



BIOMECHANICAL STUDIES ON RUNNING THE 400 M HURDLES

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JANUSZ ISKRA^{1*}, MILAN COH²

¹ Opole University of Technology, Opole, Poland

² University of Ljubljana, Ljubljana, Slovenia

ABSTRACT

Purpose. Biomechanical research conducted on hurdling are the basis for analysis of technique used in running disciplines. However, the 400 m hurdle run is an athletic discipline rarely subjected to individual biomechanical study. The aim of this study was to introduce the various forms of biomechanical studies on this difficult-to-quantify athletic event. **Methods.** In this study, 64 biomechanical articles were assessed, each covering various topics such as kinematics, dynamics, accelerometrics and rhythm knowledge in the both the men's and women's 400 m hurdles. This was conducted with regard to the specificity of studies on the 400 m hurdles, including their types, methods and difficulties. The characteristics of the study were divided, among others, into: physiological effort, centrifugal force, dynamics of movement, stride rhythm, the level of abilities, laterality and type of body build. **Results.** Numerous sources allowed the creation of a general outline of present biomechanical studies. **Conclusions.** Within the context of the conducted analysis on the present state of biomechanical analysis on the 400 m hurdles, a number of basic principles were outlined that could determine the effectiveness of future research possibilities for scientists on the 400 m hurdles.

Key words: 400 m hurdles, biomechanics, kinematic, rhythm

Introduction

Track and field athletics is a discipline of sport that includes nearly 30 different forms of competition that test various fitness (motor) abilities and specific sporting techniques. The group of competitive sports that predominantly require fitness (motor) abilities include all forms of sprint and endurance competition (from the 800 m race to the marathon). The types of track and field events that have a significant (and sometimes dominant) component of testing motor skills and coordination (in sport, both of these components are classified as *technique*) are largely those that involve jumping and throwing.

Hurdling is a form of track and field competition that mixes both motor abilities (with emphasis on speed, dynamic strength and anaerobic endurance) and specific motor skills [1–3]. The first attempts at assessing the technical skills of sprint hurdle races occurred already at the beginning of the 20th century, when Frederick Webster compared the techniques of two hurdlers, the American Alfred Copland and English A.C.M. Croom [4]

The beginnings of such research on running technique were mainly based on observation and images, which included artistic paintings, stroboscopic obser-

vation, and the application of photography, especially time-lapse photography, being the early prototype of timed-sequence sports photography [5].

However, analysis of the techniques used in the hurdle run, on the basis of the above mentioned methods, only took on a larger role much later [6]. Those early attempts of analysis focused primarily on the more basic forms of physical activity in track and field, such as running, jumping and throwing [7]. A return to the imaging methods which evaluate the movement present in hurdling took place only after World War II and continues to this day [8].

The initial forms of assessing the techniques present in hurdle races were focused on sprint distances, such as the men's 110 m hurdles or the women's 80 (100) m hurdles [9–14]. However, the 400 m hurdles was, and still is, overlooked in the biomechanical analysis of track and field sports. Although both hurdle distance are frequently treated as one group of competition, there are fundamental differences between them, as found in biomechanical studies, where the most important of which are provided in Table 1.

The 400 m hurdles is one of the most interesting yet difficult track and field competitions. The characteristics of this form of competition can be made by using such phrases as “relative” or “indirectly related to”. Here are some examples:

1. The 400 m hurdles is still a “relatively” new form of competition, the first records in the 110 m hurdle were first noted only in the mid-19th century; for the 400 m hurdles, only 50 years

* Corresponding author.

Table 1. The specificity of the 100/110 m sprint hurdle and the 400 m long hurdle

Criterion	100/110 m hurdle	400 m hurdle
1. Direction of travel	Straight course run	Straight course run with turns
2. Energy metabolism	Aerobic – non-lactate	Anaerobic – lactate
3. Hurdle technique	One leg (only the right or left leg attack)	Both legs (both right and left leg attack)

later. Women began competing in the 400 m hurdles only in the 1970s.

