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Review article

SYSTEMATIZATION OF PREVIOUS RESEARCH ON EXERCISES ON THE HIGH BAR

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Abstract. *The research was conducted with the aim to classify and systematize all the available studies that deal with exercises on the high bar. This research covered a total of 41 papers, spanning a period from 1990 to 2013. In terms of Code of points it includes as many as 144 elements that are performed and which should be performed at competitions. Of this number, only 18 elements were investigated (based on the collected papers), or 12.5%. This points to the fact that the research on exercises on the high bar, although conducted for a long period of time, is still in the beginning stages. Research of first (long hang swings and turns) and fifth (dismounts) specific requirements dominates. To a smaller extent, research on second (flight elements) specific requirements is represented, and the least attention is devoted to third and fourth requirements.*

Key words: *artistic gymnastics, high bar, systematization.*

INTRODUCTION

The emergence of this gymnastic discipline is very similar to the uneven bars. By converting natural barriers into a primitive apparatus, people very early, setting thick branches between two trees and hanging in that position compensated for that space. Since the appearance of Jana L.F, the high bar basically obtained the look and purpose which it has today (Petković, Veličković, Petković, Ilić, & Mekić, 2013). As for exercise, it should be noted, that on this apparatus, until 1930, only exercises performed by strength and hold exercises were allowed. The high bar has been an apparatus in artistic gymnastics since the very beginning of this sport.

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Modern exercises on the high bar must be entirely composed of dynamically related elements of swings, turns around longitudinal axes, releases and re-grasps of the bar, elements close to the bar in various grips and elements performed on one hand, no more than two passes through the lower vertical of apparatus with the aim to demonstrate the full potential of the apparatus (FIG, 2017). Given the high potential of this apparatus and the large number of elements which are performed on it (155 elements – FIG, 2017) it is logical to assume that there is a large number of studies on this apparatus. However, few have dealt with the problem of systematization of research on this apparatus, in order to produce the data on what is the most researched and what is neglected. Prassas (2006, 1999) attempted to systematize all the research in artistic gymnastics, on as many as two occasions: in 1999 and 2006. In his first detailed analysis he indicates that the relevant aspects of the research on the high bar are – dismounts and giant swings. Flight elements were also investigated quite often. In some research he states the additional kinematic, kinetic and EMG parameters of the giant swing, while performance of the inverse – Russian giant swing is less frequently studied. He also indicated studies related to research on the energy of the giant swing on the high bar (Arampatzis & Bruggemann, 1998).

In another study (Prassas, Kwon, & Sands, 2006), it is concluded that biomechanical research in artistic gymnastics had grown considerably in the past few years. However, most studies are still focused on several attempts at generalization. Accordingly, understanding the principles and the basis of this sport, although improved, are still marginal with gaps in knowledge about the technical characteristics of movement throughout this sport. Also in this case they emphasize that the research on the high bar is focused on dismounts and elements of release and re-grasp of the bar, as well as on giant swings. The authors give a summary of all the analyzed studies on the high bar in Table 1.

Table 1 Summary of gymnastics studies on the high bar and uneven bars

Skills	Information on
Giant swings: Overgrip, Undergrip, Inverted, Dismount	▪ Joint angles; angular momentum; kinetic energy; force on the bar; power; joint torques; timing; EMG activity; optimization
Release/regrasp skills: Gaylords, Tkatchevs, Gingers, Kovacs, Kolman, Pegan, Mariniches	▪ At release and regrasp and in-flight: joint angles; radius of gyration; angular momentum; take-off angle; flight and regrasp descriptors ▪ Preparatory giant swing requirements: kinetic energy; centre of mass velocity; angular momentum; joint and body angles; optimization
Dismounts	▪ Take-off mechanics: linear velocity; centre of mass position; body configuration; angular momentum; kinetic energy; ▪ Optimization ▪ Landing mechanics: body configuration; body angle
Kip	▪ Centre of mass trajectory; hip and shoulder joint angular velocity, torque and power

The aim of the study is to analyze and continue the systematization of studies that have dealt with: training on the high bar, characteristics and construction of the high bar and all the other problems related to training on the high bar.

