Assessment of Mechanical Stiffness of Jumping Using Force Plate

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Abstract. In this paper the basic information about methodology of assessment human body stiffness during vertical jump analysis is presented. Ten subjects (professional football player) perform ten periodic jumps and vertical ground reaction force is measured using a force plate with one axial load cell force sensor. The stiffness calculation is based on the analogy of the periodic jumping and oscillation movement of the system which consists of spring and body appropriate mass. The frequency of oscillation is obtained using Fourier transform.

Keywords: Vertical jump · Force plate · Mechanical stiffness

1 Introduction

Quantification and description of the of jumps performed during sports games, such as drop jump, squat jump, and counter movement jump is very important part of the measurement of the athletic performance in the sports. The standard method in jump analyzing is based on the use of a force sensors platform for ground reaction force measuring [1–3]. The force platform can measure force and torque during jump in different directions using a force sensor [4]. Improvement of electronic devices and gadgets in recent years has enabled us to measure jumping parameters by using wearable devices, such as sensors, in footwear [5]. This method gives much comfort and real conditions to subjects due to the fact that there is no bounded area for jumping performance. Simultaneously with force measuring, for complete biomechanical analyses it is also necessary to determine the position of a particular body part. For this purpose a high speed camera is used. The high speed camera records position marker points attached to the subject's leg, arm, hip, etc. with a frame rate of 100 Hz and higher. Using the software, 3D point coordinate of markers position can be reconstructed. It is necessary to use a number of cameras for this reconstruction. Alternatively, for position reconstruction different kinds of sensors, such as accelerometer [6], gyroscope,

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goniometer and magnetometer [7] can be used. In this paper we presented a method for measuring force during jumping activity, using force plate platform and assessment of mechanical stiffness of human body. The mechanical stiffness play a very important role in assessment sportiest performance especially the tendency to the injuries.

2 Materials and Methods

The participants in experiments followed a standardized warming-up and stretching period. During the measurements, participants wore their own indoor sport shirts, shorts and sneakers. Participants were instructed to perform a number type of jumps: (squat jump, countermovement jump and hop). Their motion was recorded using two high speed cameras with a frame rate of 200 fps. The cameras with software for acquisition and image processing are part of Innovision Systems, Inc product for tracking motion with biomedical and sports application. Before performing jumping the system is calibrated.

The ground reaction force was sampled from the multi-axis AMTI force plate Fig. 1 at the rate of 300 Hz (© Advanced Mechanical Technology, Inc.). Before the start of the experiment, calibration was required to work out the space coordinate system of the field of view area. The calibration was performed fully in accordance with the manufacturer's instructions.

Fig. 1. Performing of the jumping on the force plate platform

The participants stood in front of the force plate. After the trigger was launched, each participant executed ten jumps one by one with their commonly period. Figure 2 shows signal of vertical force value during time for this type of jump.

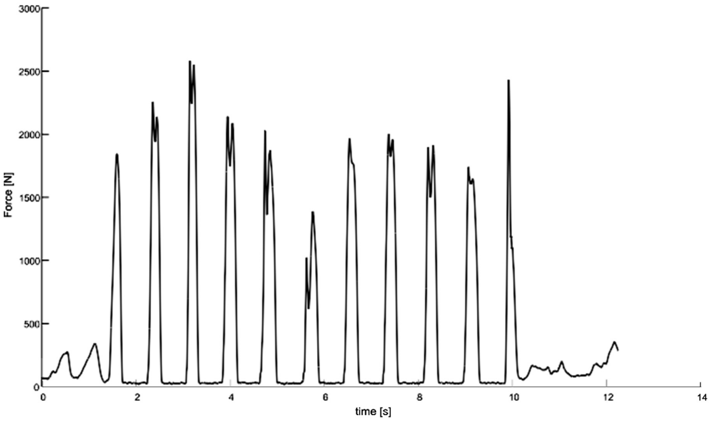

Fig. 2. Force signal during periodic jumps.

According to recorded signal the period of jumping is obtained. This is accomplished using the Fast Fourier transform FFT of the force signal.

On the Fig. 3 the amplitude of the Fourier transform is show what is known as amplitude characteristic of signal. The horizontal axis represents frequency of the signal and on the vertical axis is corresponding intensity of signal for that frequency. The peak with largest value is at point of zero frequency and it is mean value of signal. We considered only next peak at (1.2 Hz in case of this participant). This is actually the frequency of the jumping. Using this method by detecting second peak by range we can precisely obtained the jumping frequency during hop. The stiffness [N/m] of subject is given by relation

$$k_{jump} = (2\pi f)^2 m \tag{1}$$

where m is mass of the participant is experiment. The lower value of the mechanical stiffness points to the better performance of the sportiest and fewer penchant to the injuries.