2. Training for the 400 m hurdles begins “relatively” late, training first begins at the 200–400 m distances and sprint hurdles, only later is professional training for the 400 m hurdles provided
3. The 400 m hurdles is a “relatively” high-speed distance, “relative” to characteristics of endurance
4. Taking into consideration the motor and technical aspect, it can be stated that the 400 m hurdles is a form of competition that “relatively” tests fitness, which is “relatively” dependent on the technical ability to attack the hurdles

It may be that perhaps that due to the complexity of this competition, scientists which conduct biomechanical research on this sport avoid studies that involve the 400 m hurdles. In many instances, in view of the small number of publications related solely to the 400 m hurdles, this discipline was subject only to comparative analysis with sprint distances.

Therefore, the aim of this work is to present the state of biomechanical studies of the 400 m hurdles. It will take into account the historical aspect of these studies as well as the current problems associated with the objects, methods and types of analyses.

Material and methods

This study could be considered topical. In the analysis conducted herein, literature related to the wide array of biomechanical problems present in hurdling was used. In addition, a survey that was conducted by this team on a group of hurdlers during 1996–2008 was considered [2, 6, 15–22].

Analysis of the literature related (directly or indirectly) to the 400 m hurdles found that there are three basic types of approaches used (Tab. 2).

In race research, the main kind of analysis involves studying accelerometrics and study of so-called rhythmic stepping, which is performed between successive hurdles. Race analysis of the 400 m hurdles focus largely on the world’s most important competitions, such as in the 2000 Olympic Games in Sydney [23]. In some cases this kind of analysis is conducted on athletes competing at a lower level [24]. However, conducting research on the kinematic structure of race conditions is quite difficult and not very popular [25].

The most significant, from a scientific perspective, is research conducted in field conditions, as a control

element of training organized at a stadium. An analysis of the literature finds that, in 400 m hurdles, there is lack of standardized test procedures, and that those studies focused only on training and research solutions aimed at substituting classic forms of competition for testing purposes. In this group of studies, research can be found on 400 m hurdles test training [26], ideas on the concept of consecutive running [27] and on the concept of running at intervals [21, 28]. The details are presented in Table 3.

The smallest group of studies conducted on the 400 m hurdles are those of laboratory analysis. They focus mainly on issues related to strength as a static condition [29].

The difficulties in organizing studies on the movement structure and dynamics in the 400 m hurdles are due to a variety of reasons (Tab. 4). The regulations of the race (on different tracks, the positions of the hurdles in different spots), the specificity of training for competition (races are only in the summer) and a number of methodological dilemmas significantly impede conducting such tests.

The organization of biomechanical research on the 400 m hurdles requires a broader look at the specificity of both motor and technical skills in competition. It is difficult to directly transpose the results of studies conducted on the 110 m hurdles to the 400 m hurdles. The determinants of such biomechanical studies are presented in Table 5.

Attempts at conducting biomechanical analysis of running in the 400 m hurdles were concerned about previous research and studies connected with the improvement of the methodology and practical application of the results of empirical analysis to sports training. This problem can be presented as several points, some of which are emphasized below.

1. Methodological problems connected with biomechanical studies on the 400 m hurdles

An assessment of running techniques used in hurdles is based on biomechanical studies that are mostly focused on sprint distances, the men’s and women’s 100/110 m hurdles [6]. Started in the 1950s, attempts at objectively assessing the techniques of sprint hurdle races in the 1990s led to a discussion on the validity and reliability of the selection of the parameters that were used to assess the appropriate style of running [30–33]. Studies conducted on the 400 m hurdles pri-

Table 2. The types of biomechanical studies conducted on the 400 m hurdles

No.	Type of study	Characteristics	Sources
1.	Races	Analysis conducted during competition, most commonly the Olympics and in world, European, national or regional championships	8, 9, 10, 11, 17, 23, 24, 35, 46, 49
2.	Training (field)	Analysis conducted during training, frequently simulating competition	13, 14, 15, 16, 19, 28, 30, 31, 32, 36, 37
3.	Laboratory	Analysis supplemented with physiological and biochemical methods, analysis based on motor theory (e.g., from feeling the so-called sensation of rhythm) performed on a treadmill or (worse) on a ergometer	29, 38, 42, 43, 44, 54, 60, 61, 64, 67

