# COMPARISON OF THREE MOTION ANALYSIS PROGRAMS BASED ON THE SHOT PUT PERFORMANCE

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The aim of the study was to compare the results obtained using the three programs: Vicon, OpenSim and AnyBody. The feasibility of the application and of the selection of one of the programs for further analysis of the sport technique was checked. In the experiment herewith, the torque and power as function of time in the joints of the lower limb during the last phase of shot put was computed. Examinations of the kinematic and kinetic parameters of analyzed movement were carried out using Vicon system and Kistler force plates. Three top level national competitors took part in the study. The differences between the torques and power were checked with a modified RMS index. The results obtained indicate that OpenSim program may be useful for further studies, and in particular in controlling and analyzing the neuromusculoskeletal system.

**KEYWORDS:** Vicon, Anybody, OpenSim, power, torque.

**INTRODUCTION:** Shot put, discus throw and javelin throw belong to the acyclic track and field disciplines. In the shot put, the distance at which the ball will fly depends mainly on the release angle and the speed at which it will be thrown (Linthorne, 2001). Two putting techniques are in current use by shot put competitors: the glide and the spin. The spin involves rotating like a discus thrower and using rotational momentum for power. The glide technique involves the putter facing backwards, rotating 180 degrees across the circle, and then tossing the shot. With this technique, a right-hand thrower transfers the weight from right to the left leg and performs a rotation of the whole body (Lanka, 2000). As it can be seen, in the entire kinematic chain participating in the shot put, lower limbs play a significant role. For this reason, in the studies of the biomechanics of shot put, among other things, the values of ground reaction force components exerted against the right and left foot during delivery were highlighted (Peng et al., 2008). Parallel to the new techniques for measuring kinematic and kinetic parameters, there are new programs developed to carry out biomechanical simulations (Nunes, 2013). The most interesting ones include the multi body models. According to the conventional methods used in the measurements of mechanisms, in rotation pairs connecting body segments, the torques generating movement is determined. In this paper, the torques producing movement in the joints will be referred to as torques of muscular forces. Power generated by torques of muscular forces, telling in which segment the power is generated, and where it may be lost, was also calculated (Gordon et al., 1980). The main aim of this paper was to identify the torque and power of the lower limb joints and to compare the results of the biomechanical analysis of shot put performed by three top level competitors based on three programs: Vicon, AnyBody and OpenSim.

**METHODS:** Three top level national male competitors (age: 26 ± 4.5 years; height: 1.98 ± 0.6 m, weight: 131 ± 10.5 kg) participated in the experiment. First, anthropometric measurements were taken for each person. Next, spherical markers were placed at anatomical landmarks according to the biomechanical model PlugInGait standards available within the motion capture Vicon system. Three Kistler force plates, embedded into the floor, were used to determine ground reaction force data at a sampling rate of 1000 Hz. A motion capture system, consisting of nine infra-red cameras, was employed to collect kinematics data at a sampling rate of 100 Hz. The force plates were synchronized to the motion capture system. Both systems were calibrated according to the manufacturers' recommendations before the trials were conducted. In all three programs, it is: Vicon, AnyBody and OpenSim the models were built based on anthropometric parameters of the competitors, kinematic and ground reaction force data, describing the mechanics of movement during the shot put. An additional shot weights 7.26 kg was applied to the right hand of the competitors. Procedures of scaling, inverse kinematics and inverse dynamics were carried out in each program. In the Vicon program joint torques and powers were read out immediately after processing movement. To calculate this date in the program AnyBody, the multiple segments model with 17 degrees of freedom was used. Whereas, in the OpenSim program the model what was used had 23 degrees of freedom. A three-dimensional model of the human locomotors system has 37 degrees of freedom. Therefore, it was necessary to adapt the model to the dynamics of movement during the shot put. Among other things, the values of optimum forces for the torques were increased. In this paper, torques and powers of the three joints of the lower limbs were selected for further analysis. The time of movement analysis in all programs was based on data from force platforms. The analysis applies to the last phase of the throw which is the placing of the left leg on the platform, whereas the end is the moment before releasing the ball by the competitor. The joint power was calculated from the formula: $P_{M(j,n,m)} = M_{(j,n)}(\omega_n - \omega_m)$, where: *M* – joint torque; *ω* - angular velocity; *j* – joint; *n, m* – segments. The comparison of the changes in the torque and power functions observed in the three joints of the lower limbs were performed using a modified similarity index RMS, varied from 0 up to 1. The formula for RMS is as follows: $RMS = \sqrt{\frac{\sum_{i=1}^{n}((\emptyset 1(i) - \emptyset 2(i))^2}{\sum_{i=1}^{n}((\emptyset 1(i) + \emptyset 2(i))^2}}$ where: ∅ - function describing the change of the parameter values *(1, 2)* as a function of time, *i* - the value of the function at the i-point.

