}}$:

> The ball must be thrown directly at the point above the mirror image of the hoop (Figure 68). The vertical distance from this aiming point to the hoop center equals the absolute distance L_{abs} from the mirror center to the point of release. The point of release is the location of the center of the ball at the moment of its last contact with the player's hand. Absolute distance is the distance according to Figure 68 and it is defined by relation
>
> $L_{abs} = \sqrt{(H-h)^2 + L^2}$).

Ball rebound from the hoop

By analyzing the theoretical rebounds of a non–rotating and ideally spherical body made of a homogeneous material (an ideal basketball) falling directly down onto a horizontal hoop plane, we can identify two scenarios (Mačura 1984):

1) The ball enters the basket without ever touching the hoop (Figure 69). The condition that the distance between the orthogonal projection of the ball center S_n and the nearest point on the hoop must be greater than the ball radius r_l must be met.

2) The ball touches the hoop. There are three options in this scenario:

- The orthogonal projection of point S_n is reflected into the center of the circular cross section of the hoop.

  Effect: The ball bounces x times straight up and remains standing on the hoop. This is a theoretical possibility; however, it does not happen in reality.

- The orthogonal projection of ball center s_n is not in the center of the circular cross section of the hoop and the distance of this projection from the nearest point on the hoop is smaller than the ball radius r_l (Figure 70).

  Effect: The ball bounces outwards from the center of the hoop S_1. The angle of reflection will change in three–dimensional space in relation to the distance of the ball center S_n to the nearest outer point on the hoop.

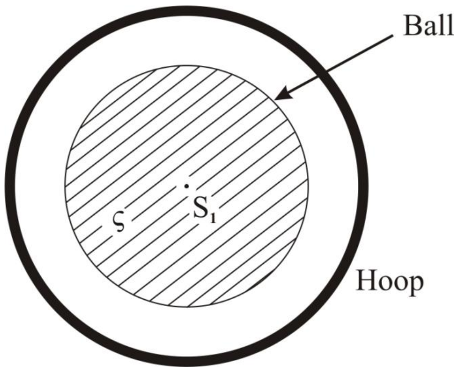


Figure 69: The ball falls into the hoop without ever touching it.

Legend: S_1 – Hoop center
ς – A set of orthogonal projections of ball centers S_n (shaded area) falling flat down on the plane where the ball falls through the hoop without ever touching it

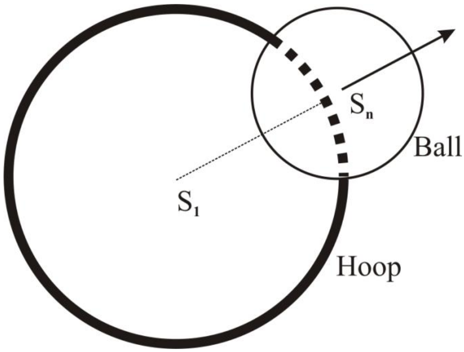


Figure 70: Ball rebound outwards from the hoop.

Legend: S_1 – Hoop center
S_n – Ball center
Thick shaded line – Part of the hoop covered by the ball
Arrow – Direction of ball rebound

- The orthogonal projection of ball center s_n is in the center of the circular cross section of the hoop and the horizontal distance of this projection from the nearest point on the hoop is smaller than the ball radius r_l.

  Effect: The ball bounces inwards into the hoop center S_1. The angle of reflection in three–dimensional space will change in relation to the distance of the ball center S_n to the nearest inner point on the hoop.

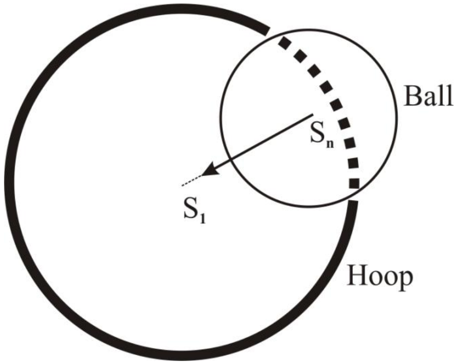


Figure 71: Ball rebound inwards over the hoop.

Legend: S_1 – Hoop center
S_n – Ball center
Thick shaded line – Part of the hoop covered by the ball
Arrow – Direction of ball rebound

It is obvious that the key aspects in analyzing the rebound of a ball falling perpendicular on the hoop plane are the ball center, which is approximately identical to its center of gravity, and ball radius r_l.

