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# ASSESSMENT OF KINEMATICS OF SPORTSMEN PERFORMING STANDING LONG JUMP IN 2 DIFFERENT DYNAMICAL CONDITIONS

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## Abstract

This paper presents results of the study devoted to analysis of impact of upper extremities' momentum on the jump length and analysis of selected kinematic data changes during the standing long jump. Four young sportsmen participated in the initial study. They have performed standing long jump in two measuring conditions: with and without arms swinging. Motion was captured using a 3D opto-electronic camera system SMART (BTS) and selected kinematic data were evaluated using software packages and data processing: trajectory of body centre of gravity (COG), velocity of COG, maximal vertical distance of COG, take-off angle together with momentum of upper extremities were analyzed. The data were statistically evaluated using descriptive statistics and analysis of variance. Statistical significance of the kinematic data and jump length were analyzed using the Kruskal-Wallis test and post-hoc test ($p<0.05$) in Statistics toolbox of Matlab program. Statistically significant differences were assessed within intraindividual and intraclass comparison of data.

Keywords: kinematics, dynamics, standing long jump, human motion analysis, sports.

## 1. Introduction

Advanced techniques of human motion analysis receive an increasing attention of researchers interested in computer vision. This interest is motivated by a wide spectrum of applications, such as athletic performance analysis, surveillance systems, man-machine interfaces, content-based image storage and retrieval and video conferencing [1]. Precise measurement of motion has been already incorporated into training routines of numerous professional sport teams in order to improve sportsmen performance [2]. Precise measurement of motion patterns proved itself to be particularly efficient in athletics, where even a small alternation of motion pattern can significantly influence the outcome performance. Standing long jump is an athletic discipline which was an Olympic discipline till 1938 [3]. However, standing long jump is not an official Olympic event anymore; it still has an important position in athletics, particularly in the training process and testing programs of the sportsmen. Athletic testing in standing long jump, also known as the broad jump, is a common and easy test to evaluate explosive properties of lower extremities. It also serves as an exercise that supports training of technical skills for triple jumps in the phase of hopping and landing. It is often adopted to be a part of physical education of school children, training of professional sportsmen and non-professional sport activities of young and adults [3-5]. It became an excellent drill for triple jumpers of all ages [3] and also a great training tool for sprinters and throwers [6]. It serves as a tool for monitoring leg power and strength and overall performance for related features of sportsmen abilities. Standing long jump is described as non-periodic locomotion. For this activity, one should reinforce the following aspects of

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technique: fixed feet, triple extension, and absorbing the landing [6]. Therefore, its analysis is more complex and requires a different approach than e.g. gait analysis. The performance of standing long jump was often adopted to examine the fitness of school children, training of professional sportsmen and non-professional sport activities of young and adults. It is often used as a functional test to assess leg power, but the test may underestimate the athlete's true potential if he or she does not perform the most suitable technique [5]. In athletes' motion analysis this test is applied to assess the power of leg muscles and thus estimate their dynamic properties. A performance of sport or even daily activities requires both strength and power. To train strength, the exercises to improve both static and dynamic muscle activities need to be included in the sport and leisure training, respectively in rehabilitation sessions. It is approved that dynamic exercises improve power and strength of the musculoskeletal system of sportsmen. Therefore, strength training in sports should be supplemented by exercises with higher velocities. Typical performance that requires explosive power–type strength, dynamic movement, includes various jumps, where the maximal strength level must exceed the load to be moved [7, 8]. In this study we aimed to determine a set of kinematic data that specify the standing long jump and evaluate the influence of dynamics of upper extremities on overall performance.

## 2. Material and methods

### *2.1. Subject*

Four healthy male sportsmen (volleyball players from Slavia VKPU in Presov) with mean age 17±0.71 years were evaluated in this study; data for 1 subject were excluded due to markers' occlusion from the motion capture which caused missing motion data. The mean height and body weight of the group was 1.81±0.05m, 71.75±7.89 kg (Table 1). The subjects were informed about the experimental procedures and gave their consent before experiment.

