Janusz Iskra[1]*
Milan Čoh[2]

A REVIEW OF BIOMECHANICAL STUDIES IN HURDLE RACES

PREGLED BIOMEHANSKIH RAZISKAV TEKA ČEZ OVIRE

Abstract

Hurdle runs belong to that group of track and field events in which superb performance is achieved by combining motor preparation with a champion's hurdle technique. The technique of the hurdle run not only involves clearing ten hurdles but also running prior to the first hurdle and running between the other hurdles. The aim of this study is to introduce the range of hurdle biomechanical investigations. Kinematic analysis constitutes the broadest range of studies in the field of biomechanics. Kinematic studies are commonly ranked in the following three categories: continual studies, cross-section studies, and comparative studies. Most studies in the field of the kinematics of hurdling concern sprint events, especially men's 110 m hurdles. The limited focus on 400 m hurdles can be attributed to the specificity of the event. Many biomechanical studies are composed of speedometric and accelerometric researches. Among biomechanical studies of hurdling an essential part is played by analysis that takes advantage of a dynamographic method. An electromiographic method is rarely used in the biomechanical studies of hurdlers. The future of biomechanical studies of hurdling is seen as moving in the direction of complex studies and comprehensive research programmes. These studies not only involve various methods of biomechanical analysis but information is also derived from other fields of sports and exercise such as physiology, the biochemistry of exercise or the theory of sports training.

Key words: hurdle runs, biomechanics, kinematics, dynamographics, accelerometrics.

Izvleček

Teki čez ovire spadajo v skupino atletskih disciplin, pri katerih odlična izvedba združuje motorično pripravo in vrhunsko tehniko teka čez ovire. Tehnika teka čez ovire ne obsega le premagovanja desetih ovir, temveč tudi tek pred prvo oviro in tek med ostalimi ovirami. Namen te raziskave je predstaviti zbirko biomehanskih raziskav teka čez ovire. Kinematične raziskave so običajno razvrščene v naslednje tri kategorije: kontinuitetne, medsekcijske in komparativne raziskave. Največje število raziskav s področja kinematike teka čez ovire obravnava sprinterske discipline, in sicer predvsem tek čez ovire na 110 metrov za moške. Zaradi svoje specifičnosti, je manjše pozornosti deležen tek čez ovire na 400 metrov. Veliko število biomehanskih študij sestavljajo študije preučevanja hitrosti in pospeškov. Bistvenega pomena pri biomehanskih študijah tekov čez ovire je analiza, ki temelji na dinamografski metodi. Elektromiografska metoda je v biomehanskih študijah tekov čez ovire redko uporabljena. V prihodnosti pričakujemo, da bodo biomehanske raziskave tekov čez ovire postale del kompleksnih študij in izčrpnih raziskovalnih programov. Te raziskave ne vključujejo le različnih metod biomehanske analize, temveč ponujajo tudi podatke, ki izhajajo iz drugih športnih in vadbenih področij kot so na primer fiziologija, biokemija vadbe ali teorija športnega treniranja.

Ključne besede: tek čez ovire, biomehanika, kinematika, dinamografija, merjenje pospeškov

[1]***University School of Physical Education, University of Katowice, Poland***
[2]***Faculty of Sport, University of Ljubljana, Slovenia***

Corresponding author:
University School of Physical Education
Ul. Mikolowska 72A, 40065 Katowice, Poland
Tel.: +4832 2075371
Fax: +4832 2075100
E-mail: j.iskra@awf.katowice.pl

INTRODUCTION

Hurdle runs constitute a group of four track and field events divided into high hurdles i.e. 100-m hurdling sprints (women) or 110-m hurdling sprints (men) and intermediate hurdles (400-m). The tradition of male hurdle runs dates back to the second half of the 19th century, whereas with women it dates back to the 1920s (Quercetani, 1990). In each stage of its development the event was regarded as a set of closely connected motor skills and technical abilities. From among those studies dealing with the theory and practice of hurdling, it is difficult to sort out which factors play a decisive role in achieving success. In most studies it is pointed out that what matters is the complementary development of motor skills (speed, endurance and strength) and the technique of clearing ten hurdles (Doherty, 1953; Hoke, 1943; McFarlane, 1988; Otrubiannikow & Razumowski, 1988; Webster, 1929).

The hurdling technique has usually been described as a way of clearing ten hurdles of 84 to 107cm in height. Obviously, in the evaluation of a hurdle clearance technique one must indicate its particular phases such as: starting out of the blocks and coming to the first hurdle, running between the hurdles, and finishing or coming out of the last hurdle. Hurdling or, to express it more precisely, hurdle clearing is a kind of complex motion of a dynamic character presented in physics textbooks as a classic example of applying the laws of physics to sport (Czistiakow & Brejzer, 1971; Dyson, 1970; Ecker, 1971; Schwirtz, 1990).

Hurdle-clearance techniques

The first attempts at evaluating hurdle-clearance techniques involved an analysis of single pictures or a sequence of frames. This primary stage of kinematic analysis was combined with experts' opinions. The very first analysis of hurdle clearance was conducted by Montaque Sherman. This outstanding sprinter, and later in his life an eminent lawyer and sports activist (Lovesey, 1980), carried out an estimation of the hurdling technique after the first match in the history of athletics (Sherman, 1888). In spite of his lack of research experience, he managed very pertinently to distinguish the style differences in the four competing hurdlers. Those initial analyses of hurdling were continued by Boyd Comstock (1924) and Frederick Webster (1929). The former would depict the technique of Alfred Copland – the best American hurdler of the 1890s, whereas the latter focused attention on the characteristic style of hurdle clearance displayed by the harbinger of English hurdling A.C.M. Croom from Oxford (Webster, 1929). Croom was the first hurdler to introduce the classical hurdle-clearance style: an extended lead leg (in the knee articulation) and a three-stride rhythm pattern.

Estimating the hurdling technique by means of single photographs has constituted the basis for the development of this event throughout history (Kolejwa, 1961; Koszewski, 1990; Quercetani, 1990). Yet this simplest method of hurdling estimation has not been entirely dismissed. Over 40 pages of the Italian periodical 'Atleticastudi' a detailed analysis of the hurdle technique in the 100-m and 110-m hurdles was presented with the aid of frames showing hurdlers at various competition levels (Bedini, 1988).

However, the analysis of hurdling techniques by means of single frames was merely an introduction to more precise and complex studies. They became feasible with the development of a kinematographic method at the turn of the 19th and 20th centuries, which enabled kinograms to be worked out. According to a historical analysis by A. Cappozzo concerning the development of kinematography for the needs of physical culture, the most significant studies involving the investigating of gait and running were conducted by French national E. J. Da Marey and Californian E. Mugbridge (Cappozzo, 1985). Taking the comprehensive study by J. D. Wilkerson into account it might be concluded that the key player in developing the kinematographic (motion picture) method was Ruth Glassow (in the scope of P. E.) and Thomas Cureton (Wilkerson, 1997).