Table 3. The organization of biomechanical research on the 400 m hurdles

Author, year, source	Type of analysis	Research procedure	Subjects
Röll, 1976 [26]	Cinematic and dynamographic analysis	Hurdles in the 3 rd , 5 th , 9 th position in the third lane (400 m hurdles run based on standard regulations)	women (n = 8), low-level athletes
Schwartz, 1990 [28]	Cinematic and dynamographic analysis	Racing with a 7-step rhythm (19 m distance) in two different variations: 1) at rest (3 hurdles) + fatigue (interval of 2 × 3 hurdles) 2) attacking the hurdles with both right and left leg	men (n = 6), high-level athletes
Iskra et al., 2000 [21]	Cinematic analysis, analysis of training loads	200 m run (in 24 s), 1 min break as well as a run over 5 hurdles (91 cm, distance 17.50 m) – the 4 th hurdle was filmed	European champion in the 400 m hurdles
Dakin, 2008 [27]	Analysis of running speed (“hurdles effectiveness”)	Running over hurdles placed on a straight (2–4); speed cameras positioned 5 and 10 m before hurdle nr. 3, the analysis included 2–3 runs of each attacking leg	a project for the athletes of a national team

Table 4. The difficulties involved in conducting biomechanical studies in the 400 m hurdles

No.	Difficulty	Specific questions
1.	Methodological	– number of times to repeat the run (a short distance is not a problem, but 9–10 hurdle runs?) – what is important, the splits, number of steps, or other kinematic parameters? – are tests performed during training reflected in true competition?
2.	Logistical	– how to conduct studies in winter conditions? – how to invite the best players during a variety of preparations?
3.	Regulations	– how to organize the study, each run performed on a different track? – how to organize analysis in field studies under conditions different from race regulations?

Table 5. Factors that determine the organization of biomechanical research on the 400 m hurdles

No.	Aspect	Characteristics
1.	Physiological work	running at the beginning (non-lactate) and second (lactate) half of the distance
2.	Centrifugal force	running on a straight course and with turns (on lanes 1 to 8)
3.	Running dynamics	running the 400 m hurdles involves 10 take-offs and landings
4.	Running rhythm	running the 400 m hurdles requires maintaining the proper proportion of steps, between those steps taken and the “rhythmic units” (the distance between hurdles)
5.	Lateralization	attacking the hurdles with both right and left legs
6.	Preparing physical fitness	the ability in effectively attacking the next hurdles depends on the level of motor abilities, mainly speed, strength and endurance
7.	Body build	the rhythm of the steps depends on an athlete’s somatic build, mainly his body height and leg length
8.	Coordinative abilities	connected with rhythmic ability and the ability to maintain the so-called hurdle rhythm

marily used **accelometric analysis** (see below); only in a few cases were efforts made at determining the methodological basis of biomechanical studies [21, 28]. These attempts, however, failed to arrive at clearly formulated conclusions as to the selection of the best options for testing in accurate, reliable and standardized conditions.

2. The selection of **kinematic parameters** in the evaluation of running techniques used in the 400 m hurdles

The most frequently used parameters in the evaluation of running techniques in hurdles were from movement kinematics. Such studies appeared during the 1980s and 1990s [9, 10, 34–36] and were highly diversified (both methodologically and thematically). The search for relevant factors that could assess the structure of hurdles running were concerned with several to several dozen parameters. However, in a few studies conducted on the 400 m hurdles, some of the selected parameters do not seem to be representative in assessing the effectiveness of various running techniques. In studies conducted by Iskra and Bacik [37], four basic parameters (mainly **different stride lengths**) were included; in Bollschweiler [35], 14 length and angular parameters were selected. The current state of research on the **kinematic parameters of hurdles running (especially in attacking hurdles)** for the 400 m distance does not allow for the strong selection of accurate and reliable timing, spatial and time-space parameters.

3. Dynamometric tests and the specificity of the 400 m hurdles

Research on ground reaction forces by using tensometric and piezoelectric platforms provides an indispensable element in biomechanical studies in track and field athletics, including hurdling. The increasingly widespread use of the devices produced by the Swiss company Kistler allows one to obtain relevant information on running the 400 m hurdles. As a general characteristic of the competition, the 400 m hurdle race is composed of a sprint with the need of jumping over 10 obstacles. Each take-off and landing is an indispensable part of the 400 m hurdles [18]. In empirical studies conducted on hurdling, dynamometric analysis was conducted by Röllä [26] and was also considered by the Polish hurdlers Dworak et al. [38].

