Characterization of the energy dissipation of a landing mat for the study of landing strategies in artistic gymnastics

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1. Introduction

During landings (apparatus dismount and on floor exercises), gymnasts are exposed with high impact loads potentially associated with an increased risk of lower extremities and trunk injuries (Bradshaw et al. 2012). During the fall, the load is generated by the gymnasts mechanical energy. At the impact, this energy is only composed of the kinetic energy. It is therefore directly related to the velocity and the mass of the object at impact.

In artistic gymnastic, the dissipation of this energy is shared between the mats and the gymnasts. Hence the landing strategy must be optimal to dissipate and distribute such a load safely (Maldonado et al. 2018).

The landing mats are made of visco-elastic components that allow for surface deformation. The elastic component will transform the kinetic energy into elastic energy, which could then be returned to the gymnast. The viscous component will dissipate part of this energy before returning it. In this context, quantifying the energy dissipated by the mat during impact is required to discriminate landing strategies.

The aim of this study was to characterize the mechanical energy to which the gymnast will be exposed following the interaction with the mat in relation to the impact vertical velocity. This study explores the dissipative behaviour of the mat using a rigid impactor dropped to reach several impact velocities. We assumed (1) that there is a relationship between different impact velocities and the amount of energy dissipated and (2) that this relationship can be linear.

2. Methods

2.1 Task and procedure

An impactor (Figure1), designed for this experiment, was dropped from seven different heights over a landing mat. These heights ranged from 0.94 to 2.15 m to produce landing velocities similar to velocities reported in gymnastics studies: between 4.3 and 6 m/s (Mills et al. 2006). Three trials per height were conducted.

2.2. Instrumentation

The impactor was composed of a 20 cm wide squared base, to reproduce the surface under the gymnast's feet, a 10 kg mass and a rod to guide the impactor from the release structure (Figure 1).

A 20cm competition landing mat was used. The base was equipped with four-reflective markers. The 3D kinematics of these markers was recorded with a 30 camera Qualisys Track Manager® motion capture system at 200 Hz.

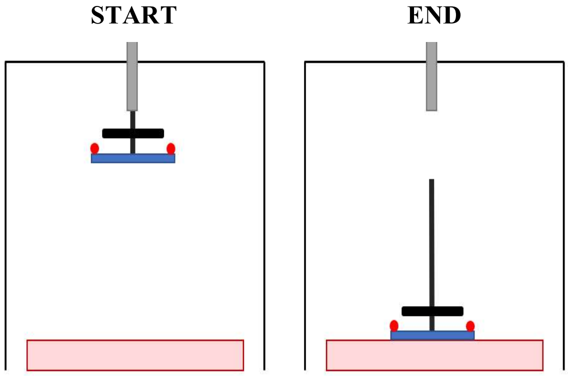

Figure 1: The impactor. The markers (red circles) placed at the four corners of the squared base (blue rectangle) were used to define the center of the impact surface. The 10kg mass (black rectangle). Rod to guide (black vertical line) and mat (red base).

2.3. Data analysis

Data were analyzed in Matlab® and filtered through a 4th order low-pass Butterworth filter with a cutoff frequency of 6 Hz and no phase shift.

The mechanical energy normalized by the mass of the impactor was calculated during the fall. The ratio of the first two peaks of normalized mechanical energy, calculated just before the first impact and at the time of the maximum impactor height at the second bounce was used to determine the dissipation coefficient of the mat. After checking for the normal distribution of the samples, a Pearson correlation test between this ratio and the landing vertical velocity was used.

3. Results and discussion

The Pearson correlation test obtained a significative positive correlation ($r=0.832$; $p<.001$).

The results obtained, as shown in Figure 2, with impact velocities ranging from 4.3 m/s to 6 m/s, allowed us to estimate the amount of mechanical energy dissipated by the mat. Indeed, over this velocity range, the mat dissipated between 85.8 and 88.2% of the total energy. This relationship may correspond to a linear relationship. With these results, we can assume that when the energy of the fall increases, the amount of energy dissipated by the mat also increases. The energy of the fall depends on the initial velocity (as tested in this study), the mass, and the initial height of the system. Reproducing this experiment with larger impact velocities can be interesting to get closer to the gymnastic condition and see in extreme values if this relationship is still observed. We would expect a decrease in the absorption slope until a threshold is reached.

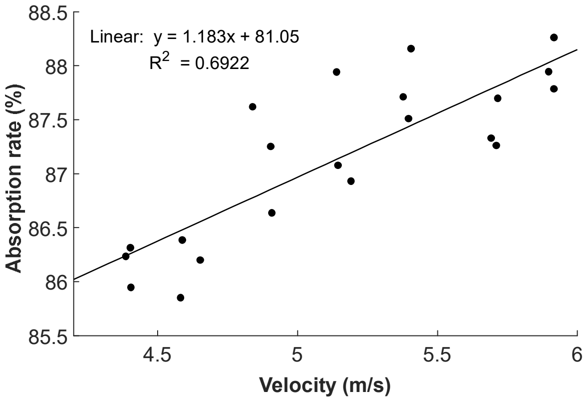

Figure 2: Mechanical energy dissipation ratio between pre- and post-impact as a function of vertical velocity.

In contact with the mat, the mat will deform to progressively dampen the acceleration of the falling body. The deformation of the mat is a function of its rigidity, and for identical velocity values, the dissipation coefficient will not be the same depending on the composition of the mat (Mills et al. 2010). For example, in competition settings, landings can be performed with an additional “over-mat” or on the gymnastics floor. The dissipation coefficient will vary from the landing mat used for this study. To account for the diversity of landing conditions, one perspective of this work is to explore and measure the impacts of landing in ecological situations, closer to the sport activity, in order to better estimate the kinetic energy and the amount of energy the athlete will have to dissipate from the mat at impact, for example with an accelerometer placed at the sacrum. As the International Gymnastics Federation's homologation tests measure the attenuation of acceleration peaks, testing the correlation between this and our rate could be interesting.

Furthermore, the dissipation coefficient might not solely depend on the mat characteristics, and on the kinetic parameters of the fall, it can also depend on the gymnast coordination during landing.

The remaining undissipated energy was sent directly back to the impactor that continued bouncing. In contrast to the impactor, the human body is a poly articulated system, capable of mechanical energy dissipation through active and passive actuation (muscles, ligaments, etc…). By adjusting the landing coordination, the gymnasts need to dissipate the remaining energy without "rebound" or additional steps. Further investigation with gymnasts, is also necessary to characterize the role of landing coordination and its relation to mats characteristic to fully understand and later optimize landing strategies in gymnastics.

The limitation of this study is that the impactor mass does not represent the mass of a gymnast. Further studies will be conducted with different impactor masses to replicate the mass of a gymnast.

4. Conclusions

This study explored the dissipation of mechanical energy by the mat during impact in relation to landing velocities. The increasing linear relationship found between the impact velocity and the percentage of load dissipation by the mat allows us to predict the energy remaining after contact of rigid solid for a given velocity. Additional experiments should be conducted, to test the dependence on mass, type of surface, and gymnast coordination in contact with the mat, to better identify optimal landing strategies with respect to their dissipative behaviour.

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