The methods of research are: the selection method, descriptive method and classification of works. The method of selection refers to the selection of works available in electronic form, dealing with research on the high bar in artistic gymnastics. By the descriptive method, selected works were analyzed and in the study we have a brief overview of the subjects of research of different authors. The classification of works was performed in relation to the subject of the research in the analyzed papers.

MAIN TEXT

This research included a total of 43 papers, written during the period from 1990 to 2013. Studies of exercises on the high bar, for the mentioned period, were published a maximum of three times per year, and on average twice (Figure 1). A slight growing trend is observed when it comes to research exercises on the high bar.

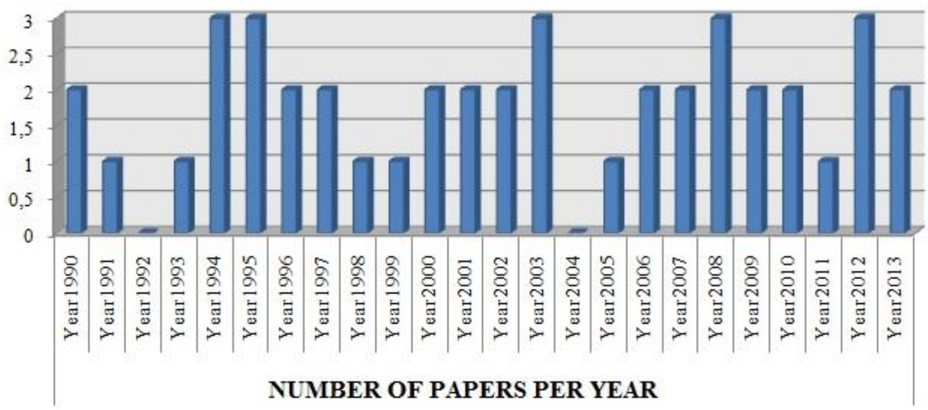

Fig. 1 Number of papers per year

Thirteen journals were registered where the papers on the mentioned issues were published, of which eight magazines in their name have the prefix "biomechanics". This finding suggests that most of the studies are of a biomechanical character. Most of the papers were published after the International Symposium on Biomechanics in Sports (13). After the mentioned symposium most of them were published in the Journal of Applied Biomechanics and Journal of Biomechanics, five papers. In all the other journals four papers or less were published (Figure 2).

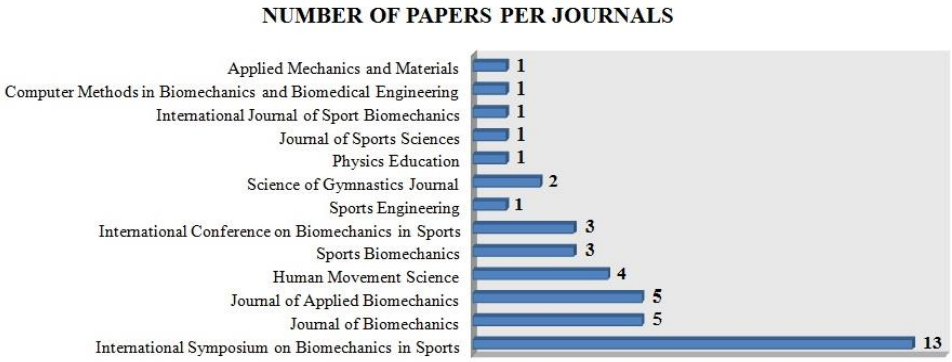

Fig. 2 Number of papers per journal

It was noted that 62 researchers dealt with the problem of exercise on the high bar. Most of the studies were conducted by Yeadon, M. R. – 15 papers, Hiley, J. M. – 11 papers and Kerwin, D. G. – seven papers. Other researchers have published four papers or less.