It was Cureton who, using the motion picture method, worked out the mechanics of many a sports discipline including track-and-field athletics (Cureton, 1939). However, the greatest impact as regards the use of kinematic analysis (in this case sprint running) was made by the American scientist Wallance Fenn. In 1929, his first article concerning biomechanics appeared in a scientific magazine (Fenn, 1929). In collaboration with the Eastman Kodak Company, Fenn used motion pictures to estimate velocity, kinematic energy and strength (Wilkerson, 1997). It is difficult to say when the very first kinogram of hurdling was elaborated. In the 1950s and 1960s kinograms of hurdlers were rife in many a textbook on the theory of sport. In 1951 the publishing company of the Chief Committee for Physical Culture introduced kinograms of the best Polish and Soviet hurdlers in several-page leaflets (Kolejwa, 1961). The estimation of the hurdle technique exclusively by means of kinograms was introduced by Tony and Elfriede Nett in 1968. 15 kinograms in the 110-m hurdles, 11 kinograms in the men's 400-m hurdles and 8 in the women's 80m hurdles were presented in a 62-page study (Nett & Nett, 1969). The significance of motion pictures in hurdle technique analysis is still being appreciated by many authors. In the 110-m hurdles particular attention should be paid to the kinograms of Olympic champions, World and European champions as well as world-record holders (Brejzer & Kajtmazowa, 1979; Buffault, 1979; Hommel, 1985, 1988; Hommel & Arnold, 1993). Motion pictures in the area of women's 100m hurdles have been analysed by Hommel and Veron (1991), whereas in the scope of 400-m hurdling that has been done by Susanka (1993), Brejzer (1986), as well as Hommel and Schmidt (1990). Only in exceptional cases were superior performers not taken into consideration. Oberbeck (1972) and Artiuszenko and Bieglecow (1975) presented the kinograms of children performing hurdle runs. In the light of hurdle technique alterations it is crucial to investigate motion pictures regularly (periodically). Such a comparative analysis of the world-record holder C. Jackson, covering his competitive period from 1986 to 1994, was made by Hommel (1995).

Kinematic structure of hurdling

Analyses of the kinematic structure of hurdling constitute the largest group of biomechanical studies in this event. When starting a vast programme of biomechanical studies of hurdlers, Grimshow et al. (Grimshow, Marar, Salo, Logden, & Vernon, 1994) divided kinematic analysis into three categories: cross sectional, longitudinal and comparative.

Comparative studies deal with selected groups of hurdlers – the higher the level of hurdling performance, the smaller the number of subjects. In this group of biomechanical analysis, investigation sessions take place only at one time and the possibilities of fully exploiting them are limited. Obviously, long-term (longitudinal) studies that cover a few research sessions are more useful.

The small number of this kind of analysis stems from arrangement difficulties. Gathering a group of hurdlers for a few consecutive sessions (sometimes on a yearly basis) creates the chief obstacle that is in principle impossible to overcome. Such an enterprise failed even in the widely-conducted studies of Mann (1985) and Grimshaw, Marar, Salo, Logden, and Vernon (1994). However, thanks to the possibility of co-operating with the Polish National Team of hurdlers Iskra managed to investigate several years of alterations of the kinematic parameters of the hurdle stride in the best 110-m hurdlers (Iskra & Bacik, 1997) and 400-m hurdlers (Iskra, 2001; Iskra & Bacik, 1999).

A considerable amount of kinematic studies consists of comparative analyses. In that group of studies, hurdlers of different sports levels are mainly investigated (Iliew & Dimitrow, 1978; Kampmiller, Slamka, & Vanderka, 1999; Marar & Grimshaw, 1994; Shi, 1998). One frequently encounters analyses of kinematic parameters comparing female hurdlers with their male counterparts (McDonald & Dapena, 1991a, 1991b; Mero & Luhtanen, 1986; Salo & Grimshaw, 1998; Salo, Grimshaw, & Marar, 1997; Salo, Grimshaw, & Viitasalo,1997). However, the abovementioned way of analysis is often disputable mainly due to the differences in hurdle competition rules between men and women (for instance, a 23cm difference in the height of the hurdle). Studies comparing hurdling with sprinting have two aims. First, they allow finding out to what extent hurdling can be regarded as sprint running. Second, they give practical advice on what the hurdler's run should look like so that their velocity can become comparable to the sprinter's velocity (Godik, Szalmanow, & Poltarapawlow, 1993; Ito, 1997; McDonald, 2002; McLean, 1994).

From among the four hurdle events, greatest interest in those studies involving biomechanics has been paid to 110-m hurdles (Godik, Szalmanow, & Poltarapawlow, 1993; Iliew & Dimitrow, 1978; Iliew & Primakow, 1978a, 1978b; Iskra, Bacik, & Krol, 1998; LaFortune, 1987; Miskos, 1988; Peltola, 1996; Ren, Niug, & Yang 1998; Salo, Peltola, & Viitasalo 1993; Schlüter, 1981; Steben, 1985; Tsarouchas, Papadopoulos, Kalamaras, & Giavroglu 1993; Ward & India, 1982; Wilimczik, 1972). This is most likely connected with a certain convenience of a technical nature because the event is run along a straight line (which makes filming easier). In fact, the same observation might be made as regards women's 100-m hurdles. The main authors investigating this area have been: McInnis (1982), Kollath (1983), Li (1990a), Rash, Garrett, & Voisin (1990), Čoh & Dolenec (1996), Salo & Grimshaw (1996), Čoh, Kastelic, & Pintarič (1998), and others.

As far as the kinematic structure of motion is concerned the 400m hurdles event is much less frequently investigated. The inconvenience of carrying out investigations mostly results from the special character of the event. In contrast to the 100 and 110m hurdles, 400-m hurdles is also performed around curves making filming particularly demanding. Moreover, what from the organisational point of view constitutes a decisive factor; incrementing fatigue in the second part of the distance makes the precise pre-determination of the lead leg dubious (Iskra, 2001). Thus, the kinematic parameters of male hurdlers over the whole distance are rarely assessed (Kaufmann, 1976; Röll, 1976); simulated fragments are much more frequently used (Iskra & Bacik, 1999; Iskra, Bacik, & Krol, 1998; Schwirtz, 1990). Further, in that respect women's 400-m hurdles is completely devoid of investigation.

In classifying kinematic studies of hurdle events one must clearly take *the range of movement* into account. It usually includes the hurdle step or hurdle clearance i.e. the phase of movement from the take-off prior to the hurdle to the touch-down after the hurdle. Performing this 4-m section of the event is frequently associated with the hurdling technique, which seems to be a highly erroneous view. The benefit of such a narrowed analysis is its simplicity and considerable accuracy. Yet a more serious challenge is confronted by those studies involving the so-called rhythmic unit. It is comprised of the hurdle stride and three strides between the hurdles. The most frequently conducted analysis concerns 100m and 110m hurdles with three strides between the hurdles (landing, recovery and preparation). This type of study has been carried out by Iliew and Primakow (1978a, 1978b), Iliew and Dimitrow (1978), McDonald and Dapena (1991a, 1991b), McDonald (2002) and many others.

There is a scarcity of papers concerning the kinematic structure of the first part of hurdling, namely the strides prior to the first hurdle (McInnis, 1982; Rash, Garrett and Voisin, 1990). There is also a lack of studies focusing on the start out of the blocks. To date this area of kinematic studies has been limited to sprint runs. Successful complex studies (going into the first hurdle, hurdle clearance and hurdle strides) have been conducted in Ljubljana (Čoh & Dolenec, 1996; Čoh, Kastelic, & Pintarič, 1998). However, they only involved a single case of an Olympic vice-champion in the women's 100-m hurdles.

The significance of the results of kinematic structure analysis results from a judicial selection of *subject hurdlers*. In that respect, one must take into consideration both the number of subjects and their levels of performance. Arranging a sizeable group of elite hurdlers is usually impossible. It is the consequence of the special character of their training involving frequent sports camps and the individualisation of elite hurdlers' preparations (Iskra, 2001). Bearing this in mind, an analysis of individual cases is often undertaken with reference to superb hurdle performers (Čoh & Dolenec, 1996; Iskra & Bacik, 1999; Iskra, Bacik, & Krol, 2000; Li, 1990a, 1990b; Ren, Niug, & Yang, 1998; Tsarouchas, Papadopoulos, Kalamaras, & Giavroglu, 1993). Such analysis might prove to be very significant in practice on the condition that it is repeated regularly. Taking into account the number of subjects from 2 to 6, sport biomechanists restrict themselves to presenting individual marks (two subjects – LaFortune (1987), Rash, Garrett, and Voisin (1990), Marar and Grimshaw (1994), Kampmiller, Slamka, and Vanderka (1999), four subjects – Salo and Grimshaw (1998), Čoh and Kampmiller (2001), or nine subjects – Salo and Grimshaw (1996). A greater number of subjects allows the averaging of the results: Iliew and Primakow (1978a, 1978b) – 38 male hurdlers, Iwkin, Jegorow, and Žukow (1987) – 23 male hurdlers and 9 female ones, Godik, Szalmanow, and Poltorapawlow (1993) – 10 male hurdlers, Iskra (2001) – 15 male hurdlers. The information concerning the numbers of subject hurdlers in selected studies is presented in Table 1.

