A MODEL FOR THE SIMULATION OF VISCERAL MASS DISPLACEMENT IN DROP JUMPING

Istok Colja and Vojko Strojnik

Faculty of Sport, University of Ljubljana, Ljubljana, Slovenia

INTRODUCTION

Drop jumps may be mathematically modelled as a mass-spring-damper system with a sufficient accuracy (Aurin and Zatsiorsky, 1984). It was stated that a mass of internal viscera does not affect a maximum jumping height and a frequency of jumping. Minetti and Belli (1994) found visceral mass, which presents 14% of the total body mass, oscillating in an opposite phase than a musculo-skeletal mass during hopping and thus significantly influencing the jumping height and frequency of jumping, but also an energy consumption as well. The aim of the present study was to assess an influence of the visceral mass on jumping height in a single drop jump by mathematical modelling.

METHODS

The model (Fig. 1) consisted of two masses connected by a spring and damper, where mass m_2 presented the visceral mass. Elastic module K_2 and damping module B_2 defined an attachment of m_2 to the other parts of the body. The model was described with two differential equations:

$$m_1 * \ddot{x}_1 - B_2 * \dot{x}_{11} + K_1 * x_1 - K_2 * x_2 = 0$$
$$m_2 * \ddot{x}_2 - B_2 * \dot{x}_2 - K_2 * x_2 = 0$$

where m_1 presented the mass of the external container, x_1 and x_2 vertical displacements of m_1 and m_2 from a position of equilibrium, B_2 the damping coefficient, K_1 and K_2 the stiffness coefficients.

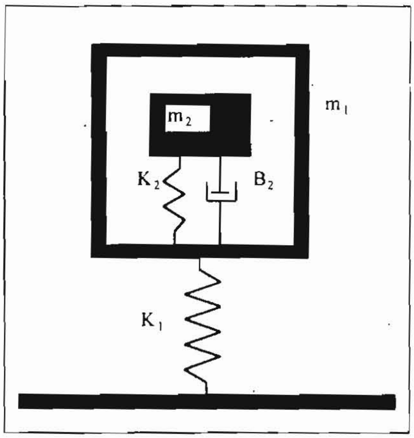

Figure 1 Scheme of mass-spring-damper system

Numerical solution was performed by MATLAB (The MathWorks Inc.). The vertical displacement of the centre of gravity of both masses (CG) was calculated by varying K_2 and B_2 systematically at constant K_1. The value for K_1 was taken from Aurin and Zatsiorsky, 1984).

Each jump was subdivided into two phases, a contact phase and aerial phase. The maximum jumping height was defined as the apex of the trajectory of CG in aerial phase, calculated by formula : $H_{max} = v_0^2 / (2 * g)$ where H_{max} was the maximum height of CG, v_0 was velocity of CG at the instant of take-off, g was gravitational acceleration.

RESULTS

Dependence of jumping height on K_2 and B_2 is presented in Figure 2.

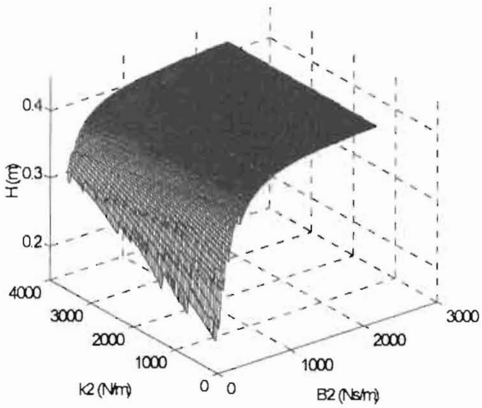

Figure 2 Jumping height (H) depending on K2 and B2

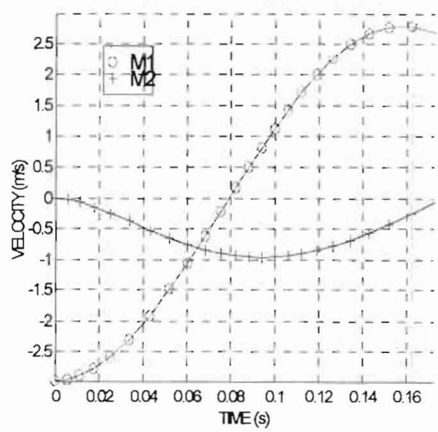

Figure 3 M1 is velocity of mass m_1 , M2 is velocity of mass m_2 relatively to m_1, at $K_2 = 0$ and $B_2 = 550$. Vertical dotted line denotes the instant of take-off.

It became clear that the main response of the system was attained by increasing B_2 from 0 to 600 Ns/m. Afterwards increased B_2 didn't influence the jumping height significantly

Figures 3 and 4 show two typical examples of m_1 and m_2 velocity during the contact phase. The velocity of m_2 is presented relatively to the movement of m_1 in both figures. The first example represents condition in which m_2 oscillated in a phase shift with m_1 and where vertical displacement according to m_1 may be up to 8 cm (Minetti and Belli (1994)). With increasing stiffness of the system, the phase shift between m_2 and m_1 become smaller and corresponding jumping height increased as well. The second example represents condition when both masses, m_1 and m_2 oscillated in parallel. When the m_2 is delayed for 0.032 s as in the first example, the jumping height was 0.388 m. When the oscillation became almost parallel (Δt=0.002 s), the jumping height reached 0.431 m.

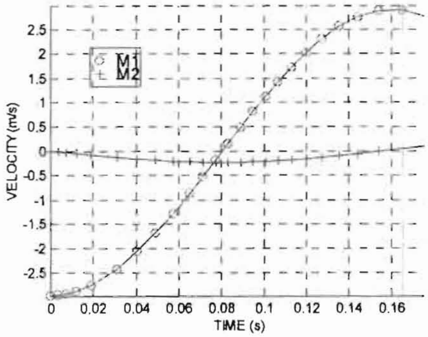

Figure 4 M1 is velocity of mass m_1, M2 is velocity of mass m_2 relatively to m_1, at $K_2 = 3600$ in $B_2 = 2200$. Vertical dotted line denotes the instant of take-off.

CONCLUSION

With increasing K_2 and B_2, the observed system became more stiff. It seems that damping was a crucial factor for determining the maximal jumping height, because at constant B_2 the increasing of K_2 did not influence the changes in jumping height a lot, except at very low B_2. Increasing stiffness of the system smaller phase shift between m_1 and m_2 as well as the oscillation amplitude of m_2. Both of them contributing to the higher velocity at the end of contact phase. With sufficiently high B_2 and K_2, m_2 would oscillate strictly in parallel with m_1 and would no longer influence the jumping height (Aurin and Zatsiorsky, 1984). In that case the observed system as presented in Figure 1, could be considered simple as a mass-spring system (Blickhan, R. 1989). Results of the present study indicating the importance for a control of visceral mass movement for maximising the result. In practice, the greater K_2 and B_2 can be achieved by increased abdominal pressure.

REFERENCES

Aurin, A.S., Zatsiorsky, V.M. (1984) Biomechanical characteristics of human ankle-joint muscles. Eur. J. Appl. Physiology 52: 400-406.

Minetti, A.E., Belli, G. (1994) A model for the estimation of visceral mass displacement in periodic movements. J. Biomechanics 27: 97-101.

Blickhan, R. (1989) The spring-mass model for runing and hoping. J. Biomechanics 22: 1217-1227