If we change the angle of entry of the ball relative to the hoop plane and consider the rebound of a rotating ball, the situation will change significantly.

We assume that the expected direction of rebound depends on the variables such as spin speed, rotation axis tilt, ball velocity in the moment of impact on the hoop, location of the point of impact on the ball and hoop both in vertical and horizontal direction etc.

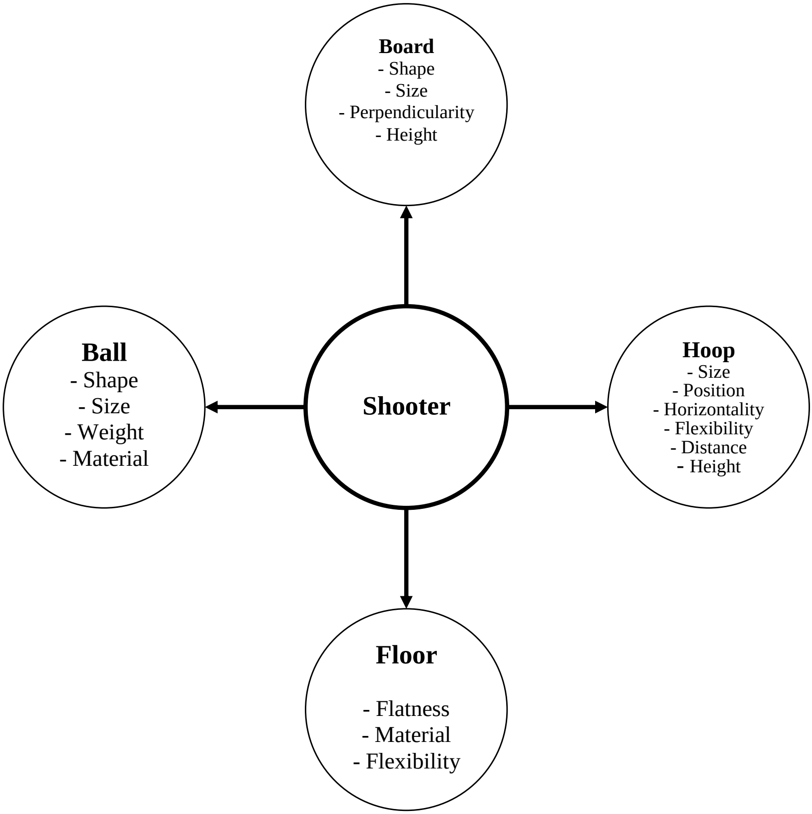


Figure 72: Relation of shooter to other key factors in basketball shooting.

The rebounds of the ball from the hoop (Figure 23) are among the least researched and analyzed rebound phenomena in basketball even though the early attempts at analyzing this particular problem in basketball shooting have already emerged (Okubo – Hubbard 2006).

Conclusion

Physical factors in basketball shooting

The results in the available (and heterogeneous) studies dealing with the physical factors of basketball shooting over the past 50 years suggest that shooting directly into the hoop (Figure 73: Physical factors in basketball shooting directly into the hoop) and bank shots (Figure 74: Physical factors in basketball shooting with the ball rebound from the board) have much in common, and yet they are diverse.

The position of the release point relative to the hoop and board requires the correct combination of throwing angle and speed.

As soon as the ball flies out of the shooter's hand, its flightpath has been ultimately defined. As soon as the ball flies out of the shooter's hand/s, the shooter cannot affect its trajectory in any way. The ball spin does not significantly alter the trajectory parameters. At the moment of release, the potential angle of entry into the hoop is set as well.

It becomes obvious whether the shooter was able to impart the right combination of the throwing angle and speed to the ball during the shooting motion.

A rationally justified theory was formulated stating that throwing the ball with its minimum throwing speed to make it through the hoop center is most advantageous. The starting point in the theory is that to throw the ball with minimum speed requires the least amount of physical effort and shooter's muscle strength, which plays an important role in teaching the shooting motion to children and youth.

The physical factors in intentional bank shots and unintentional bank and rim rebounds substantially extend the variability of the throwing angle in three–dimensional space and the respective throwing speeds.