Table 1. Basic anthropometric data of measured subjects.

| Subject | Height [m] | Weight [kg] | Age [years] |
|---|---|---|---|
| JaCe | 1.84 | 70 | 18 |
| MaVa | 1.72 | 62 | 17 |
| MiRu | 1.82 | 71 | 16 |
| ToMa | 1.86 | 84 | 17 |

### *2.2. Standing long jump as a test*

We aimed to evaluate the kinematic analysis of the standing long jump and the influence of upper extremities dynamics on overall performance.

In order to test the study hypotheses we evaluated the standing long jump with the following parameters:

- Horizontal distance = length of jump (D)
- Maximal vertical distance = height of jump (H)
- Velocity of body centre of gravity (v)
- Take-off angle (θ)
- Hip angle (α)
- Momentum of upper extremities (M)

When selecting the measured kinematic parameters, we have been inspired by oblique throw theory as the background of movement analysis. This theory assumes the moving body (in our case it is the COG of the body) reaches the maximum of the horizontal distance when the initial angle of the trajectory that the body centre of gravity reaches the optimal value together with the appropriate initial speed [9] (See Fig. 1).

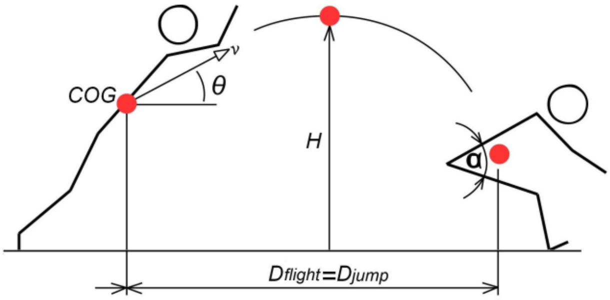

Fig. 1. Standing long jump scheme [5].

The influence of upper extremities on the sportsman's performance was evaluated by comparing the magnitude of arm's movement momentum during the jump. In order to evaluate the momentum of upper extremities, the calculation of the exact position of the centre of gravity of arms and weight of arms was conducted based on Winter's table [9].

### *2.3. Measurement set up of technical equipment*

The motion analysis system (SMART, BTS Bioengineering, Italy) used in the Laboratory of Motion Analysis at our department was the main technical equipment used to capture motion data. This system is classified as an opto-electronic system for motion analysis. Kinematic parameters of motion are calculated based on the motion of passive markers attached on the human body, captured using cameras with an infrared filter (analogue cameras with C-mount compatible lenses and a sampling frequency of 50 Hz). Measurement was performed within a calibrated space (3x2x2 m), with the measured accuracy of the system to be less than 0.3 mm. Markers have been attached to the body using anatomical landmarks derived from Kit Vaughan marker model [10]. Modifications of previous model have been done by adding additional markers on upper extremities and a marker on spinous process of C7 cervical vertebra (defining the position of the neck). The additional model of markers placed on the upper extremities was required in order calculate the centre of gravity of each extremity. Obtaining gravity information of individual extremities is essential for determination of momentum movement.

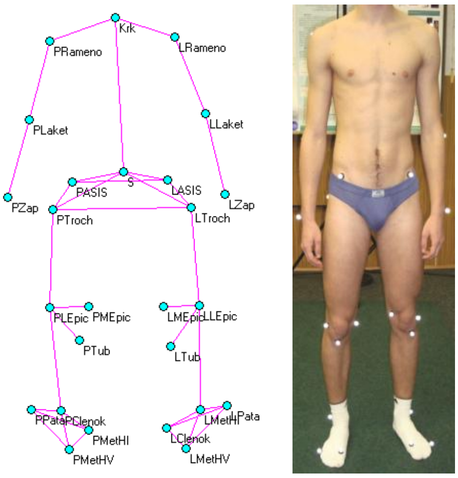

Fig. 2. Marker model. **Left**: virtual representation. **Right**: real attachment on study subject [11].