The subject of the research of exercises on the high bar is quite diverse for the analyzed period (Figure 3). On average, the most analyzed are the first (long hang swings with and without a turn) and fifth (dismounts) specific requirements. Compared to all the studies covered, 33% of them deal with the problem of the first and fifth specific requirements and to smaller percentage (19%) the elements of the second group (flight elements).

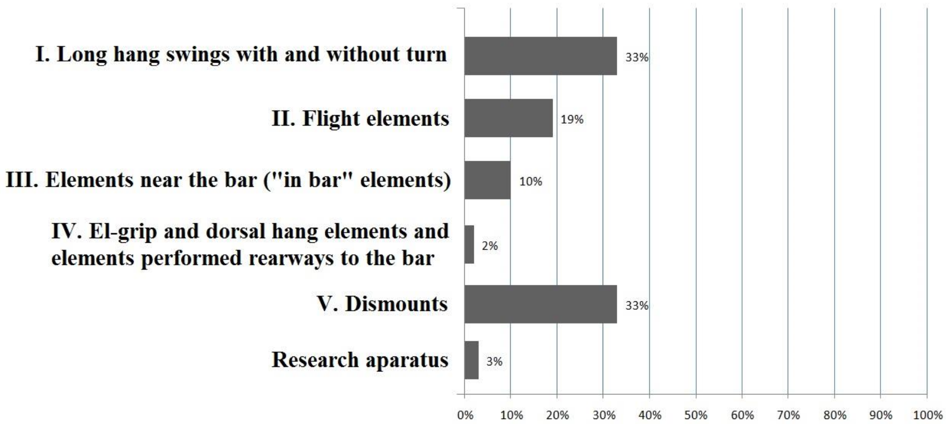

Fig. 3 The subject of research by specific requirements

The mentioned results match the results obtained by Prasas et al., (1999, 2006) and confirm the trends that dominated studies on the techniques of giant swings, releases and dismounts (Figure 3).

SYSTEMATIZATION BASED ON RESEARCH SUBJECTS BY SPECIFIC REQUIREMENTS

The first specific requirement on the high bar represents *Long hang swings with and without turn*. All the studies that have this specific requirement as their subject (a total of 15 – Figure 3) exclusively treated the problem of the technique of the giant swing. Studies in this part can be divided into two groups.

- The first group of researchers exclusively analyzed the giant swing as a special exercise: Williams, Irwin, Kerwin, & Newell (2012), they examined the progress in the methodology of training of the giant swing, with the aim to provide quality information about changes in technique during training. Frère, Göpfert, Slawinski, & Tourny-Chollet (2012, 2010) examined using electromyography the muscles of the shoulder belt during the performance of a giant swing. Irwin & Kerwin (2006) using the inverse-dynamic modeling to examine the moment of inertia, work and force in the joints of the hips and shoulders during four progressive giant swings. Hiley & Yeadon 2003a, 2003b, 2001) on several occasions dealt with the problem of the most appropriate body position during the realization of a giant swing.
- The second group of researchers examined the technique of the giant swing as an exercise preceding the execution of heavier elements, such as flight elements and dismounts. Hiley, Zovsky, & Yeadon (2013) and Chen & Liu (2000) dealt with the analysis of giant swings preceding the dismount, examining the differences between top and average competitors. Hiley & Yeadon (2008) performed the optimization of the giant swing before the dismount "triple salto backward piked". The same authors (Hiley and Yeadon, 2003a, 2003b) examined two different techniques of the giant swing (traditional and modern – kick out technique) preceding the dismount. They concluded that modern techniques have an advantage in terms of greater opportunities for correction of movement and are significantly more efficient than traditional (circular) performance. Arampatzis & Bruggemann (1998) studied energy transfer between the high bar and the gymnasts, and then defined the criteria for use of high elasticity of the bar and use of capacities of muscles on efficiency of movement, and investigated the effects of different segments of the movement on the output parameters. By analyzing the giant swing which precedes the element "Tkachev", Hailey & Yeadon (2012) concluded that the consistency of the performance of a giant swing before the "Tkachev" can be improved by changes in technique, increase of strength and increase of flexibility. Here attention should be paid to the precision of movement, the ability to repeat movement constantly in the same way in time and space.

