An Analysis of Kinematic and Dynamic Properties of Sportsmen Performing Standing Long Jump

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Abstract- This paper presents results of the study devoted to (1) analysis of impact of upper extremities' momentum on the jump length and (2) analysis of selected kinematic data changes during the standing long jump. Five young sportsmen participated on the initial study. They have performed standing long jump in two measuring conditions: jump with arms' swing and jump without arms' swing. Motion was captured and kinematic data were recorded using 3D opto-electronic camera system SMART (BTS). Trajectory of centre of gravity (COG), velocity of COG, maximal vertical distance of COG, take-off angle together with momentum of upper extremities were analyzed. Selected kinematic data were statistically evaluated using descriptive statistics. Statistical significance of the kinematic data and jump length were analyzed using ANOVA and post-hoc Scheffe test ($p \ll 0.05$) in Statistics toolbox of program Matlab. Statistically significant differences were assessed within intraindividual and intraclass comparison of data.

I. Introduction

Standing long jump was an Olympic discipline till 1938 [1]. The world record is held by Arne Tveraag who has reached limit of 3.74m on the national athletic championship in Norway in 1968 [2]. However, it is not an official Olympic event anymore. Nowadays, standing long jump still has its place in the training programs of the sportsmen, mainly athletes. It is widely used as a functional test to assess power of lower extremities. It became an excellent drill for triple jumpers of all ages [3] and it serves for monitoring power, leg strength and performance related features of sportsmen abilities. Standing long jump is described as non-periodic locomotion. Therefore, its analysis is more complex and requires different approach than e.g. gait analysis. The performance of standing long jump was often adopted to examine the fitness of the 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 the athlete does not use the best possible technique [3]. In human motion analysis this test is applied to assess legs power and thus estimate the dynamic properties of movement. A performance of sport and also daily activities requires both strength and power. To train strength the exercises that 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 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 [4].

II. Material and methods

A. Subjects

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. Their mean height and body weight were 1.81±0.05cm, 71.75±7.89kg (Table 1). The subjects were informed of 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
JaHa	1,72	62	17
MiRu	1.82	71	16
ToMa	1.86	84	17

B. Standing long jump as test

The scope of the research was to determine a set of kinematic data that specify the standing long jump. The aim of one of the study included in the research was to assess kinematic parameters and define those that are the most influenced by dynamics of upper extremities.

Standing long jump is defined by following parameters:
- Maximal horizontal distance = length of jump
- Maximal vertical distance = height of jump
- Velocity of centre of gravity
- Take-off angle (θ)
- Hip angle (α)
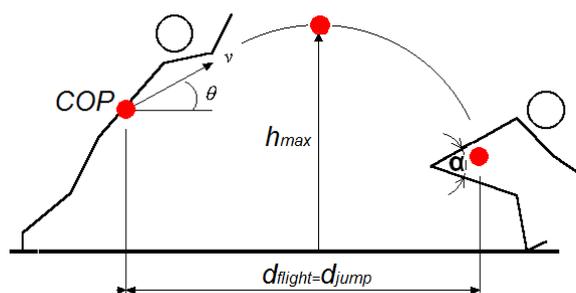- Momentum of upper extremities

Figure 1. Standing long jump

C. Measurement set up

System SMART from BTS Bioengineering, Italy used in Motion Analysis Laboratory at our department was the main technical equipment used to capture motion data. Movement capture is based on passive markers' detection placed on human body moving in the calibrated space by cameras with infrared filter. The markers are located on anatomically relevant points of human body, as it is seen on Figure 2.
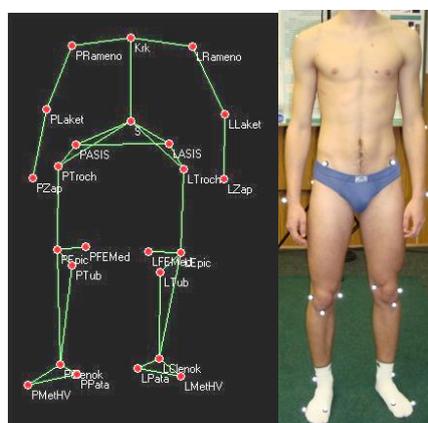

Figure 2. Model of markers' position and marker set attached on human body

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The model included 24 markers placed on anatomically significant places cervical vertebra, 1st sacral vertebra (S), acromioclavicular joint (P/L Rameno), lateral epicondyle of humerus (P/L Laket), ulnar styloid process (P/L Zap), anterior superior iliac spine-pelvis (P/L ASIS), greater trochanter of femur-hip joint (P/L Troch), lateral epicondyle of femur-knee joint (P/L Epic), medial epicondyle of femur-knee joint (P/L Med), tibial tuberosity-below patella (P/L Tub), lateral malleolus-ankle joint (P/L clenok), calcaneus (P/L Pata) and 5th metatarsal head-smallest toe (P/L MetHV.).

