A study characterizing dynamic overloads of professional dancers. Biomechanical approach

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Many jumps made in classical and modern ballet are responsible for serious injuries. A pilot experiment that was carried out with two professional dancers measured the temporary character of ground reaction forces in a few chosen elements of classical dance. The method of piezoelectric dynamometry as well as video recording were applied. The results of the experiment concerning the dynamic overloads, which are defined by the value of ground reaction forces, allow us to set the direction of a further research in the area of biomechanical interpretations.

Key words: dynamic overloads, ground reaction forces, force plate, professional dance

1. Introduction

In the last decade, there was a growth of interest in the overloads of motoric apparatus in ballet dancers, who form a very "traumagenic" group [4], [5], [14], [17], [18], [19].

The papers of numerous authors [3], [4], [5], [12], [13], [14], [15], [19] refer mainly to injuries, mostly of lower limb joints and muscles. Many researchers dealt with the analysis of traumagenics and loads of the knee joint [4], [13], [19] and hip joint [2], [3], [9], [10], [16]; some of them analyzed also the spine and the pelvis problems, that is to say, pain syndromes and morphofunctional changes of these structures [2], [3], [6], [7], [14].

Dancers often experience dynamic overloads that happen during violent impacts with force whose values may exceed the resistance of healthy bones and muscles [5],

[12], [14], [18], [19]. In literature, a dynamic overload is defined as the load exceeding the resistance threshold of muscles, joints and bones, as well as every improper mechanical action resulting in the damage to the motoric apparatus [18].

In this study, the measure of dynamic loads–overloads is the value of ground reaction forces in the movement structures typical of classical ballet dancers.

Many jumps made by the dancers in classical ballet cause serious injuries. The parts that suffer most often from injuries can be itemized as follows: ankles, Achilles tendon [11], [18] and collateral knee ligaments – mainly the medial ones [8], [18]. The specificity of a dancer's training consists in repeating some choreographic elements. A preliminary interview with dancers indicates that the majority of injuries occur during the "landing". This information gave rise to experimental research that was conducted in the laboratory of the Chair of Biomechanics of USPE in Poznań.

2. The objective of this paper

Two general objectives of this paper were as follows: to identify dynamic loads–overloads being the main elements of movements repeated by professional dancers and to create the method that allows minimizing these overloads.

A particular aim of this article was to evaluate time characteristics of ground reaction forces (vertical R_z and horizontal R_y, R_x) that arise during bouncing and landing in basic ballet jumps, which in turn will enable realization of the following tasks:

• evaluating (taking into account the complex biomechanical model of the lower limb) the extreme values and ranges of forces affecting such structures of the motoric apparatus as: Achilles tendon, joint surfaces in the ankle–tibia joint, the knee joint and the patello-femoral joint as well as the thigh quadriceps tendon and the subpatellar tendon,

• prophylactic trainings that teach the dancers how to choose the techniques that minimize the overload,

• analysing of the "dancing surface" used by dancers in such a way as to enable amortization of dynamic overloads.

3. Material and method

During this pilot experiment run on two professional classical ballet dancers, the artists of the Grand Theatre in Poznań, the time characteristics of ground reaction forces in over a dozen of elements of classical dance were measured. The research method is presented in figure 1. The measuring system consisted of a Kistler piezoelectric platform linked to an IBM PC and two video cameras (figure 1). The

sampling frequency equalled 1000 Hz. The ground reaction forces were recorded in three planes.
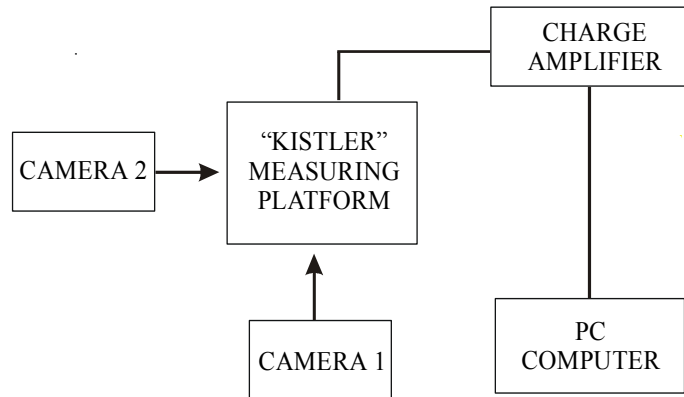

Fig. 1. Block diagram of the measuring system

4. Results and discussion

For further analysis, the researchers have chosen these movement tasks (dance elements) whose forces – especially the vertical ones – exceed several times the body weight of both dancers (table 1). On the basis of the timelines of ground reaction forces $R_x(t)$, $R_y(t)$ and $R_z(t)$, the following values have been appointed:

R_x, R_y and R_z – the extreme ground reaction forces for the horizontal (R_x and R_y), and vertical components expressed in body weight units [BW] or in [%BW];

I_x, I_y, I_z – the force buildup indexes in the impact phases expressed by quotients of extreme forces and the times of their achievement.