It is important to note that in Code of points – COP (FIG, 2017) there are 26 elements that belong to the first group of specific requirements and there are no papers that treat these elements.

The second specific requirement on the high bar represents *Flight elements*. Slightly less attention was devoted to this specific requirement (nine papers – 19%). The most explored element of this group is the "Tkachev". A total of four researches treated the problem of this element.

Hiley & Yeadon (2012) examined the consistency of the parameters during the execution of the mentioned element. Hiley, Yeadon, & Buxton (2007) compared successful and unsuccessful performances of the "Tkachev" and determined the cause of the differences.

Successful attempts result in an earlier extension of the shoulder and hip joint. In this study it was found that when performing the successful "Tkachev" element, first comes the extension of the hip joint, and then the anteflexion in the shoulder joint. The quality of the technique of this element was also studied in Prassas (1991), who, comparing successful and unsuccessful attempts, came to the conclusion that success of the element is evident among gymnasts who have a large amplitude of motion and greater flexibility in the shoulder joint and spine. Čuk, Atiković & Tabaković (2009), based on the kinematic characteristics of the "Tkachev", modeled a new element, the "Tkachev salto" and confirmed its safety.

Other elements from this group are explored to a lesser extent. Irwin, Kerwin, Manning, & Brown (2007) explored the technique of the "Kovach" element and checked the possibility of upgrading.

The technique of performing complex elements on the high bar was analyzed by Čuk on two occasions (1994, 1996). The aforementioned author deals with the specific kinematic analysis of exercises: Kovach, Gaylord, Kolman and Pegan.

In this part of the research another study was conducted that focuses on the hypothesis of the origin of the new element. Heinen et al. (2011) carried out a simulation of a new element – the double salto Jaeger, with the help of realistic kinematic parameters of Jaeger and Gejlor release elements. The obtained results of applied simulations led to the conclusion that a double Jaeger is a hypothetically possible element for gymnasts who can produce a defined angular momentum, together with defined time of flight.

Only six elements from this group can be found in research papers. In the COP there are 36 more elements from the second group for which studies have not been found.

The third group of elements are elements performed close to the bar. This group of elements does not have a large presence in the research papers. Kip to support was explored on two occasions (Yamasaki, Yamamoto, & Gotch, 2008; Yamada, Michiyoshi, & Fujii, 2002). The aforementioned group of researchers solved the problem of differences between top and low-skilled gymnasts in the realization of the kip to support. The following differences were determined: a) the difference in the onset of flexion in the hip joint, b) differences in the strength of torque in the shoulder joint, and c) time to execute torque of flexion in the hip joint. The results suggest that unqualified respondents should emphasize flexion in the hip joint in the later period, after the return swing.

Begon, Hailey, & Yeadon (2009) studied the exercise "Stadler" and showed that flexion in the hip joints affects the dynamics of the analyzed element. They confirmed that greater flexibility in the mentioned joints results in less physical strain in the realization of the element. In other research (Begon, Wieber, & Yeadon, 2008), elements near the bar (Stadler and Endo) are only intermediaries in the analysis that treats the justification of a certain number of markers in the application of the method for kinematic analysis – Vicon, with the aim of simplifying the model of research.

The aforementioned third group of elements has another 21 elements that have not been studied.