D. Data analysis

Selection of the relevant kinematic parameters, variables was based on the theory of oblique throw. Important kinematic variable is take-off angle. It is defined as inclination angle during take-off moment, angle of tangent to the trajectory of centre of gravity with horizontal axis in the moment of take off. Other variables we studied were velocity of centre of gravity (COG) during take-off , angle hip and momentum of right and left arm.
Standing long jump was performed first with arm swing and then without arm swing. The performance of the sportsman was defined as vertical distance of centre of gravity (COG) from the moment of take-off till moment of initial contact with ground. Kinematic characteristics as change of position, velocity, acceleration and angular parameters were captured by system SMART installed in Motion Analysis Laboratory at our department.
The process of data evaluation was conducted in SMART Analyzer. It is a software package provided with SMART system used for data analysis. To process and evaluate the quantitative empiric data from motion analysis, we used tools of MS EXCEL and Statistics Toolbox of MATLAB 7.0. We focused on the influence of parameters changes, relation of kinematic variables and influence that arm swing with its momentum has on sportsman performance.

III. Results

In order to achieve maximal horizontal distance of centre of gravity, the jumping body has to reach appropriate kinetic energy. To achieve the higher level of kinetic energy, it is important to reach maximal possible, attainable velocity of centre of gravity of whole body in the moment of take-off. This theory was confirmed by results achieved by measuring velocities. Maximal horizontal distance as well as velocity of centre of gravity of body during take-off was in the case of subject ToMa in both ways of jumps (with and without arm swing) the greatest of all participants. Maximal value of velocity that centre of gravity has during take-off is reasonably lower when jump without arm swing is performed. It can be caused by energy added due to arm swing that contributes to whole body momentum and dynamics. The maximal jump was reached when take-off angle α was 34.5° at the standing long jump with arms swing and 43˚ at jump without arms swing. The values for take-off angles were the lowest from all the attempts the subject made. Kinematic data with basic descriptive statistics results of all subjects can be seen in Tab.3. It includes jump length (D), height (H), velocity of COG (v), left hip angle (αL), right hip angle (αR), takeoff angle (θ), momentum of left arm (ML) and right arm (MR) for 2 conditions: without arm swing and with arm swing.

Table 2. Mean, SD of kinematic parameters, momentum of arm during takeoff all subjects

Sbj.		Jump without swing arm								Jump with swing arm							
		H1	D2	αL	αR	v	θ	ML	MR	H2	D2	αL	αR	v	θ	ML	MR
JaCe	M	0,42	1,56	78,67	80,27	0,97	36,17	4,16	4,63	0,36	2,14	79,03	76,30	0,94	32,83	15,81	15,02
	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	77,33	79,17	1,11	27,90	3,26	3,95	0,34	2,27	78,90	69,27	1,19	38,33	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	79,13	76,37	0,95	44,97	3,62	3,83	0,41	2,29	75,17	71,63	1,04	34,07	12,48	11,40
	SD	0,02	0,00	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	81,63	73,13	1,48	46,40	6,04	6,29	0,36	2,19	69,90	73,13	1,32	36,20	11,72	14,49
	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

To achieve good performance it is necessary that momentum of arms is high during take-off phase because it can influence maximal vertical position that centre of gravity reaches during jump (h). The level of the momentum of arms in the time when centre of gravity reaches maximal height has the significant role for the jump length. In that time also 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 contributes to enhance kinetic energy and improve the overall power of jumping body. It is also recommended that the maximal vertical position of COG is achieved as far as possible from the take off position.

The best jumps were done when subjects reached in the same time maximal velocity of centre of gravity and minimal take off angle while the range of the take off angles α at the best jumps with arm swing was 29° - 37°and for the best jumps without arm swing it was 31°- 49°. Every subject had own unique take-off angle connected to the top performance - longest jump.

The comparison of the jump length without and with arm swing was used to visualize the difference between 2 different conditions. It serves to achieve information about influence that dynamics of upper extremities has on overall motion activity. The results of the comparison are shown in Fig. 3. The length of standing long jump was in case of subject JaCe prolonged using arm swing (characterized by acceleration 30,01 m/s^{-2} and momentum 15.7 m/s^{-2}) with approximately 0.36m. This is the reason why it is very interesting to evaluate the relation between the arms swing and kinematic data describing dynamics of movement and can help to predict and provide diagnosis about the dynamic abilities of sportsmen.
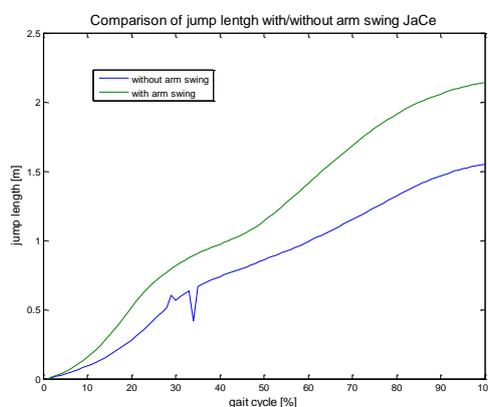

Figure 3. The length of standing long jump without and with arm swing JaCe

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

Table 3. Gain in jump length when sportsman performed jump with arm swing

Subject	D1 [m]	D2 [m]	G [%]
JaCe	1.558	2.144	27.332
MaVa	1.840	2.277	19.192
MiRu	1.703	2.291	25.666
ToMa	1.876	2.23	14.843

From the data we can confirm that arm swing can influence length of jump. The data in Tab. 3 also support the theory about great contribution of arm swing to overall performance. Therefore, we can conclude that jumps without arm swing can make jump be shorter with 15-30 %.