Physical factors in basketball shooting
directly into the hoop

1 Shooter's distance from the hoop

↓

2 Position of release point and the hoop

↓

3 Throwing angle

↓

4 Throwing velocity

↓

5 Ball flightpath and its trajectory

↓

6 Ball deceleration/acceleration

↓

7 Ball spin

↓

8 Ball entry into the hoop (with or without touching it)

↓

9 Angle of entry into the hoop

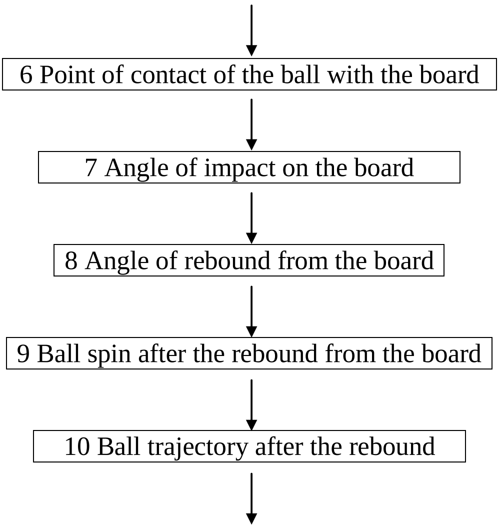
↓

10 Place of entry into the hoop

Figure 73: Physical factors in basketball shooting directly into the hoop.

Physical factors in basketball shooting
with the ball rebound from the board

For Factors 1 to 5 see Figure 73



For the following factors, see previous Figure 73 – Factor 8 to 10

Figure 74: Physical factors in basketball shooting with the ball rebound from the board.

Summary

Physical factors in basketball shooting

Floor

The most important properties of the floor (where lines delimit the basketball court) include horizontality, flatness, flexibility and floor material. Cleanness and dryness are among the characteristics that affect the shooter's confidence while stopping to take a shot or jump (Figure 1: Floor properties affecting the execution of shooting motion).

There are other qualities, characteristics and elements in basketball shooting considered being important in determining their relation to the floor. These include: shooter's weight and height, ball weight and flexibility, ball internal pressure and air temperature, ball temperature. The hoop and board height are also crucial characteristics affecting the relation to the floor (Figure 3: Relation of floor to other important factors in basketball shooting).

Basket structure

The most important parts of the basket structure are the hoop and the board.

The factors that significantly influence the possibility of scoring a successful shot are the hoop shape, size, height from the floor and its metal body, perpendicularity to the board, horizontality, flexibility, and possibly its color coating (Figure 5: Hoop factors affecting basketball shooting).

The following characteristics and factors of backboard are crucial in basketball shooting: shape, size and flatness of the front wall, its perpendicularity to the floor and hoop, height from the floor (Figure 9: Board factors affecting basketball shooting). Board color and transparency can affect the success of basketball shooting.

There are other characteristics, qualities and properties of other elements in basketball shooting significantly affecting the relations with the basketball hoop:

- Shooter's body height and jump height and distance from the hoop
- Size, perpendicularity and height of the board
- Shape, size and weight of the ball

- Parallelism of the floor plane and hoop plane (Figure 7: Relation of hoop to other key factors in basketball shooting)

Ball

The basketball is a mediating factor between the shooter and the hoop. Its shape, size, weight, internal air pressure, body temperature and air temperature, the material it is made of, surface and spin characteristics are the most significant features affecting the basketball shooting (Figure 11: Ball factors affecting basketball shooting).

The relation of the ball and the shooter is mainly defined by the shooting hand. The ability to adapt the shape of the hand to the shape of the ball is among the most important characteristics that determine the shooter's ability to successfully score by throwing the ball into the hoop (Figure 22: Relation of the ball to other key factors in basketball shooting).

The shape of the board and its size are the most prominent factors affecting the ball–board relation. The perpendicularity and height of the board also affect their relation.

In intentional or unintentional rebounds from the board, the interaction of the ball and the board is given by the fact that the ball is not hitting the board in the direction of gravitational forces as is the case of the ball falling down on the floor. The fact of the matter is that the board usually happens to be above the release point from the shooter's hand and it is not parallel to the floor.

Hoop size, horizontality, shape and flexibility are among the most prominent characteristics defining the ball–hoop relation. Naturally, we differentiate between shooting directly into the hoop without touching it, and shooting by touching the hoop, causing a random rebound from the hoop.

Flatness and horizontality of the floor, its flexibility and production material are among the least important factors, however, they are crucial in the ball–floor relation.

A significant number of shots in basketball is driven by the ability to dribble and stop as activities directly preceding the shooting. In these cases, the above characteristics have a material effect on the rebound of the ball from the floor and the consequent ball grip before the shooting motion is carried out. The floor flexibility is manifested in jump shots and it particularly affects its rebound characteristics.