The least studied group of elements is the fourth group, which contains elements of the under hang and elements performed in the inverted grip – the el grip. Only one study was noted that deals with the element "Adler", by the authors Naundorf, Lehmann, & Witte (2010). 160 whole compositions were recorded, of which more than 100 compositions contains one or two elements of this type. It is noted that 57% of them are performed with a high technique. Both techniques are usually performed successfully, but the kinematic analysis of data shows the different requirements in angles of the hip and shoulder joint.

There are 18 elements from this group of elements that have not been researched and studies that focus on them have not been found.

Dismounts as the fifth group of elements are exercises that most researchers dealt with in their work. Dismounts with back rotations were analyzed the most. Tucked dismounts with double and triple back rotations about the transverse axis were explored by Hiley & Yeadon (2005) in terms of optimization of the most complex dismounts (Fardan), then by Geiblinger, McLaughlin, & Morrison (1995) in terms of technique analysis of performing complex tucked dismounts. Park & Prassas (1994) with aim of determining the most important differences between double and triple somersaults; Kerwin, Yeadon, & Harwood (1993) in terms of determining the position of the center of gravity of the body at the moment of leaving the bar with the triple somersault and Kerwin, Yeadon & Lee (1990) in terms of a comparison with the stretched dismounts.

A certain group of works treated saltos with a double back rotation with a stretched body and an additional rotation around the longitudinal axis of the body and with 1/1, 2/1 (Watanabe) and 3/1 turns (Fedorchenko). Zhou (2013) compared the Watanabe dismount at two periods of time. Hailey & Yeadon (2003a, 2003b) analyzed the giant swings which precede the same dismounts and give priority to the eccentric technique. The same problem was treated by Chen & Liu (2000), but they checked the differences in the eccentric technique (kick-out) between the top and average gymnasts and concluded that the better performance of a dismount is achieved with gymnasts who use pronounced flexion of the shoulder and hip when passing the upper vertical of giant swing before a dismount, which better changes the moment of inertia. Yeadon (1997) compared dismounts with a double salto stretched with 1/1 and 2/1 turn around the longitudinal axis. Yang, Ma, Mao, Dang, & Shen (1995) provided the parameters of a successfully performed dismount – the double salto stretched with a 3/1 turn around the longitudinal axis of the body.

In the COP there are 26 more dismounts for which studies have not been found or were not realized.

Only on two occasions did we find studies that treat the high bar as an apparatus and examine the reactive forces that occur due to swings (Kerwin & Hiley, 2003), as well as the procedures for the measurement of dynamic parameters (inverse dynamics and the application of dynamometers) which are detected on the very apparatus (Knoll, Drenk, & Krug, 1996). The authors suggest that moderate reactive forces are the basis for the design and optimization of an apparatus. They came to the conclusion that the procedure of dynamometry is significantly more accurate than kinematic procedures, but it is less economical for application.

SYSTEMATIZATION BASED ON USED SAMPLES AND ATTEMPTS

The sample of participants by research ranges from 1 to 15, which indicates the difficulty of collecting a larger sample when trying to process the problems of exercise on the high bar. One of the causes may be different competitive levels, different anthropometric characteristics of the gymnasts, difficult access of measurements at competitions, the large processing procedure of kinematic and dynamic parameters. There are two exceptions when it comes to the sample of participants. In one case, 48 competitors made up the sample, participants of the national championships in Japan and in the US in 1990 (Takei & Dunn, 1997). In the second case, as many as 70 competitors made up the sample, participants of the Olympic Games in Barcelona in 1992 (Brüggemann, Cheetham, Alp, & Arampatzis, 1994).

Several studies treated only one competitor as a sample of participants (Zhou, 2013; Hiley & Yeadon, 2012; Begon et al., 2009, 2008; Hiley, Yeadon, & Buxton, 2007; Kerwin & Hiley, 2003; Yeadon & Hiley, 2000; Yang et al, 1995; Prassas, 1991).

Top competitors are the most studied. However, there are studies that deal with the comparison of top and average competitors (Hiley, Zuevsky, & Yeadon, 2013; Yamada et al., 2002; Chen & Liu, 2000), as well as studies that include progress in training beginners (Yamasaki et al., 2008).