**RESULTS:** The figure 1 shows the curves for left knee joint torque and joint power in a shot put performed by one of the competitors. The displacement of the curves along the horizontal axis of torque and power shown is not observed.

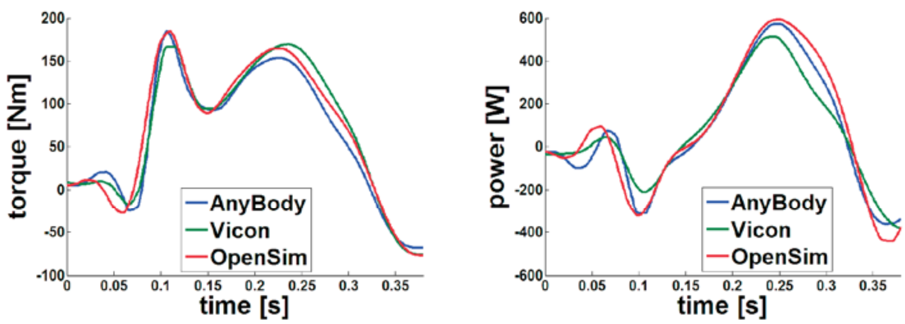


**Figure1: Comparison of joint torque and joint power in a shot put performed by one of the competitors (S1) in the sagittal plane. The results of 3 different models according to the: Vicon, AnyBody and OpenSim programs.**

There are also no significant differences in the amplitudes of the two studied parameters. For cognitive reasons it was interesting to know the extreme values of joint torques and joint powers during the shot put. Using the modified RMS index, the similarity of curves was studied for all competitors and in all joints of lower limb. Comparative analysis of the results of the three programs was carried out on a "peer" basis. The results indicated in the table 1 show differences between the maximum values of joints torque calculated by three different programs, and they range from 5 to 30%, in 20 over 27 cases. The biggest difference of about 40% was noted in one competitor at the torque developed in the hip joint. Whereas the differences between the competitors in the maximum values of torque are very large, reaching up to 70%. Analysis of similarities of all changes (RMS) shows that the most similar results are obtained between programs OpenSim and AnyBody and varied from 0,035 to 0,324. Another pair with the highest similarity of results is Vicon and AnyBody.

**Table 1: Comparison of minimum, maximum and similarity index (RMS) values of lower limb joints torque and power during shot put for: OpenSim (O) AnyBody (A) and Vicon (V).**

| | T [Nm] | | | | | | RMS [-] | | |
|---|---|---|---|---|---|---|---|---|---|
| **Subject** | **max O** | **max A** | **max V** | **min O** | **min A** | **min V** | **O - V** | **O - A** | **V - A** |
| **ANKLE** | | | | | | | | | |
| **S1** | 166 | 179 | 186 | -3 | -1 | -3 | 0,080 | 0,039 | 0,067 |
| **S2** | 205 | 200 | 215 | -5 | -4 | -4 | 0,079 | 0,035 | 0,113 |
| **S3** | 66 | 75 | 58 | -4 | -5 | -12 | 0,196 | 0,096 | 0,204 |
| **KNEE** | | | | | | | | | |
| **S1** | 211 | 191 | 195 | -20 | -21 | -32 | 0,094 | 0,068 | 0,055 |
| **S2** | 170 | 97 | 160 | -115 | -130 | -148 | 0,183 | 0,324 | 0,209 |
| **S3** | 184 | 185 | 169 | -77 | -69 | -76 | 0,064 | 0,078 | 0,076 |
| **HIP** | | | | | | | | | |
| **S1** | 87 | 102 | 61 | -13 | -33 | -51 | 0,598 | 0,156 | 0,549 |
| **S2** | 105 | 141 | 98 | -163 | -180 | -186 | 0,193 | 0,209 | 0,1845 |
| **S3** | 151 | 185 | 235 | -157 | -180 | -96 | 0,436 | 0,146 | 0,479 |
| | **P [W]** | | | | | | **RMS [-]** | | |
| **ANKLE** | | | | | | | | | |
| **S1** | 727 | 787 | 751 | -67 | -84 | -96 | 0,116 | 0,113 | 0,177 |
| **S2** | 871 | 990 | 566 | -302 | -277 | -253 | 0,263 | 0,261 | 0,280 |
| **S3** | 305 | 319 | 656 | -79 | -49 | -9 | 0,342 | 0,065 | 0,306 |
| **KNEE** | | | | | | | | | |
| **S1** | 620 | 583 | 714 | -395 | -279 | -230 | 0,161 | 0,094 | 0,169 |
| **S2** | 630 | 219 | 355 | -372 | -282 | -328 | 0,653 | 0,852 | 0,326 |
| **S3** | 594 | 572 | 514 | -442 | -363 | -384 | 0,160 | 0,093 | 0,114 |
| **HIP** | | | | | | | | | |
| **S1** | 316 | 538 | 422 | -61 | -108 | -144 | 0,367 | 0,441 | 0,140 |
| **S2** | 175 | 379 | 266 | -224 | -251 | -389 | 0,559 | 0,598 | 0,350 |
| **S3** | 466 | 629 | 269 | -282 | -85 | -17 | 0,520 | 0,339 | 0,479 |