The drawing of final conclusions is dictated by the *performance level* of the subject hurdlers. The best hurdlers in Europe and the world were investigated by Iliew and Dimitrow (1978); Iliew and Primakow (1978a, 1978b) as well as Mero and Luthanen (1984, 1986).

Most sport biomechanists analyse the technique of home runners, frequently those of outstanding performance. McDonald and Dapena succeeded in working out a kinematical model of hurdling on the basis of participants at the 1988 American Olympic trials (McDonald, 2002; McDonald & Dapena, 1991a, 1991b). British hurdlers were examined extensively by a team consisting of staff members like, among others, Paul Grimshaw and Leith Marar (Grimshaw, 1997; Marar & Grimshaw, 1994; Salo, 1999; Salo & Grimshaw, 1996, 1998; Salo, Grimshaw, & Marar, 1997; Salo, Grimshaw, & Viitasalo 1997). These authors took advantage of Aki Solo's experiences with Finnish hurdlers (Salo, Peltola, & Viitasalo, 1993). A comprehensive analysis of Australian hurdlers was conducted between 1992 and 1994 by McLean (1994).

Table 1: Kinematic studies of hurdle races

References	Hurdles run	Material	Cameras	Frequency (pictures/s)	No. of hurdles	No. of parameters
Iliew & Primakow (1978)	110 m H	38 men (x = 14.04 s)	35mm	96	II, V, IX	67
Schlüter (1981)	110 m H	9 decathletes	Locam (16mm)x 2	100/200	III	38
Mero & Luhtanen (1985)	100 m H 110 m H	3 women (12.76 s – 13.24 s), 2 men (13.22 s – 13.66 s)	Photosonic Biomechanics 500	100	III	27
Iwkin et al. (1987)	110 m H	20 Russian men (x = 13.81 s), 19 foreign men (x = 13.64 s)	Rolex Filmmaster 008	100	V, IX	9
LaFortune (1988)	110 m H	2 decathletes (14.4 s – 15.7 s) 1 hurdler (13.58 s)	Photosonic	100	III	17
Miskos (1988)	60 m H	2 men	Photosonic 500	200	III	6
Rash et al. (1990)	100 m H	6 women	Locam (16 mm)x3	100	Approach, IV	8
McDonald & Dopena (1991a, b)	100 m H 110 m H	9 women 23 men	JVC GY-X1TC	50	IV-V	36
Salo et al. (1992)	110 m H	10 men (x = 14.61 s)	Locam 51x2	100	III	24
Godik et al. (1993)	110 m H	10 hurdlers (x = 14.78 s) 10 decathletes (x = 16.06 s)	Arriflex 16 SRII		VI	14
Marar & Grimshaw (1993)	60 m H	10 men (7.70 s – 9.70 s)	JVC GY-X1TC/2	50	III	10
Tsarouchas et al. (1993)	110 m H	1 man (13.61 s)	Locam (16 mm)	100	III	77
Čoh & Dolenec (1996)	100 m H	1 woman (13.03 s)	Panasonic SVHS x2	25	IV-V	32
Salo & Grimshaw (1996)	100 m H	9 women (13.22 s – 14.50 s)	JVC GY-X1 x2	50	III	9
Salo et al. (1996)	100 m H 110 m H	4 women 3 men	JVC GY-X1TC x2	50	III	28
Chow (1998)	110 m H	1 man (10 runs)	Panasonic AG-450 x2	200	VI-X	2
Salo & Grimshaw (1998)	100 m H 110 m H	4 women (13.65 s – 14.15 s) 4 men (14.11 s – 15.38 s)	JVC GY – X1TC x2	50	III	28
Iskra & Bacik (1999)	400 m H	1 man (European champion)	Hitachi x2	50	IV	11

In the 1994-2000 period, an estimation of the technique of Polish hurdlers specialising in 110m hurdlers and 400m hurdles was made by Janusz Iskra, Bogdan Bacik and Henryk Król (Bacik, Krol, & Iskra, 1995; Iskra, 1994, 2001; Iskra and Bacik, 1997, 1999; Iskra, Bacik, & Krol,1998, 2000; Krol & Bacik, 1997). Apart from hurdle-specialists, kinematic studies have also embraced hurdle-decathlon specialists (Godik, Szalmanow, & Poltorapawlow, 1993; LaFortune, 1987; Schlüter, 1981) as well as academic-level hurdlers (untrained amateurs). In particular, experimental research can be counted in this group (Chow, 1998; Salo, 1996).

The kinematic analysis of hurdling is diversified by various research organisation methods. One of its elements is to select *part of the distance* to be filmed. In correspondence with the curve of speed the hurdles set in the middle (fastest) part of the distance are usually analysed. A variant of analysing the third hurdle in the 100m and 110m hurdles was applied in studies by Schlüter (1981), Mero and Luhtanen (1986), Miskos (1988), LaFortune (1987), Salo, Grimshaw, and Viitasalo (1997), Marar and Grimshaw, (1994), Salo and Grimshaw (1996, 1998) and others.

In the studies by McDonald and Dapena (1991a, 1991b), Čoh and Dolenec (1996) as well as Iskra et al. (Iskra, 2001; Iskra, & Bacik, 1997; Iskra, Bacik, & Krol, 1998) the fourth hurdle was filmed. The next step in extending the research distance of hurdling was linked with analysing the hurdling technique in line with accumulated fatigue of an anaerobic character. This kind of research was conducted by Iliew and Primakow (1978b), Mann and Herman (1985), Iwkin, Jegorow, and Žukow. (1987) as well as Otrubiannikow and Razumowski (1988). In the last study mentioned, each of the subsequent hurdles was analysed; thus enabling the capturing of the alterations of kinematic parameters with growing fatigue. 'The technique of growing fatigue' in hurdling was analysed by Röll (1976) and Schwirtz (1990). The results of these studies may prove to be of great significance when conducting the instruction process.

Data analysis consists of working out diverse *numbers of parameters*. In most studies these parameters are divided into spacious ones (mainly of length and height), time ones and time-spacious ones (Iliew & Primakow, 1978a, 1978b; McLean, 1994; Otrubiannikow & Razumowski, 1988; Röll, 1976). The number of investigated parameters is not a clue as to the value of a study. In a study investigating the reliability of kinematic measurements, Chow (1998) included only the length of strides (prior to, over and post the hurdle) and their horizontal velocities. A considerably small number of parameters (up to 15) were taken into account in studies by Iwkin, Jegorow, and Žukow (1987), Miskos (1988), Rash, Garrett, and Voisin (1990), Godik, Szalmanow, and Poltorapawlow (1993), Marar and Grimshaw (1994) as well as Iskra and Bacik (1999). In contrast to the above reports, tens or hundreds of parameters have been put under investigation. For instance, Iliew and Primakow (1978a) included 67 parameters in their study, Tsarouchas et al. (Tsarouchas, Papadopoulos, Kalamaras, & Giavroglu, 1993) looked at 77, whereas Wilimczik (1972) in a monograph about hurdling took over 120 parameters into consideration.