Relation shooter – ball

The top players are mindful of the ball properties such as shape imperfections, size, softness, porosity, wear and tear and moisture.

Depending on the ball softness, moisture and hand moisture, the ball grip properties change. The shooter grabs, holds and carries the ball differently during the preliminary, main and final phase of the shooting motion.

The softness and surface characteristics of the ball determine how the shooter holds the ball and handle it.

These features extended the range of contingency relations between the shooter the ball.

Shooter and distance from the hoop

Generally, the percentage of successful shots increases as the shooter gets closer to the hoop.

System of basketball shooting

Selected characteristics and properties of basketball shooting show that the reasons why the shooter ultimately hits or misses the hoop are manifold.

The combination of the initial direction of the ball in three dimensional space and adequate ball velocity should be such that the ball flies into the hoop either directly or with various intentional or random rebounds from the hoop and/or board.

The shooter is mindful of the ball size, weight, shape and surface material. With regard to the position in the field at the moment of shooting relative to the board, the shooter decides whether to shoot directly into the basket or use the ball rebound from the board. In the second scenario, he/she takes into account the shape, size and height of the board and its perpendicularity to the hoop (Figure 72: Relation of shooter to other key factors in basketball shooting).

Just like in bank shots, even when shooting directly into the hoop, the shooter perceives its size, horizontality and distance. If the ball bounces randomly off the hoop, the hoop flexibility contributes to whether it falls through it or not.

The floor with its flatness, flexibility and surface friction is the starting point for shooter's confidence in the shooting motion not only in set shots, but also in jump shots.

List of references

1. AJD, S.A. (1985). Vlijanije razmerov mjača i vysoty ustanovky koľca na daľnosť i točnosť broskov v mini-basketbole u devoček 8-12 let. (Influence of basketball size and the height of the hoop on the shooting distance and accuracy of 8-12 year old girls). *Teorija i praktika fizičeskoj kuľtury.* 48 (3): 27-29.
2. ANDERLE, J. (1977). Technika střelby jednou rukou v basketbalu. (The mechanics of one-hand basketball shooting). Praha: Sportpropag. 18.
3. BRANCAZIO, P.J. (1981). Physics of basketball. *American Journal of Physics.* 49 (4): 356-365.
4. BRANCAZIO, P.J. - BRODY, H. (1987). How much air is in basketball? *American Journal of Physics.* 55 (3): 276.
5. BUNN, J.W. (1963). *Naukowe zasady treningu.* (The scientific principles of sport training). 3rd edition. Warszava: Sport and turistyka.
6. BUTAUTAS, ST. (1954). *Krepšinis.* (Basketball). Vilnius: Valstybiné - Politinés ir Mokslinés literatúros leidykla.
7. CETLIN, P.M. (1955). *Basketbol.* (Basketball). Moskva: Fizkuľtura i sport.
8. CHIU, Ch-h. (1985). The effect of horizontal deviation on basketball shooting. *Asian Journal of Physical Education.* 7 (4): 50-55.
9. COOPER, D.F. - HAMLEY, E.D. (1974). The basketball free throw. *British Journal of physical Education.* 5 (1).
10. CORCORAN, J. - RACKSTRAW, R. (1999). *Proper inflation of a basketball.* Writing Laboratory Reports. Section 1, January 1, 1999. http://www.isat.jmu.edu/common/projects/StyleManual/ExampleReport/ProperInfaltionofaBasketball.doc (27.09.2006).
11. DOBRÝ, L. (1963). Útok v košíkové. Základní útočné činnosti jednotlivce. (The basketball offence. The fundamentals). Praha: Sportovní a turistické nakladatelství.
12. DONSKOJ, D.D. – ZACIORSKIJ, V.M. (1979). Biomechanika: Učebnik dľa institutov fizičeskoj kuľtury. (Biomechanics: A textbook for sports institutes). Moskva: Fizkuľtura i sport.
13. FONTANELLA, J.J. (2006). *The physics of basketball.* Baltimore, Maryland: The Johns Hopkins University Press.
14. GOLOMAZOV, S.V. (1971). Točnosť basketbolista. *Sportivnyje Igry.*17 (3): 28.
15. HAGEDORN, G. - LORENZ, H. - MESECK, U. (1981). Die Vorteilung spieltypischer Aktivitäten im Basketball - Untersuchung im Rahme des

Forschungsvorhabens Computerstütze Leistunganalyse im Sportspiel. *Leistungssport.* 11 (6): 442-449.