The examples of curves representing vertical and horizontal components of ground reaction forces are presented in figures 2–7.
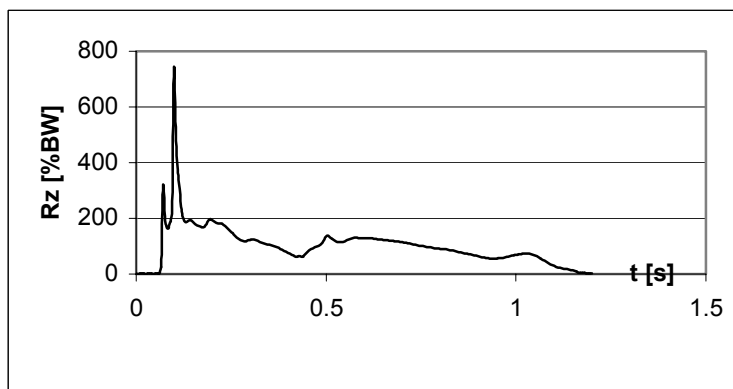
Fig. 2. Vertical component of the reaction force in the landing phase
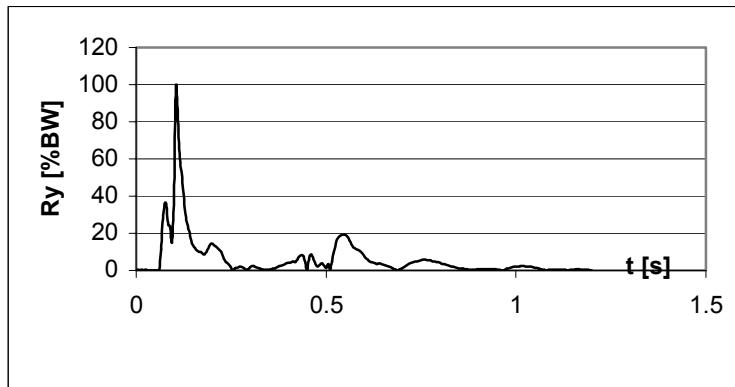versus time of execution of the *grand pas de chat*

Fig. 3. The component R_y of the ground reaction force in the landing phase
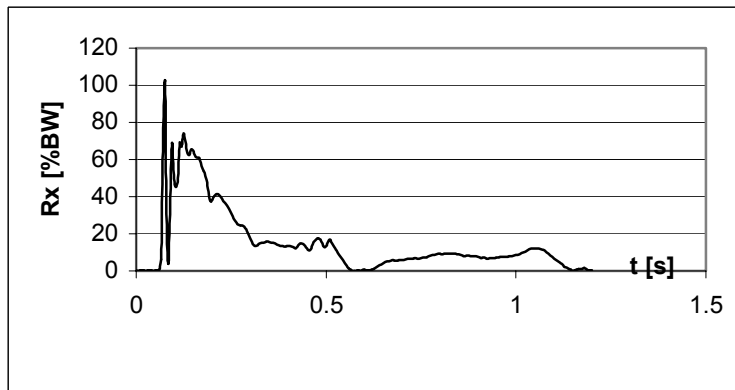versus time of execution of the *grand pas de chat*

Fig. 4. The component R_x of the ground reaction force in the landing phase
versus time of execution of the *grand pas de chat*

Table 1. Relative values of forces generated during the execution of certain jumps in classical dance
and the values of the force buildup indexes in the impact phases of the jumps.
The dancer's body mass – 59.5 kg

Type of jump	R_z [BW]	R_y [BW]	R_x [BW]	T [s]	I_z [BW/s]	I_y [BW/s]	I_x [BW/s]
Grand pas de chat – landing	7.56	1.00	1.00	0.109	69.3	9.2	9.2
Grand pas assemblé – landing	6.55	0.59	1.43	0.150	43.6	3.9	9.5
Entrelacé – landing	5.88	0.23	0.54	0.096	61.2	2.4	5.6
Saut de basque – landing	5.71	1.31	1.68	0.151	37.8	8.7	11.1

| *Pas jeté* | 5.34 | 1.18 | 0.94 | 0.204 | 26.2 | 5.7 | 4.6 |

The male dancer performed dancing elements whose characteristics have been presented in table 2.

Table 2. Relative values of forces generated during the execution of certain jumps
in classical dance and the values of the force buildup indexes in the impact phases of the jumps.
The dancer's body mass – 56.5 kg