The purposefulness of using a certain group of kinematic parameters should be decided upon according to their *relevance* (in relation to the estimation of sports mastership) and *reliability of measurement*. The issue of the variability of kinematic parameters of the hurdle stride was examined by Salo (1996), Salo, Grimshaw, and Viitasalo (1997) and Salo and Grimshaw (1998). These authors found that intra-personal variability coefficients (in reference to the same hurdler repeating the run several times) yielded 200%. Such high values question some of the parameters used in hurdle-technique analysis. These doubts were confirmed by the results of a statistical analysis of selected parameters of the hurdle stride conducted in a group of Polish hurdlers competing in the 110-m hurdles and 400-m hurdles (Iskra, 2001). In the first case of fifteen 110-m hurdlers, variability coefficients yielded from 4.92% (the height of the whole body centre of gravity at touchdown) to 58.43% (the distance of the WBCG to the hurdle upon hurdle clearance). In an individual case of a 400-m hurdler (the 1998 European Champion) the differences were even greater over a four-year period.

The quality of research is largely determined by the *measurement equipment*. The kinds and numbers of cameras in use are presented in Table 1. Their frequency rates have varied from 25 Hz (Čoh & Dolenec, 1996; Čoh, Kastelic, & Pintarič, 1998), 50 Hz (Iskra & Bacik, 1999; Salo & Grimshaw, 1996, 1998) to 100 Hz and even 200 Hz (Iwkin, Jegorow, & Žukow, 1987; La Fortune, 1980; Mero & Luhtanen, 1986; Schlüter, 1981).

Measurement errors can be attributed to the kinds of equipment used, the ways of filming and data reduction. Salo and Grimshaw (1998), when carrying out an eight-fold digitisation of the same run, found out that variability coefficients of 28 parameters yielded from 0.3% to 93.1% (in men) and from 0.1% to 151.2% (in women). These analyses indicated that a relatively small degree of variability (which implies only small measurement errors) involved spacious parameters. In a study by Tomica (1999), digitisation errors occurring as a result of the work of two independent people were investigated. Having analysed only angular parameters, the author showed that the average absolute error (measured in all recorded moments) yielded 4.14° for the lower limbs and 7.18° for the upper extremities. The estimation of measurement errors occurring during the filming of hurdle runs was made by Chow (1998). Using pictures delivered by three cameras, Chow calculated measurement errors concerning five hurdles that were filmed (from the sixth to the tenth hurdles). For the length of the hurdle strides (prior to, over, and post the hurdle) the error was 0.07m, while it was 0.15m/s for analogical horizontal velocities. According to the author, such errors are fully acceptable in biomechanical hurdling studies.

As regards measurement errors it is worth noting the different modes of *statistical analysis* used in biomechanical investigations of hurdling. From among the result presentation methods, there are analyses of individual cases (Čoh & Dolenec, 1996; Čoh, Kastelic, & Pintarič, 1998; Iskra, 2001; Iskra, Bacik, & Krol, 2000; Li, 1990a; Mero & Luhtanen, 1984, 1986), averaged data (Godik, Szalmanow, & Poltorapawlow, 1993; Iwkin, Jegorow, & Žukow, 1987; McDonald & Dapena, 1991a, 1991b; Schlüter, 1981) as well as various types of comparable analyses (mentioned earlier). Correlation analysis is mainly used for estimating the pertinence of chosen kinematic parameters with reference to hurdlers' performance (Iskra, 2001; Marar & Grimshaw, 1994; Otrubiannikow & Razumowski, 1988). Searching for mutual relationships among kinematic parameters as well as the need to find those which are the most significant committed Iliew and Primakow (1978a) to apply factor analysis. Conducted on a representative group of 38 elite European hurdlers, the analysis enabled them to sort out five factors characterising the 110m hurdle technique: running velocity; hurdle clearance efficiency; in-between hurdles running; somatic composition; and pre-hurdle clearance hurdle preparation. The high load of common variability of the first factor (35.7%) indicated that hurdling is some sort of sprint running. Yet this is only one of the many conclusions of biomechanical investigations of hurdlers. After 24 years of thorough and precise kinematic studies of hurdling, McDonald entitled his report 'Hurdling is not sprinting' (McDonald, 2002).

Experimental research

A separate group of kinematic studies is represented by *experimental research* involving conditions of 'technical training', in other words, various runs with the use of hurdles. Investigating 81 students of the Physical Culture Institute in Gangzhou (China), Fang (1989) tried to find basic differences in running technique in runs involving three different distances between the hurdles.

Hurdling as an 'experimental model of complex and cyclical motor abilities' was examined by Hay and Schoebel (1990). The investigators compared time and spacious parameters of standard hurdle runs with a run that had shortened distances between the hurdles, a run over horizontal signs supplanting hurdles, as well as with a hurdle imitation run without any barriers. Krol and Bacik (1997) and Bacik, Krol, and Iskra (1995) were interested in alterations of kinematic parameters in runs involving different heights (91-100-107-cm) of hurdles. An even closer approach to the specific character of hurdling practice was achieved by Grimshaw (1997). He estimated the differences between the motion structure of special exercises characteristic of hurdling (special drills performed from one side of hurdles for the lead and for the trail leg) and the competition event. In conclusion, Grimshaw questioned the indiscriminate application of hurdle drills pre-supposed to have a special character. In this group of literature one may find also studies which investigate the relationships between the alterations of kinematic parameters and somatic composition or training modules (Iskra, Bacik & Krol, 2000; Ren, Niug & Yang, 1998; Salo, 1999).

An important aspect of biomechanical studies of hurdling is constituted by analyses of the influence of sports training on alterations of the hurdle technique. These multi-direction analyses are particularly important in light of using their results in the process of training instruction. This specific feedback seems to be the most useful aim of biomechanical studies of hurdling. Problems connected with this issue were handled by Papadopoulos (1990) and Iskra, Bacik and Krol (2000).

Speedometric and accelerometric research

A separate and large group of biomechanical studies of hurdling is composed of *speedometric and accelerometric research*. By means of sets of photocells or, more frequently, film analysis, the time and velocity of particular parts of a run are determined. The considerable convenience of such research lies in the fact that each hurdle run can be split into the same nine fragments: the run between the hurdles + hurdle clearance. These specific 'rhythmical units' divide the whole distance into sections of 8.50 m (women's 100-m hurdles), 9.14 m (men's 110-m hurdles) or 35 m (both 400-m hurdles). At the outset, attempts at evaluating velocity alterations were occasionally conducted in correspondence with the best hurdle performances (Sadowski, 1967). The very first and wide time analysis of hurdling (men's 400m hurdles) was carried out during the Olympic Games in Mexico in 1968 (Canova, 1979; Hemery & Housden, 1969). Such studies have been conducted during most important track and field fixtures ever since. The details of the time structure of hurdling are presented in Table 2.

Apart from the results of elite hurdlers, many investigators analysed this problem in hurdlers of different performance levels (Bankin, 1995; Letzelter, 1980; Matousek & Sedlacek, 1987). Time analyses of hurdling enabled the creation of so-called touchdown charts or split times

Table 2: Accelerometric studies of hurdle races

Year	Competition	References	Hurdles run
1968	Olympic Games (Mexico)	Hemery & Houston (1969)	400 m men
1972	Olympic Games (Munich)	Letzelter (1977)	110 m men, 100 m women
1976	Olympic Games (Montreal)	Canova (1979)	400 m men
1986	European Championship (Stuttgart)	Moravec & Susanka (1986)	All 4 runs
1986	World Junior Championship (Athens)	Miskos & Susanka (1986)	All 4 runs
1987	World Championship (Roma)	Susanka et al. (1988)	All 4 runs
1988	Olympic Games (Seoul)	Susanka (1990)	All 4 runs
1990	European Championship (Spolito)	Stepanek & Susanka (1990)	All 4 runs
1996	Olympic Games (Atlanta)	Moriorka (1997) Yasui (1997)	400 m men 400 m women
1997	World Championship (Athens)	Müller & Hommel (1997) Dai (2000)	110 m men 100 m women
2000	Olympic Games (Sydney)	Ditoilo (2001)	400 m men

in connection with performance levels. Such charts were worked out by McFarlane (1978), Righi (1986), Railsback (1990) and others. The next stage of the time analysis of hurdling was the creation of a computer programme enabling an athlete to run according to split times (showing the effort distribution over the whole distance). The differences occurring in relation to 'model split times' were analysed in studies by Susanka (1989), Barac (1992) and Papadopoulos (1995). Their studies proved significant in practice because they allowed the assessment of shortcomings in hurdlers' technical and motor preparations. Balchaniczew (1987) considered the time difference between the first and second part of the 110m hurdles as an indicator of a hurdler's special endurance. It was proved in an analysis by Iskra (1994) that in the men's and women's 400m hurdles a decisive factor contributing to the final mark lay in velocity losses identified between the sixth and ninth hurdles.