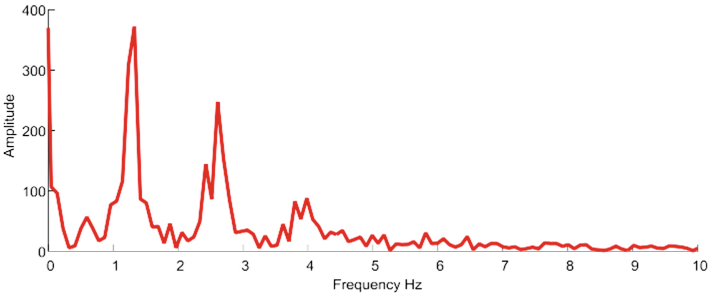

Fig. 3. Frequency spectra of the force signal

The relation between stiffness, body mass and frequency of periodic jumps is obtained by analogy between free oscillation of system which consist of body mass *m*and spring stiffness *k* Fig. 4.

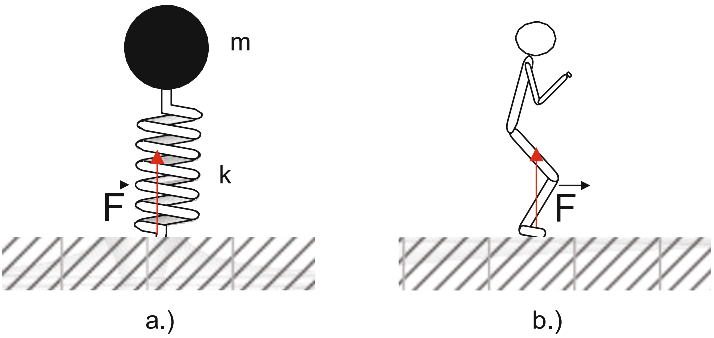

Fig. 4. Analogy between (a) spring oscillation and (b) periodic jumping

The frequency of spring oscillation is given by relation:

$$f = \frac{1}{2\pi}\sqrt{k/m} \tag{1}$$

where *k* is corresponding spring stiffness. For jumping the analog stiffness can be defined and adopt that mass of performer jumping and frequency of jumping by the corresponding mass-spring system. The ground reaction force during jumping is analog with the straining force in the spring.

For the all performers the body center mass displacement is measured using innovision camera system Fig. 5.

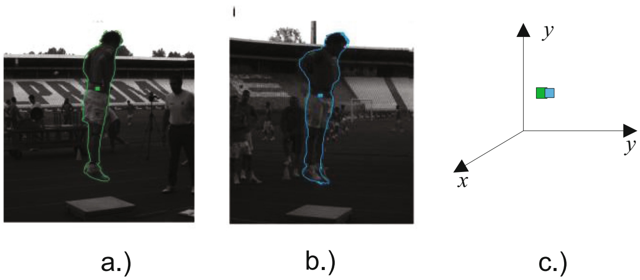

Fig. 5. (a) Left camera (b) Right camera (c) Reconstructed 3D coordinates of body mass center

The coordinates of body mass center are obtained by calculation momentum of contour of performer body during jumping.

3 Results

In the Table 1 the mechanical stiffness of body for ten subjects is shown. The stiffness is calculated using Eq. (1).

Table 1. Body weight and stiffness for ten subjects

Subject no.	Body weight [kg]	Stiffness [N/m]
1	72.2	3.1835e+03
2	74.8	3.4151e+03
3	76.4	4.2512e+03
4	63.6	4.9135e+03
5	87.0	5.2573e+03
6	62.2	4.3482e+03
7	68.3	4.5653e+03
8	59.9	3.6217e+03
9	73.5	4.4198e+03
10	72.1	4.7214e+03

The ground reaction force is related with the mechanical stiffness by relation

$$F_{ground} = K_{jump} \, . \, x \tag{2}$$

where x is displacement of the body mass center. In the Table 2 the measured and calculated displacement of the body center mass is shown. The difference of calculated and measured displacement occurs due to uncertainty of the mechanical stiffness.

Table 2. Center mass displacement for ten subjects

Subject no.	Center mass displacement [m] (obtained)	Center mass displacement [m] (measured)
1	0.79	0.93
2	0.58	0.97
3	0.64	0.88
4	0.73	0.91
5	0.67	0.95
6	0.81	0.93
7	0.65	0.64
8	0.56	0.65
9	0.78	0.86
10	0.63	0.75

4 Conclusion and Discussion

In this paper the result of measuring force during performing periodic jumps is shown. The force plate platform is one of the basic devices for biomechanical analysis. The achieved force signal is used for calculation mechanical stiffness of human body during jump. The first step is calculation mean frequency of the jump using Fourier analysis and finally the stiffness is obtained using relation of free osculation of the spring and loaded by the body corresponding mass. The ten subjects participate in the experiment and stiffness is calculated using their body mass weight. The mechanical stiffness can be used as parameter for assessment sportsman performance. The lower stiffness value indicate a less stress of lower limb during jumping. The mechanical stiffness can be used for calculation body mass center displacement according to relation between force and stiffness. The acquired results suggest difference between calculated displacements and measured using high speed camera. This is repercussion of the adapted model of the just one spring and frequency of the jumping and exemption of influence of the complex movement whole body during performing jumping. In the future work we will try to calculate mechanical stiffness using more complex model which will be include consider a number of harmonics in spectra of force signal.

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