The sample of attempts is very diverse and ranges from 1 to 15 attempts per competitor. The sample of attempts can be systematized in the following way:

1. The sample of participants (one or more gymnasts) perform one successful attempt of the exercise that is the focus of the research (Heinen et al, 2011; Naundorf et al., 2010; Čuk et al., 2009; Hiley & Yeadon, 2008, 2005, 2001; Irwin et al., 2007; Čuk, 1996; Geiblinger et al., 1995; Brüggemann et al., 1994; Park & Prassas, 1994; Yeadon, Lee, & Kerwin, 1990). This is mainly material from official competitions;
2. The sample of participants (one or more gymnasts) perform several successful attempts of the exercise that is the focus of the research (Williams et al., 2012; Frère et al., 2012, 2010; Begon et al., 2009; Yamasaki et al., 2008; Begon et al., 2008; Irwin & Kerwin, 2003);
3. The sample of participants (one athlete) performs an exercise that is the focus of the research in two periods of time (Zhou, 2013);
4. The sample of participants (one or more gymnasts) perform one or more successful and unsuccessful attempts of the same element in order to make comparisons and find errors (Hiley & Yeadon, 2012; Hiley, Yeadon, & Buxton, 2007; Yang et al., 1995; Prassas, 1991).

SYSTEMATIZATION BASED ON METHODS OF ANALYSIS OF MOVEMENT

In most studies, as many as 90%, the kinematic method of analysis of movement was used. Therefore, the kinematic parameters of movement were taken for further data processing, as well as goniometric parameters of mutual relations of various body parts, body relations and relations between the apparatus and space. Systems for obtaining kinematic parameters are very different:

- VICON Motion Analysis System (Hiley et al., 2013; Begon et al., 2009; Begon et al, 2008; Hiley et al., 2007);
- CODA motion analysis system (Williams et al., 2012);
- TARGET high resolution motion analysis system (Irwin et al., 2007; Irwin & Kerwin, 2006);
- PEAK Motus motion measurement system (Chen & Liu, 2000; Geiblinger et al., 1995);
- APAS motion analysis system (Park & Prassas, 1994; Prassas, 1991);
- CONSPORT motion analysis system (Čuk, 1996, 1994)

Some of these systems involve invasive approaches to obtaining kinematic parameters (require the use of markers). They are much more precise, but it is possible to use them only in experimental conditions (VICON, CODA, PEAK). The second group of systems involves no invasive approach to obtaining kinematic parameters (it is necessary to calibrate space and capture movement in this space). This is a slightly imprecise method, but application is possible in competitive conditions (APAS, CONSPORT).

One group of researchers involved with kinematic parameters calculated dynamic parameters by using an inverse dynamic analysis (Yamasaki et al, 2008; Irwin & Kerwin, 2006, Kerwin & Hiley, 2003) and these values were used in the further research procedure.

Direct measurements of the dynamic parameters are very rare. There has been only one paper involving the procedure of application of dynamometric tapes (Knoll et al., 1996). This procedure has proven to be a significantly more precise procedure than calculating dynamic parameters from kinematic ones.

There was also a study that applies the direct measurement of timing of leaving the bar, which is detected by opening and closing the electric circuit, voltage of three volts (Gervais & Pierre Baudin, 1995). However, a much cheaper procedure (video recording) proved to be equally precise.

Some of the researches use methods of computer simulation and optimization of movement (Hiley & Yeadon, 2012, 2008, 2005, 2003, 2001, Begon et al., 2009; Čuk et al., 2009; Yeadon, 1997). In this sense, it is possible on the basis of the recorded movements, to simulate the reaction in changed conditions and predicted the products of these reactions, a more complete movement or new movement. Kinematic parameters are also received, which have the most influence on changes in the execution of some exercises. Today, a large number of software packages are available, with which we can make a simulation of appropriate processes in defined conditions that the researchers can specify.