Dynamographic and electromiographic methods

Studies of the kinematic structure of hurdling and accelometric analyses do not provide the whole range of information required. An essential input for estimating the technique and economy of movement in this event is delivered by studies of dynamic parts of hurdle runs by means of a *dynamographic method*. Ultra-sensitive tensometric platforms constitute a helpful means in measuring ground force reactions (horizontal and vertical) as well as in recording time and velocity parameters concerning two characteristic phases of hurdle clearance: takeoff and touchdown. The dynamic parameters of the hurdle stride were presented by McLean (McLean, 1994). In a study involving seven Australian male hurdlers as subjects, the author showed that highly performing hurdlers are characterised by a shorter time of ground contact (mainly at touchdown) and a lower value of maximal horizontal force at takeoff. Having investigated a 43-person group of male hurdlers of different performance levels, Czeczkowski (1994) concluded that superior performance is determined by a shorter time of front resistance i.e. smaller force decreasing one's horizontal velocity. Changes in ground force reactions during takeoff and touchdown are also presented in the many-aspect studies of Röll (1976) and Kollath (1985). An estimation of the influence of fatigue on the alterations of dynamic parameters of a hurdle stride in men's 400-m hurdles was made by Schwirtz (1990). In this study it was found that upon ground contact after the hurdle the peak vertical force yielded about 6000 N. This indicates that the strength of one's endurance character bears a vast significance for hurdling. Dworak, Iskra, Kaczkowski, and Maczynski (1998), when carrying out an analysis of the dynamics of takeoff and touchdown in 110m hurdles, presented differences in parameters in correspondence to hurdle runs of various hurdle heights. Another type of analysis in that area of investigation was undertaken by Čoh, Kastelic and Pintarič (1998). Using a modified type of starting blocks with built-in small tensometric platforms, the authors obtained the values of several kinematic parameters in combination with plots revealing the alterations of horizontal forces of both legs. However, studies dealing with the dynamic structure of hurdling only constitute a tiny fragment of biomechanical analysis. This is chiefly caused by the difficulty of using special apparatuses directly on the track.

Another method of hurdle technique estimation lies in taking advantage of *force moments*. While searching for selection criteria in the men's 400m hurdles, Erdman (1976) took into consideration moments of resistance forces and moments of inertia of the lower and upper extremities. His analysis revealed that the greatest relationship with the hurdle performance was the moment of the resistance force of a shank in relation to the axis of a knee joint ($r = 0.822$). Tiupa et al. (Tiupa, Michajlow, Jakunin, Aleszinski & Kajmin, 1978) analysed a group of twelve 110-m hurdlers in respect of the alterations of force momentums in their angle, knee and hip joints during hurdling. Force moments in the lower extremity joints of female and male hurdlers were also taken into account by Fujii, Miyashita, and Ae (1997). On the basis of the obtained results the authors concluded that in the preparatory phase hurdling resembled typical sprinting, whereas upon takeoff this analogy could not be derived.

An electromiographic method (EMG) is rarely used in biomechanical studies of hurdling. EMG changes in selected muscle groups during runs of different velocities were demonstrated by Salczenko (1974). The inner structure of hurdling was reproduced by Mero and Peltola (1989).

Future of biomechanical studies of hurdling

The future of biomechanical studies of hurdling is expected to belong to complex studies and comprehensive research programmes linking not only various methods of biomechanical analysis (kinemtics, dynamography, accelometry, EMG, and others) but also interdisciplinary studies (for instance, those connected with physiological aspects of exercise, somatic composition, type of training loads etc.). A large programme of biomechanical studies in hurdling was proposed by Mann (1985). This was made possible through a grant from the US Olympic

Foundation, which was dispensed via the Athletics Congress of the USA. In an effort to gain more knowledge in the area of hurdling and help elite women and men hurdlers in the United States their technique was analysed. The analyses were mainly conducted in a fully equipped lab in the Olympic Training Centre in Colorado Springs. Although in this investigation a kinematographic method was mainly used, in the discussion part of the report there are many references to training.

A huge grant concerning the biomechanics of hurdling has been used by the British since 1992. Under the leadership of Paul N. Grimshaw, in collaboration with Aki Salo, British investigators carried out a series of research chiefly with respect to the kinematics of hurdle clearance. In spite of the fact that this well-prepared project (Grimshaw, Marar, Salo, Logden, & Vernon, 1994) has never been fully completed, it has enriched our knowledge of hurdling by unveiling the results in many publications (Grimshaw, 1997; Marar & Grimshaw, 1994; Salo & Grimshaw, 1996, 1998; Salo, Grimshaw, & Marar, 1997, Salo, Grimshaw, & Viitasalo, 1997).

Awarding Australia with organising the Olympic Games in 2000 was the main reason behind the many sports research programmes in this country. The Australian Institute of Sport and the Department of Biomechanics in particular piloted investigations of Australian male hurdlers in Canberra. The programme covered kinematic and dynamographic investigations (McLean, 1994).

Other motivations behind undertaking complex studies are seen in the case of Čoh and colleagues. Taking advantage of the sports success of Slovenia's best female hurdler (the 1992 Olympic silver medallist) they conducted a vast biomechanical study of an individual case (Čoh & Dolenec, 1996; Čoh, Kastelic, & Pintarič, 1998). The investigation took place in a laboratory of the Department of Biomechanics at Ljubljana University and covered kinematic and dynamic parameters, accelometry as well as elements of sports practice.

In the context of Wilkerson's study (Wilkerson, 1997), the investigation of Čoh et al. represents the future of biomechanical research in sport. One might find in it individual characteristics, a holistic approach as well as a search for intra-disciplinary bridges. The abovementioned author points out that the biomechanics of sport follow the route from analyses of average values, through optimal parameters, to finding what is normal. Coaches' expectations concerning biomechanical studies were articulated by Terauds (1986). Investigations involving a group of competitors must be only a foundation for individual analyses. Single analyses ought to be only an introduction to continual biomechanical control. In addition, the most important observation – biomechanical studies in hurdling must have a complex character i.e. they should not be exclusively restricted to methods of biomechanical analysis. One ought to take into account elements such as somatic parameters, motor skills, co-ordination levels or kinds of applied training.

REFERENCES

Artiuszenko, A., & Bieglecow, A. (1975). Barierist I kłasa [First class hurdler]. *Legkaja Atletika, 9,* 14.

Bacik, B., Krol, H., & Iskra, J. (1995). Struktura kroku plotkowego w zaležnošci od wysokošci plotka [Structure of hurdle clearance according to the height of a hurdle]. *Zeszyty Metodyczno-Naukowe,* 359-365.

Balchaniczew, W.W. (1987). *Bieg na 110 m s barierami* [110-m hurdle run]. Moscow: Fizkultura i Sport.

Bankin, W.N. (1995). Analiz soriewnowatielnoj diejatielnosti junych biegunij razlicznoj kwalifikacji na 400 m s barierami [Competition analysis of young 400-m hurdlers of different sport levels]. *Teoria i Praktika Fiziczeskoj Kultury, 3,* 3-6.