The model included 26 markers placed on anatomically significant places - 7th cervical vertebra (Krk), 1st sacral vertebra (S), acromioclavicular joint (P/LRameno), lateral epicondyle of humerus (P/LLaket), ulnar styloid process (P/LZap), anterior superior iliac spine-pelvis (P/LASIS), greater trochanter of femur-hip joint (P/LTroch), lateral epicondyle of femur-knee joint (P/LLEpic), medial epicondyle of femur-knee joint (P/LMEpic), tibial tuberosity-below patella (P/LTub), lateral malleolus-ankle joint (P/LLClenok), medial malleolus-ankle joint (P/LMClenok), calcaneus-heel bone (P/LPata), 5th metatarsal head-smallest toe (P/LMetHV.), 1th metatarsal head-smallest toe (P/LMetHI.).

### *2.4. Methodology of measurements*

Standing long jump was measured in two sequences:

1. Standing long jump without arms swinging
2. Standing long jump with arms swinging

The performance of a sportsman was defined as the horizontal distance of body centre of gravity (COG) from the moment of take-off till the moment of initial contact with ground. The take-off angle is an important kinematic variable we were focused on in our study. It is defined as the inclination angle at the take-off moment, angle of tangent to the trajectory of centre of gravity with the horizontal axis at the moment of take-off. Other variables in our study were: velocity of the centre of gravity (COG) during take-off, angle hip and momentum of right and left arm. Standing long jump was performed first with arms swinging and then without arms swinging. Kinematic characteristics as change of position, velocity and angular parameters were captured by the SMART video-capturing system. The basic processing of kinematic data (trajectory of the body centre of gravity, speed of the body centre of gravity, hip angle and momentum of the upper extremities) was performed in SMART Analyzer software (See subsection 2.5).

The main assumption was the following: to achieve good performance of a technically correct long jump, it is necessary that the momentum of arms is high during the take-off phase because it can influence the maximal vertical position (H) that COG reaches during the jump.

### *2.5. Statistics of measurement evaluation*

Data analysis protocols in SMART Analyzer were used not only for calculating the kinematic parameters and displaying graphical results in the form of graphs and tables, but also to export the data in *emt format that is compatible with MS Excel for further data analysis. We used descriptive statistic tools available in MS Excel and Statistics Toolbox of MATLAB 7.0 to process and evaluate the quantitative empiric data from motion analysis. We focused on the influence of parameter changes, mutual relation of kinematic variables and influence of arms swinging on sportsman's performance. The aim of the statistics was to determine whether differences in selected parameters are statistically significant for the intraclass and intraindividual evaluation of data variability.

The Kruskal-Wallis test was applied to analyze variability and point out the differences between processed data. The null hypothesis was that all data of 3 jumps without arm swinging equals those performed with arm swinging. The subject of the statistical assessment for intraindividual and intraclass data variability evaluation consisted of the following parameters: length, height of jump and hip angle (left, right). The significance of these parameters was shown by:

1. Intraindividual data variability evaluation
    - significance of both ways of jump separately,
    - significance in comparing both ways of jump.

2. Intraclass data variability evaluation
    - significance of jump without arm swinging (1),
    - significance of jump with arm swinging (2).

The alternative hypothesis is that at least one of them is statistically different and the null hypothesis needs to be rejected. There is between-group variation (between 3 jumps) and within-group variation (within each jump) expressed statistically using analysis of variance.

## 3. Results

Observed kinematic parameters include jump length (D), jump height (H), velocity of COG (v), left hip angle (αL), right hip angle (αR), take-off angle (θ), momentum of left arm (ML) and right arm (MR) for 2 different dynamical conditions: jump without and with arms swinging. Kinematic data with basic descriptive statistics results of all subjects can be seen in Table 2.