SYSTEMATIZATION BASED ON ANALYSIS METHODS OF THE RESULTS

In view of this criterion, papers can be systematized based on:

Studies that deal only with the description of kinematic parameters and obtain results in order to determine the model of performing techniques of analyzed exercise. This group includes classified studies that perform a simple comparison of the obtained results between:

a) the same kinematic parameters of different gymnasts who perform the same element (the most frequently – more than 55% of the studies),
b) the same kinematic parameters of different gymnasts who perform different elements (represented to a lesser extent than the previous one – 30%) and
c) same kinematic parameters for different attempts based on successfulness of the same element, realized by the same gymnast (represented in the smallest degree – 15%).

Statistics procedures are not extensively represented in the research of exercises on the high bar. Procedures for the analysis of differences were mostly applied, including:

1. The T - test (6 studies) – to determine the statistical significance of differences between arithmetic means between:
    a) kinematic parameters of different gymnasts who perform the same element (Hiley et al., 2013; Williams et al., 2012; Takei & Dunn, 1997);

b) kinematic parameters of one gymnast, who repeatedly, successfully and unsuccessfully, realized the same element (Begon et al., 2008; Hiley et al., 2007; Yamada et al., 2002). This method determines the cause of the wrong execution.

2. ANOVA (2 studies) – to determine the statistical significance of differences between arithmetic means between:
   a) Electromyographic parameters of different gymnasts who perform the same element (Frère et al., 2012),
   b) kinematic parameters of different gymnasts who perform different elements (Brüggemann et al., 1994).
3. MANOVA (1 study) – for determining the statistical significance of differences of the set of kinematic parameters between different groups of gymnasts who perform the same element (Hiley et al., 2013).
4. The Kruskal-Wallis test (1 study) – a nonparametric test for determining statistical significance of differences between EMG parameters, different gymnasts who perform the same element (Frère et al., 2010).
5. The Pearson correlation coefficient (1 study) – for determining the relationship between kinematic parameters of different gymnasts who perform different elements.

CONCLUSION

Research papers that deal with training on the high bar mainly use methods of kinematic analysis of movements. Methods that calculate dynamic parameters are represented to a much lesser extent. The sample is generally between one and 15 gymnasts, mostly top level. In the COP for evaluation as many as 144 elements are shown that are performed and which can be performed at competitions. Only 18 elements of this number were investigated (based on the collected papers), i.e. 12.5%. This only points to the fact that research of exercises on the high bar, although conducted over a long period of time, are still in their early stages.

Having in mind the perspective and ability to upgrade elements from the third and fourth groups of specific requirements, future research should deal with elements of this group as well as the methodological processes of their training.

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SISTEMATIZACIJA PRETHODNIH ISTRAŽIVANJA VEŽBI NA VRATILU

Istraživanje je sprovedeno sa ciljem da se klasifikuju i sistematizuju sva dostupna istraživanja koja se bave vežbama na vratilu. U ovom istraživanju analiziran je ukupno 41 rad koji obuhvata period od 1990 do 2013. Kada je u pitanju broj tačaka za analizu, uvršćeno je čak 144 elemenata koji se izvode na takmičenjima. Od ovog broja, analizirano je samo 18 elemenata (na osnovu prikupljenih radova), ili 12,5%. Ovo ukazuje na činjenicu da su istraživanja o vežbama na vratilu, čak i kada obuhvataju duži vremenski period, i dalje u početnoj fazi. Istraživanja prvih (izdržaj u zamahu i okret) i petih (doskok) specifičnih zahteva dominiraju. U manjoj meri zastupljena su istraživanja drugih (elementi leta) specifičnih zahteva, a najmanje pažnje posvećeno je trećem i četvrtom zahtevu.

Ključne reči: *umetnička gimnastika, vratilo, sistematizacija*