Barac, F. (1992). Expert system – 110 m hurdles. In T. Raz-Liebermann & Z. Artzi (Eds.), *Proceedings of the International Conference on Computer Applications in Sport and Physical Education.* Netanya: Wingate Institute.

Bedini, R. (1988). I 100 m e 100 m ostacoli [The 110-m and 100-m hurdle events] *Atleticastudi, 3-4,* 479-520.

Brejzer, W. (1986). Na distancii S. Busch [S. Busch on distance]. *Legkaja Atletika, 10,* 16-17.

Brejzer, W., & Kajtmazowa, J. (1979). Bieg R. Nehemiaha *[R. Nehemiah's run]. Legkaja Atletika, 1,* 14-15.

Buffault, H. (1979). Propos des haies hautes: La technique selon G. Drut [110-m hurdle run: Technique of G. Drut]. *Amicale des Entraineurs Francais d'Athletisme, 1,* 34-36.

Canova, R. (1979). Distribuzione ritmica della sforzo nei 400 ostacoli [400-m hurdle rhythm splits]. *Atletica Leggera, 6,* 58-62.

Cappozzo, A. (1985). Biomeccanica del movimento: Introduzione storico – metodologica [Biomechanics of movement: Historical and methodological introduction]. *Atleticastudi, 2,* 155-166.

Chow, J.W. (1998). A panning videographic technique to obtain selected kinematic characteristics of the strides in sprint hurdling. *Journal of Applied Biomechanics, 9,* 149-159.

Čoh, M., & Dolenec, A. (1996). Three-dimensional kinematic analysis of hurdles technique used by Brigita Bukovec. *New Studies in Athletics, 1,* 63-69.

Čoh, M., & Kampmiller, T. (2001). Biomechanical analysis of hurdle clearance technique. *TVS Telesna Vychova and Sport, 3,* 32-37.

Čoh, M., Kastelic, J., & Pintarič, S. (1998). A biomechanical model of the 100 m hurdles of Brigita Bukovec. *Track Coach, 142,* 4521-4529.

Comstock, B. (1924). *How to hurdles.* New York: American Sport.

Cureton, T.K. (1939). Elementary principles and techniques of cinematograpfie analysis as aids in athletic research. *Research Quarterly,* 3-24.

Czeczkowski, K. (1994). Próba oceny techniki biegu na dystansie 110 m przez plotki na podstawie przebiegu sily reakcji podłoża [Approach to assess 110-m H clearance technique on the ground of the course of reaction forces]. *Studia i Monografie,* 112-114.

Czistiakow, W., & Brejzer, W. (1971). Biomechaniczeskij analiz priedolienia bariera [Biomechanical analysis of hurdle clearance]. *Legkaja Atletika, 6,* 12-13.

Dai, Y. (2000). Analysis of full-length speed changes of hurdling – based on the World best hurdler's experiences. *Journal of Beijing University of Physical Education, 3,* 418-419.

Ditoilo, M. (2001). Analysis of the race distribution for male 400 m hurdles competing at the 2000 Sydney Olympic Games. *New Studies in Athletics, 3,* 15-30.

Doherty, K. (1953). *Modern Track and Field.* Englewood Cliffs: Prentice Hall.

Dworak, L.B., Iskra, J., Kaczkowski, Z., & Maczynski, J. (1998). The dynamics of take-off and landing in hurdles. *Biology of Sport, 15*(8), 81-86.

Dyson, G.H. (1970). *The mechanics of athletics.* London: University of London Press.

Ecker, T (1971). *Track and field dynamics.* Mountain View: Trafnews Press.

Erdman, W. (1976). *Biomechaniczno-morfologiczne kryteria selekcji zawodników do biegu na 400 m przez płotki* [Biomechanical and morphological criteria of selection for the 400-m H run]. Doctoral dissertation, Gdansk: Akademia Wychowania Fizycznego.

Fang, J. (1989). Mathematical models of morphology and physical fitness of hurdling with suitable interval. *Track and Field quarterly review, 1,* 45-48.

Fenn, W.O. (1929). Mechanical energy expenditure in sprint running as measured by moving pictures. *American Journal of Physiology, 90,* 343-344.

Fujii, N., Miyashita, K., & Ae, M. (1997). Three dimension analysis of joint torques and powers of the lower limbs in sport hurdles. *Japanese Journal of Biomechanics in Sports and Exercise, 1,* 41-50.

Godik, M.A., Szalmanow, A.A., & Poltorapawlow, N.I. (1993). Srawnitelnyj analiz kinematiki sprinterskowo i bariernowo biega djesiatiborcew i legkoatletow – specjalistow [Comparative analysis of sprint and hurdle run kinematics of decathletes and athlete-specialists]. *Teoria i Praktika Fiziczeskoj Kultury, 2,* 39-43.

Grimshaw, P.N. (1997). A kinematic analysis of sprint hurdles training strategies (isolation drills). In J. Jarver (Ed.), *The hurdles: Contemporary theory, technique and training.* Mountain View: Tafnews Press.

Grimshaw, P., Marar, L., Salo, A., Logden, B., & Vernon, J. (1994). Biomechanical analysis of sprint hurdles. *Athletics Coach, 4,* 10-12.

Hay, L., & Schoebel, P. (1990). Spatio-temporal invaviants in hurdle racing patterns. *Human Movement Science, 1,* 37-54.

Hemery, G., & Housden, H. (1969). Olympischer 400-m-Hürdenlauf in Zahlen [Olympic 400-m hurdle run in values]. *Leichtathletik, 20,* 34.

Hoke, R.J. (1943). *Hürdenlauf* [Hurdle run]. Berlin: Wilhelm Lipert Verlag.

Hommel, H. (1988). NSA photosequences 4 - 110 m hurdles: Stephane Caristan. *New Studies in Athletics, 2,* 75-82.

Hommel, H. (1995). NSA photosequences 33 and 34 – 110 m hurdles: Colin Jackson. *New Studies in Athletics, 3,* 57-65.

Hommel, H., & Arnold, J. (1993). NSA photosequence 26 – 110 metres hurdles: Roger Kingdon. *New Studies in Athletics, 2,* 65-72.

Hommel, H., & Schmid, H. (1990). NSA photosequence 14 - 400 m hurdles. Andre Philips and Edwin Moses. *New Studies in Athletics, 5,* 64-72.

Hommel, H., & Vernon, J. (1991). NSA photosquence 16 - 100 metres hurdles. Yordanka Donkowa. *New Studies in Athletics, 2,* 67-71.

Iliew, I., & Dimitrow, D. (1978). Srawnitelen analiz na technikata na najdobritie prepiastwenici na 110 m u nas i w czužbina [Comparative study of parts of the 110-m hurdle technique of Bulgarian and world athletes]. *Waprosy na Fiziczeskata Kultura, 4,* 206-212.

Iliew, I., & Primakow, J. (1978a). Faktornata struktura na technikata w biaganeto na 110 m s priepastwia [Factor analysis of the technique of the 110-m hurdle run]. *Trenorska Misl, 4,* 7-13.

Iliew, I., & Primakow, J. (1978b). Izsliedowanie wariatiwnostta na kinematiczeskitie charakteristiki na technikata w priepriatstwienoto biaganie na 110 m [Variability of kinematics parameters of the 110-m hurdle technique]. *Waprosy na Fiziczeskata Kultura, 10*, 604-612.

Iskra, J. (1994). Zależnošč wyników w biegu na 400 m przez plotki od wyodrebnionych parametrów czasowych w praktyce szkolenia [Dependence of the 400-m hurdle run on temporal parameters in training practice]. *Trening, 2,* 109-117.

Iskra, J. (2001). *Morfologiczne i funkcjonalne uwarunkowania rezultatów w biegach przez plotki* [Morphological and functional factors of hurdle results]. Katowice: Akademia Wychowania Fizycznego.