Table 2. Mean, SD of selected kinematic parameters of all subjects.

| Sbj. | | Jump without arms swinging | | | | | | | | Jump with arms swinging | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | H1 | D1 | αL | αR | v | θ | ML | MR | H2 | D2 | αL | αR | v | θ | ML | MR |
| JaCe | M | 0.42 | 1.56 | 78.70 | 80.30 | 0.97 | 36.17 | 4.16 | 4.63 | 0.36 | 2.14 | 79.00 | 76.30 | 0.94 | 32.80 | 15.81 | 15.00 |
| | SD | 0.01 | 0.06 | 6.72 | 4.36 | 0.20 | 4.70 | 0.67 | 1.06 | 0.07 | 0.01 | 4.47 | 2.10 | 0.04 | 0.24 | 1.75 | 2.54 |
| MaVa | M | 0.33 | 1.84 | 77.30 | 79.20 | 1.11 | 27.90 | 3.26 | 3.95 | 0.34 | 2.27 | 78.90 | 69.27 | 1.19 | 38.30 | 8.76 | 7.99 |
| | SD | 0.01 | 0.03 | 4.78 | 1.27 | 0.04 | 6.11 | 0.36 | 0.14 | 0.04 | 0.03 | 1.67 | 1.07 | 0.08 | 3.95 | 0.79 | 2.61 |
| MiRu | M | 0.38 | 1.70 | 79.10 | 76.40 | 0.95 | 44.97 | 3.62 | 3.83 | 0.41 | 2.29 | 75.20 | 71.63 | 1.04 | 34.10 | 12.48 | 11.40 |
| | SD | 0.02 | 0.01 | 7.30 | 1.65 | 0.05 | 2.18 | 0.61 | 0.07 | 0.02 | 0.04 | 3.79 | 2.62 | 0.14 | 2.10 | 0.65 | 2.27 |
| ToMa | M | 0.29 | 1.88 | 81.60 | 73.10 | 1.48 | 46.40 | 6.04 | 6.29 | 0.36 | 2.19 | 69.90 | 73.13 | 1.32 | 36.20 | 11.72 | 14.50 |
| | SD | 0.02 | 0.03 | 5.82 | 5.27 | 0.04 | 2.51 | 0.72 | 1.43 | 0.02 | 0.05 | 5.59 | 4.36 | 0.05 | 1.48 | 1.27 | 4.19 |

Subject ToMa achieved the best results - maximal horizontal distance as well as velocity of body COG during take-off for both ways of jumps (with and without arm swinging). The longest jump from all attempts was reached when θ = 34.5° (jump with arm swinging) and θ = 43˚ (jump without arms swinging). The values for take-off angles were the lowest of all the attempts the subject made.

The significance of both ways of jump separately has proved no significant differences.

The results of the comparison of the jump length without and with arm swinging are shown in Fig. 3. The length of the standing long jump was in case of subject JaCe prolonged using arm swinging (characterized by acceleration 30.01 m/s$^{-2}$ and momentum 15.7 kg.m/s) with an additional length of 0.36 m.

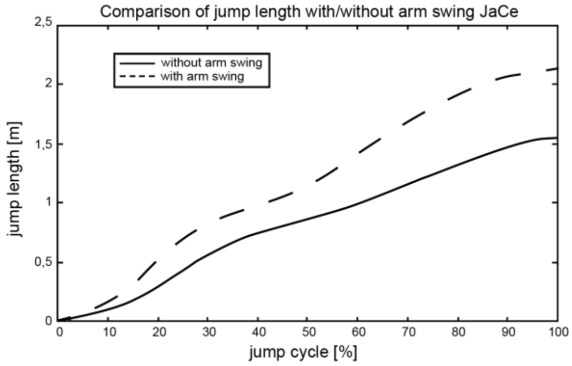

Fig. 3. Jump length without and with arms swinging of subject JaCe.

The difference between the average jump length without (D1) and with arms swinging (D2) is displayed in Table 3 in the form of gain in jump length (G) that sportsman achieved with arms swinging acting during the jump.