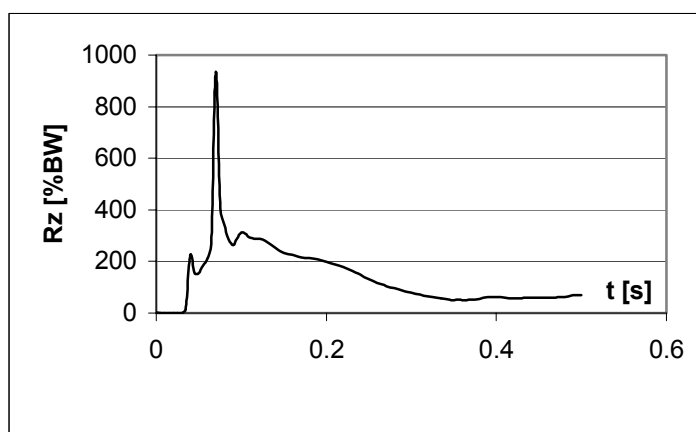| Type of jump	R_z [BW]	R_y [BW]	R_x [BW]	T [s]	I_z [BW/s]	I_y [BW/s]	I_x [BW/s]
Grand pas de chat – landing	9.38	0.81	1.40	0.073	128.5	11.1	19.2
Grand jeté – landing	9.38	1.09	1.16	0.105	89.3	10.4	11.0
Entrelacé – landing	7.61	0.92	1.85	0.117	65.0	7.9	15.8
Double tour – landing	7.61	1.23	0.56	0.096	79.3	12.8	5.8
Jeté en tournant	7.08	0.03	0.42	0.158	44.8	0.18	2.6

Fig. 5. Landing in *grand pas de chat* – vertical component of ground reaction forces
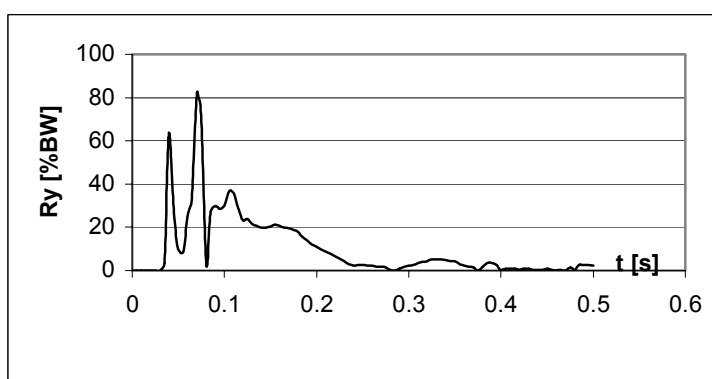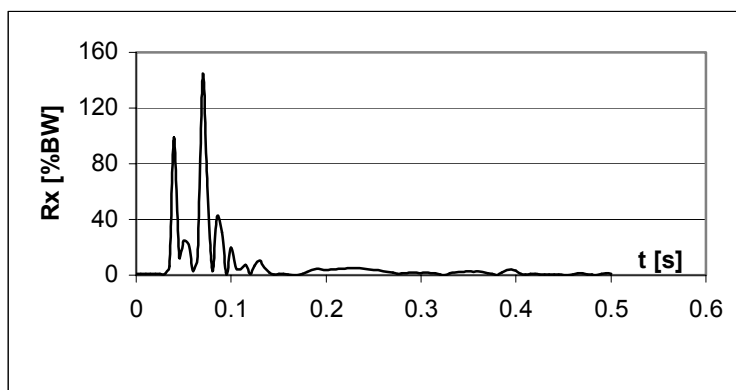
Fig. 6. *Grand pas de chat* – R_y component of ground reaction forces

Fig. 7. *Grand pas de chat* – R_x component of ground reaction forces

Extreme ground reaction forces have been accepted as global indicators defining overload of the skeletal–joint and muscular systems of the dancers. The meaning of these parameters is such that their higher values result in greater reaction forces in the lower limb joints and greater tensions in the long bones and muscle tendons.

During the pilot research in the laboratory, the dancers bounced and landed on a dynamometric platform, whose top surface is covered with carpet lining. During the everyday exercises, ballet artists made their jumps on a different, often mixed, type of surface.

The results of dynamic overloads, expressed by the level of ground reaction forces in the examined movement structures typical of classical ballet dancers, allowed us to prepare a research program that made a biomechanical interpretation of these overloads possible.

Huge forces measured in the landing phase of the classical ballet jumps were considered to be the most interesting result obtained. The most amazing were the values of the vertical components of the ground reaction forces, which exceeded several times the value of the body weight. Most of the jumps selected for the analysis were finished with a landing on one lower limb. Considering the value of the component R_z, one can only suspect the enormousness of the loads that the lower limbs of dancers are subjected to.

The high values of the components R_z, R_y, R_x explain the cause of so numerous injuries and often pain reactions in ballet dancers. One should notice that the extreme forces during the impact phases occur after a few dozens of milliseconds, that is why the values of force build-up indexes I_z, I_y, I_x are so high.

It should be emphasized that, on average, dancers work out about 8 hours daily. And if they rehearse a performance, this time extends to 10–12 hours. Such an

enormous exploitation of the motoric apparatus and the level of overloads may result in permanent deformation and damage to tissue structures.

5. Summary

Great forces occurring during the impact phases of ballet jumps cause overloads of tissue structures of the dancers. Serious injuries often happen during these phases of jumps.

The bodies of dancers are tools in their profession which mostly depends on the dancer, for how long he or she will enjoy good health and physical condition. They must use their body with skill, and when it is necessary be able to avoid situations that may result in interrupting their career. In the light of the results obtained, it seems indispensable to conduct prophylactic trainings monitored by measuring equipment similar to that used during the research, which would teach the dancer to choose techniques that minimize loads.

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