Iskra, J., & Bacik, B. (1997). Wykorzystanie kinematycznej analizy ruchu w korygowaniu techniki pokonywania płotka [Advantage of kinematics analysis of movement in the correction of hurdle technique]. *Trening, 2,* 257-264.

Iskra, J., & Bacik, B. (1999). Hurdle clearance technique of the European Champion in 400 m. *Kiesiologia Slovenica, 5,* 53-70.

Iskra, J., Bacik, B., & Król, H. (1998). Zmiany parametrów kinematycznych kroku plotkowego w 4-letnim okresie treningowym w grupie najlepszych polskich plotkarzy [Changes of kinematics parameters of hurdle clearance in a 4-year period of athletic training in a group of the best Polish hurdlers]. *Monografie* (pp. 129-133). Poznan: Akademia Wychowania Fizycznego.

Iskra, J., Bacik, B., & Król, H. (2000). The effect of specific exercises on changes in hurdle technique. In J. Raczek, Z. Waškiewicz, & G. Juras (Eds.), *Current research in motor control* (pp.104-110). Katowice: Akademia Wychowania Fizycznego.

Ito, A. (1997). Biomechanical analysis of hurdle running in comparison with sprinting. *Japan Journal of Physical Education, 4,* 246-260.

Iwkin, G.W., Jegorow, A.S., & Žukow, N.L. (1987). Sawriemiennaja technika bariernowo biega [Modern hurdle run technique]. *Teoria i Praktika Fiziczeskoj Kultury, 9*, 32-34.

Kaufmann, D.A. (1976). Biomechanical analysis of intermediate and steeplechase hurdling technique. In P.V. Komi (Ed.). *Biomechanics V-B* (pp. 181-187). Baltimore: University Park Press.

Kampmiller, T., Slamka, M., & Vanderka, M. (1999). Comparative biomechanical analysis of 110 m hurdles of Igor Kovac and Peter Nadelicky. *Kinesiologia Slovenica, 1-2,* 26-30.

Kolejwa, M. (1961). Rozwój techniki biegu na 110 m p.pl [Development of the 110-m hurdle technique]. *Lekka Atletyka, 4,* 6-7.

Kollath, E. (1983). Zum Einfluss einzelner Körpersegmente auf die vertikale Abfluggeschwindigkeit des KSP beim 100 m Hürdenlauf [The influence of individual body segments on the vertical take-off velocity of the CG during the 100 metres hurdles]. *Leistungssport, 4,* 37-43.

Kollath, E. (1985). Biomechanische Aspekte des Hürdensprints der Frauen [Biomechanical aspects of women's sprint hurdles]. *Leichtathletik,* 24: 1319-1324.

Koszewski, D. (1990). Hürden auf dem Weg zum olympischen Gold: Entwicklung des modernen Hürdenlaufens [Hurdle run from the Olympic gold point of view: The development of modern hurdle runs]. *Leichtathletik, 46*: 87-90.

Krol, H., & Bacik, B. (1997). Kinematyka kroku płotkowego w zależnošci od wysokošci plotka [Kinematics of hurdle clearance according to the height of a hurdle]. *Antropomotoryka, 16,* 103-111.

LaFortune, M.A. (1987). Biomechanical analysis of the 110 metres hurdles. *Excel, 3,* 2-4.

Letzelter, M. (1977). *Hürdensprint* [Sprint hurdles]. Berlin: Verlag Bartels & Wernitz.

Letzelter, H. (1980). Geschwindkeitsverhalten beim 400-m-Hürdenlauf der Frauen [Decrease in velocity of the women's 400-m hurdle run]. *Leistungssport, 4,* 300-310.

Li, J. (1990a). A kinematic analysis of Liu Huajin's 100 m hurdling technique. *Sports Science, 6,* 67-70.

Li, J. (1990b). Kinematical analysis of Yu Zhicheng's 110-meter hurdling techniques. *Chinese Sports Science and Technology, 7,* 13-17.

Lovesey, P. (1980). *The official centenary history of the Amateur Athletic Association.* London: Guinness Superlatives Limited.

Mann, R. (1985). Biomechanical analysis of the elite sprinter and hurdler. In N.K. Buttsand, & T.T. Gushken (Eds.), *The elite athlete* (pp. 43-80). New York: SP Medical and Scientific Books.

Mann, R., & Herman, J. (1985). Kinematic analysis of Olympic hurdle performance: Women's 100 meters. *International Journal of Sport Biomechanics, 2,* 163-173.

Marar, L., & Grimshaw, P.N. (1994). A comparative biomechanical analysis of sprinting and hurdling technique. *Journal of Sports Sciences, 1,* 174.

Matousek, R., & Sedlacek, J. (1987). Vztah sportovniho vykonu na 400 m prekazek muzu a rychlosti behu v jednolivych rytmiskych jednotkach [Men's 400-m hurdle results and speed in split-rhythmic units]. *Teoria i Praxe telesna Vychowy, 12,* 732-741.

McDonald, C., & Dapena, J. (1991a). Angular momentum in the men's 110-m and women's 100-m hurdles races. *Medicine and Science in Sports and Exercise, 12,* 1392-1402.

McDonald C., & Dapena J. (1991b). Linear kinematics of the men's 110-m and women's 100-m hurdles races. *Medicine and Science in Sports and Exercise, 12,* 1382-1391.

McDonald, C. (2002). Hurdling is not sprinting. *Track Coach, 161,* 5137-5143.

McFarlane, B. (1978). Touchdown times. *Track and Field quarterly review, 4,* 33.

McFarlane, B. (1988). *The science of hurdling.* Ottawa: Canadian Track and Field Association.

McInnis, A. (1982). Feminine approach to the first hurdle: Cinematograpfic analysis of biomechanical variables. *Track and Field quarterly review, 2,* 39-41.

McLean, B. (1994). The biomechanics of hurdling: Force plate analysis to assess hurdling technique. *New Studies in Athletics, 4,* 55-58.

Mero, A., & Luhtanen, P. (1984). A biomechanical analysis of top hurdling. *Modern Athlete and Coach, 3,* 3-6.

Mero, A., & Luhtanen, P. (1986). Biomechanische Unterschung des Hürdenlaufs wahrend der Weltmeisterschaften in Helsinki [Biomechanical investigations of sprint hurdles during the World Championships in Athletics in Helsinki]. *Leistungssport, 1,* 42-43.

Mero, A., & Peltola, E. (1989). Elektromyographische Aktivität und Reaktions Kräfte beim Hürdenlauf Eine Fallstudie [Study of electromiographical activity and reaction forces in hurdles]. *Leistungssport, 4,* 29-31.

Miskos, G. (1988). Biomechnila analyza probehu prekazek. *Teorie a Praxe telesne Vychowy, 11,* 648-654.

Miskos, G., & Susanka, P. (1986). Hurdle races. In P. Susanka, P. Brüggemann, & E. Tsarouchas (Eds.), *1st World Junior Championships. Athens'86. IAAF Biomechanical Research.* Athens: IAAF.

Moravec, P., & Susanka, P. (1986). Metodicke poznamky k prubehu nekterych zawodu na ME Stuttgartu [Methodological aspects of some competitions at the European Championships in Stuttgart]. *Atletica, 12,* 18-19.

Moriorka, Y. (1997). Analysis of the race-patterns of men's 400 M hurdles: The races of the XXVIth Olympiad in Atlanta 1996. In *Book of abstracts of XVIth International Society of Biomechanics Congress* (pp. 207). Tokyo: University of Tokyo.

Müller, H., & Hommel, H. (1997). Biomechanical research project at the VIth World Championships in Athletics Athens 1997: Preliminary Report. *New Studies in Athletics, 2-3,* 43-55.

Nett, E., & Nett, T. (1969). *Weltbeste Leichtathletik in Lehrbildreihen Hürdenlauf* [The best athletes in pictures]. Berlin: Bartels and Wernitz.