Table 3. Gain in length of jump with arms swinging.

| Subject | D1 [m] | D2 [m] | G [%] |
|---|---|---|---|
| JaCe | 1.56 | 2.14 | 27.33 |
| MaVa | 1.84 | 2.28 | 19.19 |
| MiRu | 1.70 | 2.29 | 25.67 |
| ToMa | 1.88 | 2.23 | 14.84 |

The difference between the average jump of relevant kinematic parameter without (1) and with arm swinging (2) is in the form of gain of relevant kinematic parameters displayed in Table 4. Gain is defined in percentages that show the gain in distance, velocity, angle when the average parameter is compared for jumps with arm swinging and without. It shows an increase if the gain is a positive number or decrease when the gain is a negative number.

Table 4. Gain in all kinematic parameters made by arms swinging.

| Gain of relevant kinematic data G[%] | | | | |
|---|---|---|---|---|
| Subject | D | H | α | v |
| JaCe | 27.33 | -16.66 | 0.70 | -3.54 |
| MaVa | 19.19 | 2.94 | 27.21 | 6.46 |
| MiRu | 25.67 | 7.31 | -31.99 | 8.94 |
| ToMa | 14.84 | 19.44 | 21.98 | -12.37 |

Based on the differences proved in values of gain in jump length that sportsman achieved using arm swinging, we have decided to conduct an analysis of variance in order to analyze the various results of individuals.

We analysed data using Kruskal-Wallis with the level of significant differences $p<0.05$.

Boxplot in Fig. 4 displays the comparison of jumps of subject JaCe. It displays the difference of jump length for 3 jump attempts between jumps without (left) and with arms swinging (right). The boxplot represents the medians, 5 and 95 percentile and the whiskers (upper and lower extreme value).

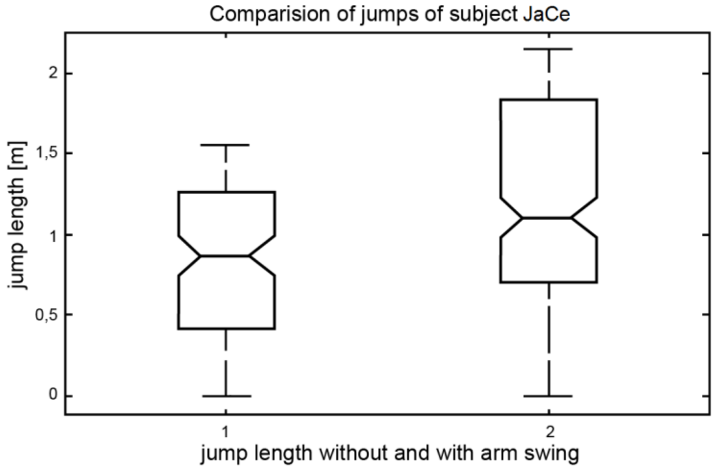

Fig. 4. Comparison of jump length of jump with and without arms swinging.

The results of the significance testing for jump length are stored in Table 5 where it can be seen that 3 out of 4 subjects' jumps were influenced significantly (two of them with $p<0.0001$).

Table 5. Jump length - results of analysis of variance, $p<0.05$.

| Subject | p-value | Statistical |
|---|---|---|
| JaCe | $2.39.10^{-5}$ | $p<0.0001$ |
| MaVa | $1.87.10^{-4}$ | $p<0.0001$ |
| MiRu | $4.50.10^{-3}$ | $p<0.01$ |
| ToMa | $1.43.10^{-1}$ | Non-significant |

From the evaluation of variability of jump height with and without arm swinging, we can see it in the boxplot in Fig. 5. It displays the difference of jump height for 3 jump attempts between jumps without (left) and with arm swinging (right). The boxplot represents the medians, 5 and 95 percentile and the whiskers (upper and lower extreme value).