4. The energy specificity in the 400 m hurdles and changes in hurdling technique

Scientific analysis on the 400 m distance (also with hurdles) found that maximum effort performed in a time less than 1 min was dominated by transforma-

tions of **an aerobic-lactate character with some non-lactate** (typical in sprint distances) and aerobic changes, typical in endurance races [39–41]. Attempts at organizing training course in the 400 m hurdles in accordance with the demands of energy exertion were presented earlier by Iskra [18]. Charatimowa [42] as well as Gupta et al. [43] noted that the effort in the 400 m distance, in terms of energy, is slightly larger than in the 400 m hurdles. Changes in the biomechanical parameters during a sprint (at intervals of 100–200–400 m) were presented by Nummela et al. [44].

The different stages of the 400 m hurdles race are presented in Table 6. These data indicate that the evaluation of running techniques in the **400 m hurdles should include two fragments and a beginning phase** (hurdles 1–5) **as well as fatigue phase** (in the second part of the run). Preliminary analysis of the above problem were conducted by Ikwin et al. [45], in the 110 m hurdles, and by Schwirtz [28], in the 400 m hurdles. The results of the studies found that technique used in the first and final part of the race can vary considerably.

5. **Accelometric research as the basis for biomechanical research** in running the 400 m hurdles

Biomechanical analysis on running the 400 m hurdles has been from the beginning connected with the evaluation of hurdling techniques through the use of sequence photography and research performed on time differences in certain parts of the race. Accelometric analysis constitutes a major part of the publications published to date that merge the 400 m hurdles and the method of biomechanical research on human movement. Since the 1968 Olympic Games in **Mexico**, analysis in the changes of running speed in the 400 m hurdles have become an indispensable part of scientific investigation in this form of competition [24, 46]. These studies have become a sort of inspiration for studies conducted later in analyzing athletes of a lower level [24, 47].

Analysis in the changes of speed (and mainly its reduction after 150 m) are significant in the organization of sports training. **Assessment of the differences between running “tactics”** at different levels (juniors-seniors, women-men) is only the beginning for further research. Additional questions should be asked on the assessment of which parts of the run can be the most significant in winning the race. Not only are absolute results important (finishing times), but also the impact of deceleration during the race.

6. **Running “rhythm”** in the 400 m hurdles as the most used and most enigmatic term in competitive hurdling

The concept of **rhythm**, understood within the theory of **motor coordination**, is clearly formulated.

Rhythm in hurdling is a term that is found more in practical training and competition than in scientific literature. A review of the definition that is used to define “hurdling rhythm” in the 400 m hurdles was conducted by Iskra [47] and distinguished three variants:

1. Rhythm is the number of steps performed in each successive “rhythmic unit”.
2. Rhythm as the number of steps in relation to the time spent covering the specific parts of the race (frequency of steps).
3. Rhythm is the optimized (in terms of the number of steps and running pace) form of running the entire distance in the shortest possible time by taking into consideration the level of preparation of one’s motor skills, technique and somatic build.

This relatively expanded definition illustrates the complexity of “rhythm” in the 400 m hurdles. The number of steps taken in the nine successive distances between the hurdles implies using both the right and left legs to attack the hurdles, under different conditions of energy-related effort (rest-fatigue) and the course structure (straight or turn). Changes in the attacking legs of hurdlers with different rhythms are presented in Table 6 [22].

7. Attacking hurdles on the straight and turns – the problems of training and scientific analysis

Running the 400 m hurdles is an alternating combination of attacking hurdles on the straight and turns of the track. The running distance after the turn is considered one of the two most difficult parts of the race, the acceleration phase and the first phase of fatigue due to anaerobic work, closely tied with the changes of step rhythm (Tab. 6).

In the more than 100-year history of biomechanical research in sport, there is still no study which analyzes the problems of different techniques in hurdling on the straight and turns. The question of differences in the biomechanical parameters of running on the different parts of the course have only been conducted on a flat distance of 400 m [48]. If we were to add the level of fatigue (e.g., during the second turn) as a factor to the entire distance, the need for research on the techniques of attacking hurdles on turns appears to be even more necessary.