Oberbeck, H. (1972). *Das Training des jungendlichen Leichtathleten* [Training of young athletes]. Stuttgart: Verlag Karl Hofmann.

Otrubiannikow, P.J., & Razumowski, J.A. (1988). *Sprint s barierami* [Sprint hurdles]. Kiew: Zdorowia.

Papadopoulos, C. (1990). Empirische Untersuchung zur Trainierbarkeit ausgewählter Technikmerkmale bei der Hürdenüberquerung [Empirical study of the trainability of selected technical parameters of the hurdle clearance]. Köln: German College of Physical Education.

Papadopoulos C. (1995). The application of the biomechanics models for the control of the 'improvement targets' in 110 m men's hurdles. In A. Barabas, & G. Fabian (Eds.), *Biomechanics in sports XII. Proceedings of the 12th Symposium of the International Society of Biomechanics in Sports* (pp. 329-332). Budapest: Informational Society of Biomechanics in Sports.

Peltola, E. (1996). Biomechanical analysis of sprints and hurdles. In *Proceedings of the 1996 National Coaching Congress* (pp. 65-78). Canberra: Australian Track and Field Coaches Association.

Quercetani, R. (1990). *Atletica: Storia dell'atletica moderna dalle origini ad oggi (1860-1990): Uomini e donne* [Track and field: History of modern athletics: Men and women]. Milano: Vallardi and Assocciati.

Railsback, D. (1990). Split and interval difference times. *Track and Field quarterly review, 1,* 26.

Rash, G.S., Garrett, J., & Voisin, M. 1990. Kinematic analysis of top America female 100-meter hurdles *International Journal of Sport Biomechanics, 4,* 386-393.

Ren, R., Niug, C., & Yang, C. (1998). The biomechanical analysis of Qingyue Zhang's techniques in the 110-metre hurdle race. *Journal of Shandong Physical Education Institute, 2,* 45-47.

Righi, T. (1986). Le curve di velocita nelle corse con ostacoli [The curve of velocity in hurdle races]. *Atleticastudi, 6,* 463-476.

Röll, B. (1976). Eine Untersuchung des 400-m-Hürdenlaufs der Frauen [The study of women's 400-m hurdle runs]. *Leistungssport, 2,* 116-124.

Sadowski, W. (1967). *Bariernyj bieg* [Hurdle run]. Moscow: Fizkultura i Sport

Salczenko, I. (1974). Bolsze wnimanie skorosti [Greater look at the speed]. *Legkaja Atletika, 6,* 20-21.

Salo, A. (1996). Repeatability of motion analysis and reproducibility of athletes in sport hurdles. In T. Bauer (Ed.), *Proceedings of XIII International Symposium for Biomechanics in Sport* (pp. 380-383). Tunder Bay: Lakehead University.

Salo, A. (1999). The use motion analysis as a coaching aid to improve the individual technique in sprint hurdles. In R.H. Sanders, & B.J. Gibson (Eds.), *Scientific Proceedings of International Symposium on Biomechanics in Sports* (pp. 57-60). Perth: Edith Cowan University.

Salo, A., & Grimshaw, P.N. (1996). Kinematische Veäderungen der Hürdenüberquerung im 100 m Hürdenubständen in einer Trainingssituation [Kinematic analysis of 100-m hurdle clearance in various training situations]. *Leistungssport, 2,* 24-27.

Salo, A., & Grimshaw, P.N. (1998). An examination of kinematic variability of motion analysis in sprint hurdles. *Journal of Applied Biomechanics, 2,* 211-222.

Salo, A., Grimshaw, P.N., & Marar, L. (1997). 3-D biomechanical analysis of sprint hurdles at different competitive levels. *Medicine and Science in Sports and Exercise, 2,* 231-237.

Salo, A., Grimshaw, P.N., & Viitasalo, J.T. (1997). Reliability of variables in the kinematic analysis of sprint hurdles. *Medicine and Science in Sports and Exercise, 3,* 383-389.

Salo, A., Peltola, E., & Viitasalo, T. (1993). Einige Biomechanische Merkmale des Zwischenhürdenlaufs im 110 m hürdenlauf [Some biomechanical characteristics of the run between hurdles in the 110-m hurdles run]. *Leistungssport, 2,* 59-62.

Schlüter, W. (1981). Kinematische Merkmale der 110-m-Hürdentechnik [Kinematic characteristics of 110-m hurdles technique]. *Leistungssport, 2,* 118-127.

Schwirtz, A. (1990). Wplyw zmeczenia na technike biegu na 400 m przez plotki [Influence of fatigue on the 400-m hurdle technique]. *Sport Wyczynowy, 3-4,* 60-63.

Sherman, M. (1888). *Athletics and football.* London: Longmans Green and Co.

Shi, H. (1998). An analysis of technical parameters of the starting hurdle in Chinese male 110 m hurdle athletes. *Journal of Wuhan Institute of Physical Education, 3,* 40-43.

Steben, R.E. (1985). Hurdle technique of an elite athlete. In J. Terauds, & J.N. Barham (Eds.), *Research Center for Sports II: Proceedings* (pp. 280-284). Del Mar: Research Center for Sports.

Stepanek, J., & Susanka, P. (1990). Casova analyza, frekvence a dalka kroku na ME 1990 [Time analysis, frequency and stride length at the European Championships 1990]. *Atletica, 12,* 18-19.

Susanka, P. (1989). Hints on computer processing of biomechanical data. In L. Tsarouchas (Ed.), *Biomechnics in Sports: Proceedings of the Fifth International Symposium of Biomechanics in Sports* (pp. 569-596). Athens: Hellenic Sports Research Institute.

Susanka, P. (1990). Time analysis of the 110 metres and 100 metres hurdles: Time analysis of the 400 metre hurdles events. In G.P. Brüggemann, & B. Glad (Eds.), *Scientific research project at the Games of the XXIVth Olympiad: Seoul 1988* (pp.91-175). Monaco: International Athletic Foundation.

Susanka, P (1993). Tak beha prekazky J. Akii-Bua [J. Akii-Bua runs hurdles]. *Atletika, 2,* 14-15.

Terauds, J. (1986). What biomechanics can do for the average coaches and athletics. *New Studies in Athletics, 3,* 9-12.

Tiupa, W., Michajlow, N., Jakunin, N., Alieszinski, S., & Kajmin, M. (1978). Biodynamika preodolienia bariera [Biodynamics of hurdle clearance]. *Legkaja Atletika, 12,* 12-13.

Tomica, A. (1999). *Ocena dokladnošci komputerowej obróbki obrazu video* [Estimation of the accuracy of the computer treatment of video pictures]. Master's thesis, Katowice: Akademia Wychowania Fizycznego.

Tsarouchas, L., Papadopoulos, C., Kalamaras, K., & Giavroglu, G. (1993). Approach phase for the clearance of the hurdle in the 110 m high hurdles run. *Track and Field quarterly review, 1,* 40-45.

Ward, T., & India, D.T. (1982). Temporal and kinematic facts on 100 m hurdling: High level performers. *Track and Field quarterly review, 2,* 30-32.

Webster, F.L. (1929). *Athletic up to date.* London: Frederick Warner and Co.

Wilimczik, K. (1972). *Leistungsbestimmende Bewegungsmerkmale der 110-m-Hürdentechnik* [Qualifying of movement characteristics in the 110-m hurdle technique]. Berlin: Verlag Bartels und Wernitz.

Wilkerson, J.D. (1997). Biomechnics. In J.D. Massengale, & R.A. Swanson (Eds.), *The history of exercise and sport sciences* (pp. 321-366). Champaign: Human Kinetics.

Yasui T. (1997). The analysis of race in 400 M hurdle for woman. In *Book of abstracts of XVIth International Society Biomechanics Congress* (pp. 207). Tokyo: University of Tokyo.