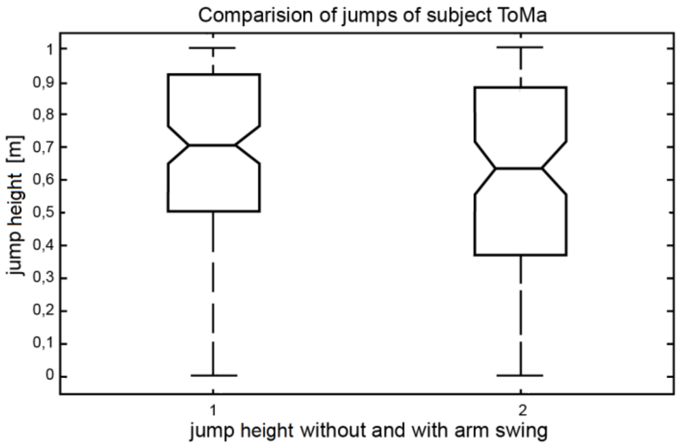

Fig. 5. Comparison of jump height of jump with and without arms swinging.

The results of the significance test within intraindividual evaluation comparing 2 ways of jump are stored in Table 6 for each kinematic parameter (jump length, jump height, left and right hip angle).

Table 6. Results of intraindividual analysis of variance, $p<0.05$, for jump length, jump height and hip angle.

| Subject | p-value | | | |
|---|---|---|---|---|
| | Length | Height | Hip angle | |
| | | | Left | Right |
| JaCe | $2.39.10^{-5}$ | $3.3.\ 10^{-1}$ | $2.5.10^{-3}$ | $1.10^{-4}$ |
| MaVa | $1.87.10^{-4}$ | $9.5.\ 10^{-1}$ | $1.1.\ 10^{-3}$ | 0 |
| MiRu | $4.50.10^{-3}$ | $8.6.\ 10^{-1}$ | $4.6.10^{-1}$ | 0 |
| ToMa | $1.43.10^{-1}$ | $2.7.\ 10^{-1}$ | $1.0.10^{-4}$ | 0 |

Fig. 6 shows the comparison of the hip angle of the 4 subjects within intraclass evaluation. The boxplot represents the medians, 5 and 95 percentile and the whiskers (upper and lower extreme value).

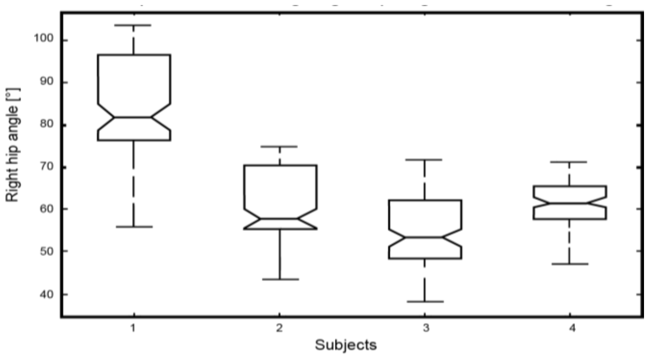

Fig. 6. Comparison of hip angle of jump with and without arms swinging of 4 subjects.

The results of the significance test within intraclass evaluation are shown in Table 7, where row 1 indicates the p-value as a result of analysis of variance for jump length or jump height and the p-value for hip angle of the group of the sportsmen for jumps without arm swinging. Row 2 shows the same parameters for jumps with arm swinging.

Table 7. Results of intraclass analysis of variance, $p<0.05$. for jump length, jump height and hip angle.

| Way of jump | p-value | | | |
|---|---|---|---|---|
| | Length | Height | Hip angle | |
| | | | Left | Right |
| 1 | $1.5.10^{-1}$ | $2.8.10^{-1}$ | 0 | 0 |
| 2 | $8.1.10^{-1}$ | $3.8.10^{-1}$ | 0 | 0 |

## 4. Discussion

The results presented are in the agreement with previous studies and prove that in order to achieve maximal horizontal distance of the centre of gravity; the jumping body has to reach an appropriate kinetic energy to overcome the gravity. To achieve the higher level of kinetic energy, it is important to attain the maximal reachable velocity of COG at the moment of take-off. This theory was confirmed by results achieved by measuring velocities.