16. HAJOSSY, R. – MAČURA, P. (2011). Fyzika a matematika úspešnej streľby v basketbale (Physics and Mathematics of Successful Shooting in Basketball). 2nd edition. Brno, Masarykova univerzita.
17. HAY, J.G. (1973). *The biomechanics of sport techniques*. 1st edition. New Jersey. Prentice Hall, Inc. – Englewood Cliffs.
18. HAY, J.G. (1985). *The biomechanics of sport techniques.* 3rd edition. New Jersey, Prentice Hall, Inc. – Englewood Cliffs.
19. HERRMANN, G. (1957). *Basketbal. (Basketball).* Vysoká škola pedagogická, Fakulta spoločenských vied: Slovenské pedagogické nakladateľstvo.
20. HERRMANN, G. (1976). Basketbal. Presnosť a istota streľby. (Basketball shooting accuracy and certainty). In: ROVNÝ, et al.: Športové hry. Bratislava: Slovenské pedagogické nakladateľstvo.
21. HOFER, H.H. (1978). Develop the arc for better shooting. *Athletic Journal*. 59(2): 34.
22. ISAACS, L.D. - KARPMAN, M.B. (1981). Factors effecting children's basketball shooting performance: A log-linear analysis. *Carnegie Research Papers.* 1 (3): 29-32.
23. IVOJLOV, A.V. - GINZBURG, G.I. - BREGER, M.L. (1976). Nekotoryje zakonomernosti funkcionirizovanija systemy čelovek - cieľ. (Laws and functions of the man-target system). In: *Systemnaja organizacija dviženij sportsmena*. Volgograd: no publisher. 73-82.
24. KNUDSON, D. (1993). Biomechanics of the basketball jump shot - six keys to teaching points. *Journal of Physical Education, Recreation and Dance.* 64 (2): 67-73.
25. KONDRAŠIN, V. (1973). Uzel problem. (The key point). *Sportivnyje Igry.* 19 (4): 16-17.
26. LINDEBURG, F.A. - HEWITT, J.A. (1965). Effect of an oversized basketball on shooting ability and ball handling. *Research Quarterly for Exercise and Sport.* 36 (2): 164-167.
27. LIU, S. - BURTON, A. (1999). Changes in basketball shooting patterns as a function of distance. *Perceptual and Motor Skills.* 89: 831-845.
28. MAČURA, P. (1984). Analýza a syntéza niektorých poznatkov súvisiacich s technikou streľby v basketbale. (Analysis and synthesis of knowledge

connected with the basketball shooting technique). In: *Teoretické základy osvojovania si pohybov v športe. Zborník VMR ČSZTV XI: 96*.

29. MAČURA, P. (1987). Príspevok k nácviku streľby začínajúcich basketbalistov. (Contribution to the shooting practice of beginning basketballers). *Bratislavský basketbalový bulletin.* 1: 19-23.
30. MAČURA, P. (1987). Faktory úspešnosti streľby mladých basketbalistov. (Factors affecting the shooting performance of young basketball players). *Kandidátska dizertačná práca.* Unpublished thesis.
31. MAČURA, P. - ŠELINGEROVÁ, M. (1988). Vztah vybraných somatických a silových ukazatelů k úspěšnosti střelby mladých hráčů. (Relationship of selected somatic and strength indicators with the shooting effectiveness of young players). *Zpravodaj Výboru basketbalového svazu ÚV ČSTV.* 50: 39-45.
32. MAČURA, P. (1991). Faktory úspešnosti streľby mladých basketbalistov. (Factors affecting the shooting performance of young basketball players). *Kandidátska dizertačná práca.* Unpublished thesis.
33. MAČURA, P. (2007). Proposal for a didactic aid to practice and train bank shots in basketball. *Sport science review.* 19 (1-2): 47-62.
34. MATHES, S. - FLATTEN, K. (1982). Performance characteristics and accuracy in perceptual discrimination of leather and synthetic basketballs. *Perceptual and motor Skills*. 55:128-130.
35. MOLTEN For The Real Game. Catalog 2007/2008; p. 31.
36. MORTIMER, E. (1951). Basketball shooting. *Research Quarterly*. 22 (2): 234-243.
37. OKUBO, H. - HUBBARD, M. (2006). Dynamics of basketball shot with application to the free throw. *Journal of Sport Sciences.* 24 (12): 1303-1314.
38. PETROV, V.A. (1968). K voprosu o "čuvstve prostranstva". (The problem: Peripheral vision). *Teorija i Praktika fizičeskoj Kuľtury.* 31 (2):71.
39. RHEINSTEIN, D.J. - MOREHOUSE, CH.A. - NIEBEL, B. (1978). Effects on traction of oustsole composition and hardness of basketball shoes and three types of playing surfaces. *Medicine and Science on Sports*. 10 (4): 282-288.
40. ROVNÝ, M. (1963a). Základy biomechaniky športových hier. (Fundamental axioms of biomechanics of sport games). *Tréner a cvičiteľ.* 7(9): 452-455.

