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

Rebecca Crolan, Diane Haering, Suzon Pucheu, Mathieu Ménard, Charles Pontonnier

To cite this version:
Rebecca Crolan, Diane Haering, Suzon Pucheu, Mathieu Ménard, Charles Pontonnier. Characterization of the energy dissipation of a landing mat for the study of landing strategies in artistic gymnastics. Computer Methods in Biomechanics and Biomedical Engineering, 2022, pp.1-2. hal-03693388

HAL Id: hal-03693388
https://inria.hal.science/hal-03693388
Submitted on 10 Jun 2022
Characterization of the energy dissipation of a landing mat for the study of landing strategies in artistic gymnastics

R. Crolan*, D. Haeringa, b, S. Pucheu, M. Ménardb, d and C. Pontonniera

*a Univ Rennes, Inria, M2S, IRISA – EA 7470, F-35000 Rennes; b Univ Rennes, M2S – EA7470, F-35000, Rennes, France; c Ecole Normale Supérieure de Rennes, Bruz, France; d Institut d’Ostéopathie de Rennes-Bretagne, Bruz, France

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 gymnast’s 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 gymnastics, 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 (Figure 1), 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.

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.

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 
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.

Acknowledgements
This study is supported by the ANR within the 
framework of the PIA EUR DIGISPORT project 
(ANR-18-EURE-0022).
We thank GYMNOVA® for the support of the mats for 
this experiment.

References
Bradshaw EJ, Hume PA. 2012. Biomechanical 
approaches to identify and quantify injury 
mechanisms and risk factors in women’s artistic 
of Parkour practitioners for executing soft 
36(22):2551–2557.
Mills C, Pain M, Yeadon M. 2006. Modeling a 
Viscoelastic Gymnastics Landing Mat during 
Impact. Journal of applied biomechanics. 22 
Mills C, Yeadon MR, Pain MTG. 2010. Modifying 
landing mat material properties may decrease 
peak contact forces but increase forefoot forces in 
gymnastics landings. Sports Biomech. 9(3)

Keywords: Mechanical Energy; Dissipation; Landing 
strategy; Gymnastic; Kinetic Energy.

*Corresponding author. Email: crolan.rebecca@hotmail.fr