The level of the momentum of arms at the time when the centre of gravity reaches maximal height has a significant role for the jump length. In that time also the momentum of arms accelerates the whole body moving forward. The movement was determined as the difference between the values at take-off. Momentum of upper extremities, called also arm swing, starts to act the most significantly and it enhances the kinetic energy and improves the overall power of the jumping body. It is also recommended that the maximal vertical position of COG be achieved as far as possible from the take-off position [12]. The best jumps were performed when the subjects reached the maximal velocity of COG and minimal take-off angle at the same time. While the range of the take-off angles θ in the best jumps with arm swinging was 29˚ - 37˚, for the best jumps without arm swinging it was 31˚- 49˚. Every subject had his own unique take-off angle related to the top performance, i.e. the longest jump.

The comparison of the jump length without and with arm swinging was used to visualize the difference between 2 different conditions. It enables to achieve information how great the impact of the upper extremities' dynamics is in relation to overall motion activity. For example, the results of the comparison of the jump length without and with arm swinging prolonged using arm swing with an additional length of 0.36 m. This is the reason why it is very interesting to evaluate the relation between the arms swinging and kinematic data describing the dynamics of movement can help to predict and provide a diagnosis on the dynamic abilities of sportsmen. From the data represented by the gain in jump length we can confirm that arms swinging can influence the length of jump positively. On the other hand, we can conclude that jumps without arm swinging can make a jump shorter by 15-30%.

From the evaluation of variability of jump height with and without arm swinging, we found no significant differences between jump height performed with and without arm swinging. It means that the momentum of upper extremities did not influence critically the jump height by any of the tested sportsmen.

The comparison of the hip angle of the 4 subjects within intraclass evaluation proved statistically significant differences. It shows the importance to analyze the angles of the lower extremities more in the detail.

## 5. Conclusions

In the paper, we have focused on conducting a pilot research in the area of movement kinematics in standing long jump. From the achieved results we can conclude that dynamics of upper extremities characterized by momentum can significantly influence the jump length defined as horizontal distance. Single momentum of upper extremities affected kinematic parameters, which had an influence on the overall performance too. However, there was no statistically significant influence on the jump height, vertical distance observed. We have also proved that the distances as well as the maximum height of the centre of gravity are non-significant within the statistical evaluation of class variability. The hip angle has shown statistical significance within both evaluations (intraindividual and intraclass data variability evaluation). The significance of both ways of jump separately has proved no significant differences. The intraindividual comparison showed the statistically significant differences in 75% of jump length and 88% of hip angle. The jump height proved no differences. However, the only kinematic parameter that proved the significant differences between jumps with and without arm swinging was the hip angle.

Currently we are completing more experiments and all required data will be used for the analysis of arms swinging, momentum of upper extremities, and its contribution to the jump length before and after the dynamic training that enhances arms acceleration and the most efficient performance style. In future research it would be interesting to conduct more experiments with quantification of the momentum of upper extremities (arm swinging), before dynamic training that enhances the arms acceleration. And it is also challenging to see how the training, focused on the dynamics of movement, can influence take-off and kinematic parameters.

Therefore, it would be advisable to analyze also other upper and lower limb angles and to apply two-ANOVA's test to figure out whether the changes of the angles have any influence on the achieved performance. However, there was a technical limitation occurring in the movement capture process, i.e. marker occlusion problems.

Our final goal is to use the evaluation of standing height jump as standard assessment of sportsmen to control their training plans and add also additional tests to evaluate the movement of our sportsmen.

It is a challenge for further analysis to investigate more exercises, e.g. standing height jump to predict and control the ability of athletes or sportsmen in general to take-off.

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