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Kinematic analysis of modern dance movement “stag jump” within the context of impact loads, injury to the locomotor system and its prevention

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Statistical Analysis C
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Manuscript Preparation E
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Background: This paper presents a case study of kinematic analysis of the modern dance movement known as the “stag jump”. Detailed analysis of the kinematic structure of this movement as performed by the dancers, accompanied by measurements of impact forces during landing, will allow the authors to determine, in subsequent model-based research phases, the forces acting in knee joints of the lower landing limb.

Material/Methods: Two professional modern dancers participated in the study: a male and a female. The study consisted in recording the values of ground reaction and body motion, and then determining and analyzing kinematic parameters of performed movements.

Results: The results of measurement of joint angles in the landing lower limb, pelvis, and foot position in relation to the ground, as well as the level of vertical components of ground reaction, provided insight into the loading response phase of the “stag jump”. The measurements and obtained results show differences between the man and woman in ground reactions and kinematic quantities.

Conclusions: The results obtained during the research may be used in the development and teaching of dancing movements. Training sessions, carried out in the biomechanical laboratory, with active participation of dancing teachers, could form a basis for a prevention model of injuries and physical overloads occurring within this occupational group.
Primary differences in the “stag jump” performance technique probably result from the different educational path the man and the woman went through.

Keywords: **Biomechanics • Stag Jump • Professional Modern Dance • Kinematic Analysis • Overloads • Injury Prevention**

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Background

Modern dance developed from expressionist dance, which rejected the rules of ballet. It originated in Germany in the 1920s and was defined by rules of a specific technique evolved in the USA in the years 1930–1950, employing elements of African and Native American folklore. Modern dance employs all the techniques of ballet; however, a modern dancer is not obliged to uncritically follow the classical rules of execution of these techniques.

Classical style strongly emphasizes esthetics, precision, and height. In modern dance, the distance and motion through space is of utmost importance.

Cohan writes that the most important elements of a modern dancer's work are: "ground work", "work with the center of gravity", and "motion in space" [1]. He mentions that the most important thing in a well performed movement is self-awareness, and that modern dance consists of "centering, gravitation, balance, posture, gestures, rhythm, motion in space, and breathing".

Although ballet is a form of art, it has much in common with professional sports. Modern style choreographers often propose very dangerous dancing movements from the point of view of biomechanics of the locomotor system. These dangerous situations created by "movement designers" are often the result of absence of basic knowledge about the capabilities and limitations of the human locomotor apparatus.

Modern dancers in many shows perform falls, using their upper limbs as shock absorbers, they roll around the stage, women lift men, and men not infrequently lift persons heavier than themselves, they wear heavy costumes, they walk on stilts, hang from ropes, etc. In addition, the performances often take place outdoors or in halls that are not prepared for such events.

The majority of dancers' expressive movements consist of jumps. Research shows that some of them, particularly during the landing phase (during the eccentric phase of muscle work related to shock absorption), generate high values of the vertical component of ground reaction force (GRF), which may reach 7.4 BW [1–3]. Serious injuries often happen during these phases of jumps (Table 1). Peak forces of impact phases occur after a few dozen milliseconds [2].

According to Luke, Solomon, Liederbach, and Nicholas [4–8], the largest percentage of injuries affecting professional dancers are chronic injuries, such as soft-tissue inflammation, injuries resulting from overload, and muscle strains and tears. Fractures represent the lowest percentage of all injuries. Various authors report different locations total number of injuries [2,9–13]. Nevertheless, ankle joint, foot, spine, hip joint, and knee joint are the most frequently listed regions of the body injured by dancers. Research by Gorwa shows that modern dancers are primarily exposed to injuries of the spine, Achilles tendon, knee joint, and hip joint [2].

Studies performed by Gorwa also show that up to 93% of modern dancers (female and male) suffer from chronic injuries directly related to their profession [2]. Around 30% of persons who reported these conditions associated them with specific movements. Female modern dancers complained of spine conditions such as neck pain and lumbar or sacral spine region pain; they associated them with "sudden twists" and the very expressive movements so common in modern dancing style. Male modern dancers listed pain and injuries of the spine, feet, and knees as chronic conditions and indicated these problems were caused by lifting dancing partners, as well as by "bizarre" choreography.