41. ROVNÝ, M. (1963b). Základy biomechaniky športových hier. (Fundamental axioms of biomechanics of sport games). *Tréner a cvičiteľ.* 7(11): 506-512.
42. ROVNÝ, M. (1973). Reynoldsov efekt pri pohybe lôpt v športových hrách. (The Reynolds effect and ball motion in sports games). In: Acta Facultatis Educationis physicae Universitatis Comenianae. 14. Bratislava. 265-273.
43. SALEH SATI. (2006). The perfect basketball shot. http://www.wooster.edu/Physics/JrIS/Files/Satti.pdf. (29.09.2006).
44. SATERN, M.N. - MESSIER, S.P. - KELLER-McNULTY, S. (1989). The effect of ball size and basket height in the mechanics of the basketball free throw. *Journal of Movement Studies.* 16: 123-137.
45. SHARPE, H. (1975). Improve shooting with small goals. *Athletic Journal.* 56 (1): 24-25, 102.
46. SEMAŠKO, N.V.et al. (1976). Basketbol. (Basketball). 2nd ed. Moskva, Fizkuľtura i Sport.
47. SEMIKOP, A.F. - BARKOV, B.A. (1976) Orientir dlja severšenstvovanija broskov v basketbole. (Special device to improve basketball shooting). *Teorija i praktika fizičeskoj kuľtury*. 39 (9): 63-64.
48. SKLERYK, B.N. - BEDINGFIELD, E.W. (1985). Ball size and performance. *Biomechanics in Sports II.*
49. SMIRNOV, Ju. I. - BELOV, A.S. - POLJAKOVA, L.S. (1973). Zavisimosť točnosti broska v basketbole ot sposoba, napravlenija i distancii. (Dependency of basketball shooting accuracy on the technique, position and distance). *Teorija i Praktika fizičeskoj Kuľtury.*36 (4): 12-17.
50. SOUTHARD, D. - MIRACLE, A. (1993). Rhythmicity, ritual, and motor performance: A study of free throw shooting in basketball. *Research Quarterly for Exercise and Sport.* 64 (3): 284-290.
51. TAN, A. - MILLER, G. (1981). Kinematics of the free throw in basketball. *American Journal of Physics.* 49 (6): 542- 544.
52. TAVARES, F. – GOMES, N. (2003). The offensive process in basketball – a study in high performance junior teams. *International Journal of Performance Analysis in Sport* (3)1, 34-39.
53. TEHNICA si tactica individuala a jocului de basket. (The individual technique and tactics in basketball). (1952) *Editura cultura fizica si sport*.
54. TOYOSHIMA, S. - HOSHIKAWA, T. - IKEGAMI, Y. (1979). Effects of initial ball velocity and angle of projection on accuracy in basketball shooting. In. *International Congress of Biomechanics. VII-B.* 525-530.

55. VOJTOV, O.G. (1967). Značenije vybora traektorii i orientira pri broskach v basketbole. (Importance of varieties of trajectory and bench marks in basketball shooting). In*: Materialy naučno-metodičeskogo vospitanija vuzov BSSR.* 9-10.
56. WOODEN, J.R. – SHARMAN, B. – SEIZER, B. (1975). The Wooden-Sharman method: A guide to winning basketball. New York, Mcmillan Publishing Co., Inc.
57. YATES, G. - HOLT, L.E. (1982). The development of multiple linear regression equations to predict accuracy in basketball jump shooting. *Proceedings of the international symposium Biomechanics in Sport*. 2. ed. Ed. J. Terauds. San Diego : Research Center for Sports, Del Mar - 103-109.
58. ZACIORSKIJ, V.M. - GOLOMAZOV, S.V. (1972). Biomechaničeskoje issledovanije basketboľnogo broska. (Mechaniko-matematičeskij analiz i eksperimenty). (Research on biomechanics in basketball shooting. The mechanistic and mathematical analysis and experiments). *Teorija i Praktika fizičeskoj Kuľtury.* 35 (11): 17-24.