8. Lateralization (functional asymmetry) – not only scientific problems, but also of sport

The aspects of the human body’s functional asymmetry are present in many sports that require the effective use of, mainly, two limbs (e.g., the left and right legs in soccer, the left and right hand in basketball or boxing). An excellent example of track and field athletic competition that takes the problem of lateralization

Table 6. Variants in step rhythm when running the 400 m hurdles within biomechanical studies in racing conditions

Hurdle	Rhythmic variant			
	A	B	C	D
1	L	L	L	L
2	L	L	P	L
3**	L	L	L	L
4	L	L	P	L
5	L	L	L	P*
6	L	P*	P	L
7	L	L	L	P
8	L	P	P	L*
9**	L	L	L	L
10	L	P	P	L

A – homogeneous rhythm (odd)

B – single alternating rhythm

C – homogeneous rhythm (even)

D – double alternating rhythm

L – attacking left leg, P – attacking right leg

* changes in the running rhythm

** jumping hurdles 3 and 9 has a similar movement structure (attacking left leg), regardless of rhythm choice

Figures in bold denote change in the running rhythm.

into account is the 400 m hurdles. It is known that the “dominant” lower limb in hurdling is the left leg, which minimizes the negative effects of centrifugal force.

The specificity of the 400 m hurdles excludes (except in certain cases) the possibility of attacking the hurdles with only one lead leg. This is connected to instances of 13- and 15-step rhythm. However, such a concept is not entirely optimal within the context of a runner changing stride length. Due to increasing fatigue in the second part of the 400 hurdles race not only is there a reduction in speed, but also the hurdlers’ stride length (from 3.73 cm to 3.39 cm). Therefore it appears that it is necessary for the hurdler to change his attacking leg, and by changing the attacking leg, we need to be aware of significant changes in the training process of hurdlers. Similar to how basketball and handball players, in certain circumstances, need to throw using either their right or left hand, the same applies for running in the 400 m hurdles, which involves using both legs for attacking hurdles.

Research conducted by Iskra and Walaszczyk [22] and Iskra [49] found that hurdlers in the 400 m hurdles exploit their strength in different ways (with their “dominant” leg) as well as using their weaker (“alternative”) leg in different ways when attacking hurdles. However, the problems of the functional differentiation of the “attacking leg” have been more closely examined by trainers than by sport researchers.

9. The strength and direction of wind and changes in running rhythm in the 400 m hurdles

Accelometric research and cinematic analysis on the 400 m hurdles does not take into account the ef-

fect of wind speed and direction on the choice of the attacking leg, running rhythm and, consequently, on attacking hurdles. An example of the importance that weather conditions (in this case wind speed and direction) have on tactics and technique used in the 400 m hurdles was during the elimination trails during the Olympic Games in Sydney, when the wind force on the last straight was more than -4 m/s. Previous analyses on the impact of wind speed and direction on one lap race results were only conducted on the straights of a track [50–52].

Analyses in the changes of technique between the straights, by taking into consideration the impact of wind, seems to be necessary from the standpoint of practical training. This is particularly important in competition, which can take place in a variety of directions and on tracks of varying curvature. Some of the most radical changes are proposed by Mureika [53], who demanded the recalculation of competition results in sprint races by including wind strength and the height above sea level of where the competitions took place. Questions on the impact of weather on the way (style, technique) hurdling is performed still remain open. Recent analysis conducted by Quinn [53] provides interesting data on hurdling on different tracks during the same (measured) wind speed.

10. Comparison of the specificity of the 400 m hurdles to other track and field competitions

The history of running the 400 m hurdles has become a derivative of sprint hurdles race (110 m hurdles) and the 400 m dash. Comparisons (including biomechanical) among these three types of competitions have become popular in the evaluation of techniques in running the 400 m hurdles in the 1970s [55]. The understanding of the 400 m hurdles as an extended form of the 110 m hurdles have for long hindered biomechanical studies comparing it to completely different distances. Moreover, all studies on hurdling frequently combine both distances as one. Recent studies on the 400 m hurdles suggest that it is (mainly due to the obstacles present) connected more to the 3000 m [25, 26] steeplechase run. Thirty years of physical education progress was not enough to clearly state that the

400 m hurdles is a specific form of competition, distinct from the 110 m hurdles, 400 m dash or the 3000 m steeplechase. The main differences are provided in Table 7.