Since correct technique is a factor that significantly decreases the risk of injury [14,15], and the degree of motor habit control (e.g.,

Table 1. Topography and frequency of injuries in professional modern dancers [2].

Body parts	Female dancers (n=7) [%]	Male dancers (n=7) [%]
Achilles tendon	42.9	42.9
Ankle joint	14.3	28.6
Metatarsus	0.0	42.9
Phalanges	14.3	28.6
Lumbar and sacral spine region	85.7	85.7
Knee joint	42.9	100.0
Shank	14.3	28.6
Thigh	14.3	14.3
Hip joint	28.6	57.1

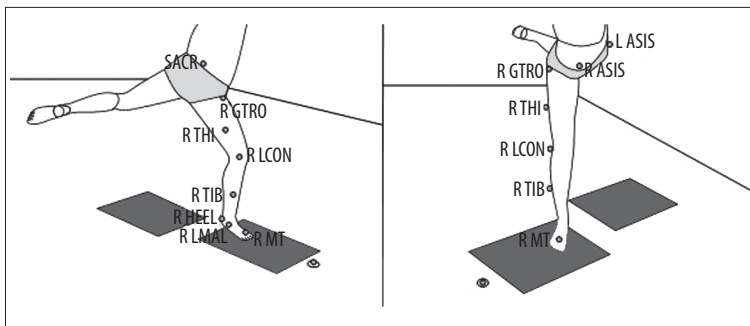


Figure 1. Location of markers: R MT – the head of metatarsal bone of second toe of right foot, R HEEL – right foot calcaneus, R LMAL – center of right foot lateral malleolus, R TIB – right limb tibia, R LCON – left femur lateral epicondyle, R THI – right thigh, R GTRO – right femur greater trochanter, L ASIS – left anterior superior iliac spine, R ASIS – right anterior superior iliac spine, SACR – L_5S_1 .

the proper execution of a given sports technique) determines the values of forces recorded during the landing phase [16], we observed kinematic values and recorded the technique of execution of a modern dance movement referred to as the “stag jump”.

The purpose of this study was to conduct a thorough analysis of kinematic structure of the landing phase in a selected expressive dance movement called the “stag jump” performed as a case study of 1 male and 1 female professional modern dancer. Researchers who compared the technique and morphological differences between modern and ballet dancers were Bronner and Ojofetimi [17], Solomon and Micheli [12], and Solomon et al. [18]. The methodology and measurements presented in this work are part of a project whose purpose will be to devise guidelines for new training methods to prevent injuries in dancers.

The conducted kinematic analysis consisted in establishing such characteristic parameters as trajectories of joint centers and movement sequences of lower limbs, pelvis movement, angle changes in hip, knee, and ankle joints in the sagittal plane, as well as changes of foot position in relation to the ground. Synchronization of kinematic measurements with the measurement of vertical components of ground reaction forces in the landing phase during this stage of the study allowed us to identify impact loads on the locomotor apparatus of the studied dancers and to forecast methods for minimizing such loads.

Material and Methods

Material

This work is a case study of 2 professional modern dancers (a female and a male) who work full time in dance theatre, 6 days per week on average, and do not perform any other job. They train for 42 hours a week. Daily training sessions last 8 hours on average. During the dance season, however, the number of daily working hours increases to 11–13. There are about 8–9 monthly performances, but during the “artistic season” there may be up to 20 monthly performances [2]. It should be stressed that although artists in ballet dance groups in Poland

have identical education (National Ballet Schools: Primary and Secondary [2]) around 7% of members of modern dance groups begin their dance education after age 18 [2].

Each participant performed the expressive movement called the “stag jump”.