Based on the differences described with values of gain in distance that sportsman achieved using arm swing, we decided to conduct analysis of variance.

One-way ANOVA (Kruskal-Wallis) test can applied to analyze variability and point out the differences between compared data. The subject of statistical interpreting within intraindividual and intraclass evaluation were the following parameters: length, height of jump and hip angle (left, right). The significance of these parameters was performed as follows:

1. Intraindividual evaluation
   - significance at both ways of jump separately
   - significance at comparing of both ways of jump
2. Intraclass evaluation
   - significance of jump without arm swing (1)
   - significance of jump with arm swing (2)

The result of ANOVA test is p-value, critical value, with which we compare the level of significance that data are evaluated on.

We analysed data using 1way ANOVA test, with level of significant differences $p<0.05$. Boxplot on Fig.4 displays the results of comparison of jumps of subject JaCe within intrandividual evaluation. It displays difference between medians of average jump length from 3 jump attempts between jumps without (left) and with arm swing (right).
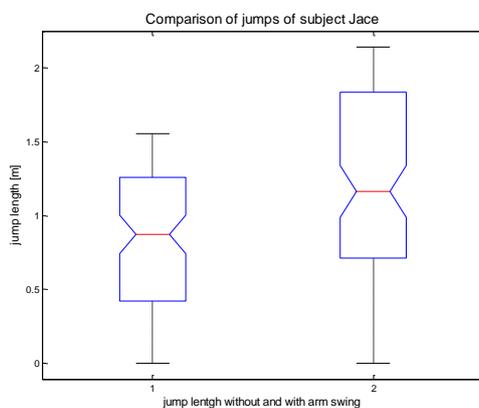

Figure 4. Comparison of jump length

The results of the significance testing within intraindividual evaluation comparing of both ways of jump are stored in Table 4.

Table 4. Results of analysis of variance 1 way ANOVA test, $p<0.05$

Subject	Length	Heigth	Hip angle	
			Left	Right
JaCe	0.2988	0.3348	0.0025	0.0001
MaVa	0.1071	0.9462	0.0011	0
MiRu	0.0045	0.8603	0.4588	0
ToMa	0.1931	0.2679	0.0001	0

The Figure 5 shows that hip angle of the subject 1 within intraclass evaluation is significantly different.
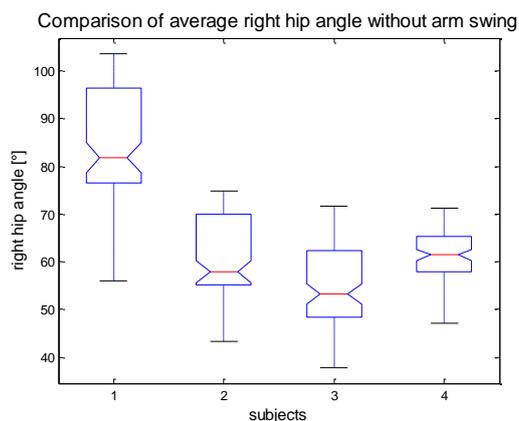

Figure 5. Comparison of hip angle

The results of the significance testing within intraclass evaluation are showed in Table 5.

Table 5. Results of analysis of variance 1 way ANOVA test, p<0.05

Way of jump	Length	Heigth	Hip angle	
			Left	Right
1	0.1551	0.2791	0	0
2	0.8141	0.3847	0	0

IV. Conclusion

Our meaurements of standing long jump in the small group of sportsmen showed that dynamics of upper extremities characterized by momentum can significantly influence length of jump. From the gained results we can conclude that the distances as well as the maximum heights of the mass of gravity are non-significant within the statistical evaluation of class variability. It was approved by hypothesis testing – 1way ANOVA method. Hip angle does statistically difference within both of evaluations and therefore it would be advisable to analyse also other upper and lower limb angles and by two-ANOVA's test figure out, whether the changes of the angles have any influence to the achieved performance. Currently we are completing more experiments, and all required data will be used for the analysis of arm swing, momentum of upper extremities, and its contribution to the jump length before and after the dynamic training that enhance the arms acceleration and the most efficient performance style. Our final goal is to use evaluation of standing height jump for standard assessment of sportsmen to control their training plans.

Acknowledgement

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