In a similar way, the analysis was made for mechanical power. The power values are in the range of -442 to 990 W. In the interval of 0 to 30% of the maximum comprise 19 to 27 cases. In view of changes in the curve of the power as a function of time, observed in the three joints of each of the subject as expected, the greatest powers are developed in the ankle joint, then in the knee and hip. Mostly the power of the knee joint is reduced by about 20% compared to the ankle and the power of the hip is reduced by 30% compared to the knee. The similarity of the curves of power in the individual joints expressed in the RMS value is significant and closes in the range of 0.09 to 0.852. Cross-section analysis between programs clearly prefers OpenSim program when the Vicon was chosen as the reference program.

**DISCUSSION:** According to Lindhorne (2001) in order to achieve good performances, it is not necessary to throw at very close release angle. Throwing with high speed is more important than throwing with the optimum release angle. This shows that shot put is a dynamic event demanding high power production. Many studies have shown that both lower and upper-body muscles contribute to the development of the total force value (Peng et al., 2008). The muscles of the lower limb are designed to generate power in order to impart the appropriate momentum to the whole body and to stabilize the competitor. The torque and power as function of time for the knee joint presented in Figure 1 and determined using computer software Vicon, OpenSim, AnyBody, show high compatibility. This confirms the correctly tracked lower limb kinematic model and the correctly applied ground reaction forces. Hill's model used in the above-mentioned programs is characterized by the fact that if a passive work force is applied on the muscle, then along with the lengthening of the muscle an increase in strength over the maximum isometric strength is observed. The muscle then works under eccentric condition. When we consider the activation of the muscles throughout the entire kinematic chain the interplay of concentric and eccentric contractions decide on the mechanical energy flow in the motor system of the human body. Generation and dissipation of mechanical energy in the individual segments of the body, starting from ankle to wrist, may be a good criterion for assessing the correctness of the performance of shot put (Guo et al., 2003, Gordon et al., 1980). In conjunction with the analysis of the activity of individual muscles, the possibility of which is offered by OpenSim and AnyBody programs, sports practice receives a powerful tool for planning and monitoring the methodology for improvement of sports technique. AnyBody - the commercial program seems to be more able to create its own models, which is important in the simulation of movements in various sports, especially with regard to the upper limbs. OpenSim program is free of charge and only some of the properties of the model can be changed in the program window. However, OpenSim program is continuously developed and expanded by many laboratories around the world, thus creating a powerful simulation environment, also with a wide variety of models (Łysoń et al., 2015). Assuming that the Vicon program is the base, the choice of modeling software takes place between OpenSim and AnyBody. The available method of analysis for the curves, based on the RMS does not give the obvious solution to achieve an objective selection. The reason is the lack of statistical criterion, i.e. thresholds of statistical significance for the RMS values for different movements (Mayagoitia et al., 2002).

**CONCLUSION:** The above three programs allow for an adaptation or creation of own mathematical models for the analysis of movement in shot put. No significantly large differences between the results of calculations made using these three programs were observed. The analysis of the differences was provided by available RMS method. The focus should be on the OpenSim program, which seems to be more accessible and future-oriented. The pattern of activating individual muscles as well as the value of the forces developed in subsequent phases of movement is a key issue in training to improve sports technique.

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