11. The problem of motor control and the specificity of hurdles

The effort required in hurdling is connected to the repeatability of specific movement sequences in jumping over the hurdles and then running to the next obstacle. The so-called rhythmic unit [3, 57], in the case of running the 110 m hurdles, are associated with running in a 3-step rhythm, while running the 400 m hurdles requires a variable number of steps (12–19). Analysis of the movement sequences is characteristic of research in the field of motor control, where it is usually associated with movements with a limited aspect of mobility (e.g., typing, playing the piano, etc.) [58, 59].

Comparison of the movement sequences in the range of the so-called fine motors have in fact much in common with the rhythmic units present in the 400 m hurdles. Such a hypothesis was used in hurdles research conducted by Hay and Schoebel [60]. Clearing obstacles of low height during walking and running is a significant part of empirical research that borders with motor and biomechanical theory. Referring the experience of hurdlers in clearing obstacles finds that this group of track and field competitors can provide a stimulus for wider, non-sport empirical analysis [61, 62].

The problems associated with the use of biomechanical methods in controlling the training as well as assessment of competition in the 400 m hurdles is connected to numerous problems taken from the wider understood aspect of physical culture. Comprehensive analysis that takes into account a wide range of purely biomechanical problems as well as the necessary information on the theory of sports training, stress parameters, anthropometric measurements, etc., belong to the biomechanical studies of the past. This applies not only hurdling, but all professional sports.

Within the evaluation of the specific problems connected with the biomechanics of running the 400 m hurdles, several important aspects need to be taken into account:

1. The differences in the **method of teaching hurdling techniques** (e.g., analytic, synthetic, and recreational) that have an effect on improving hurdling techniques, assessed on the basis of selected kinematic and dynamic parameters [63].
2. **The effect of body build** (e.g., height or leg length) on selecting the optimal running rhythm or hurdling technique [64].
3. Changing *sports training* (which includes measures used in the improvement of motor skills

Table 7. Similarities and differences among the running events of track and field with the 400 m hurdles

Parameter	400 m hurdles	400 m dash	3000 m steeplechase
Length of effort	–	+	–
Obstacle height	±	–	±
Distance between obstacles	–	–	–
Training	±	±	–

“–” – significant difference, “+” – substantial similarity, “±” – different interactions

Table 8. A schematic for biomechanical studies on the 400 m hurdles (project)

Phase	Characteristics
1. Training	the volume of technical training, the proportion of training measures classified as “motor” and “rhythmical” (in hurdling)
2. Competition racing	assessing the changes in running rhythm, analysis of the time spent on each section of the course
3. Laboratory and field testing (dependent on the cooperation between the coach-researcher)	cinematic analysis of running in each of its phases: – running with the right and left attacking leg – running on the straights and turns – measurements during the beginning and final (fatigue) running phases – measurements before and after rhythm change
4. Analysis of running technique	assessing the key elements of techniques, whether positive or negative
5. Training modification	qualative and quantative changes
6. Repetition of competition race	evaluation of positive and negative changes

and technique) and the desired changes in hurdling technique [65].

4. Changes in the *regulations* of hurdling in terms of biomechanical analysis [66, 67]. There are many problems associated with biomechanical analysis performed on the 400 m hurdles. The past efforts of researchers could be considered being partial, and perhaps, even, rudimentary. Attempts at comprehensive research on hurdling have, so far, included only the 110/100 m hurdles [13, 56, 68]. There is a necessity in developing a comprehensive study on only the 400 m hurdles, with the proposal for such a study provided in Table 8.

Conclusion

Within the context of the conducted analysis on the present state of biomechanical analysis on the 400 m hurdles, a number of basic principles can be stated that could determine the effectiveness of future analyses.

- The recognition of the 400 m hurdles as a specific, autonomous form of track and field competition, which differs from sprint hurdles performed on the track straight
- The conducting of research on the kinematic physical movement structures present, based on both training and competitive conditions
- The search for methods to assess the movement techniques in training conditions (field testing)
- The search for parameters (time, kinematic and dynamic) that can be used with a high degree of accuracy and reliability
- The conducting of a comprehensive analysis that takes into account the expectations of researchers of different disciplines, as well as the knowledge of trainers

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Correspondence address

Janusz Iskra
Wydział Wychowania Fizycznego i Fizjoterapii
Politechnika Opolska
ul. Prószkowska 76
45-758 Opole, Poland
e-mail: j.iskra@awf.katowice.p