Laboratory experiments

The tests used for this study were carried out in the Biomechanical Laboratory of the Chair of Biomechanics at the University School of Physical Education in Poznan, Poland. Kinematic values and line graphs of GRF were determined during the measurements. Kinematic values were computed with the use of APAS motion analysis system and GRFs were measured with the use of Kistler force plate sampling at 1000 Hz. The motion of test participants was recorded by 4 Basler digital cameras with recording frequency of 200 Hz. The images recorded by the cameras were transferred to a computer, where, with the use of APAS software, the films were processed and the locations of markers positioned on dancers' bodies were determined. At the same time, GRFs acting during the landing phase were recorded. Due to the extensiveness of performed dancing movements, the cameras were arranged to allow us to precisely determine the kinematics of the pelvis and the right lower limb during the landing phase. The number and location of markers (Figure 1) made it possible to determine the positions of right lower limb joint centers and, in consequence, the relative angular motion of particular lower limb segments and the pelvis.

Results

The measurements allowed the authors to determine values of lower limb joint angles and pelvis position within the coordinate system (Figure 2). The following angle vs. time graphs were drawn:

- for hip joint – flexion/extension, abduction/adduction, and rotation;
- for knee joint – flexion/extension and rotation;
- for talocrural joint – dorsal/plantar flexion and pronation/supination.

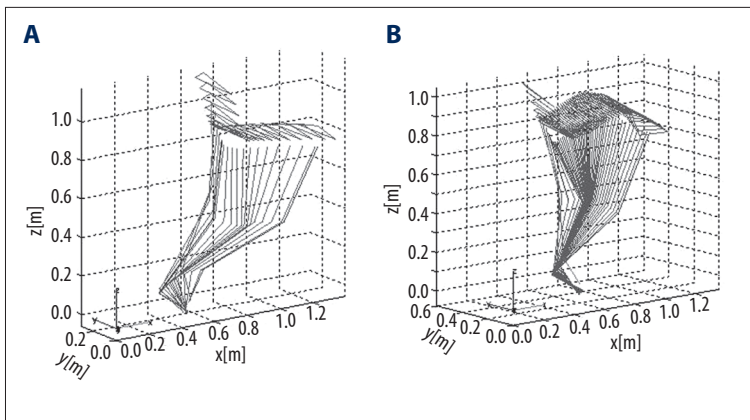


Figure 2. Trajectories of joint centers and successive positions of lower limb segments during the landing phase of the "stag jump" movement performed by the female dancer (A) and male dancer (B).

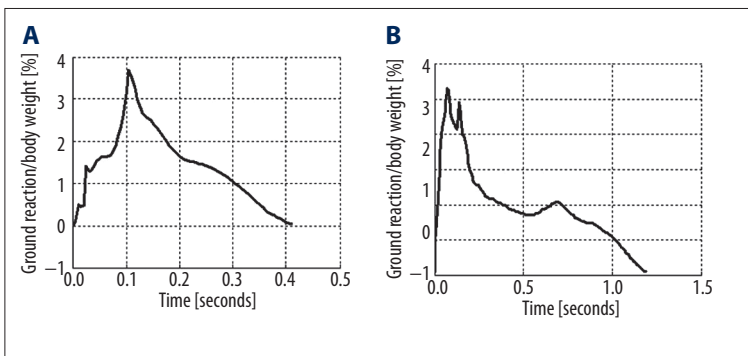


Figure 3. Line graph of the vertical component for: (A) male dancer and (B) female dancer.

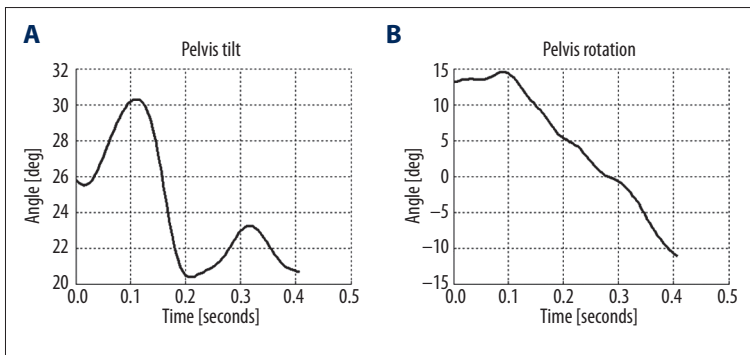


Figure 4. (A, B) Line graph of pelvis tilt angle in the sagittal plane and pelvis rotation in relation to the vertical axis of a dancer (male dancer results).

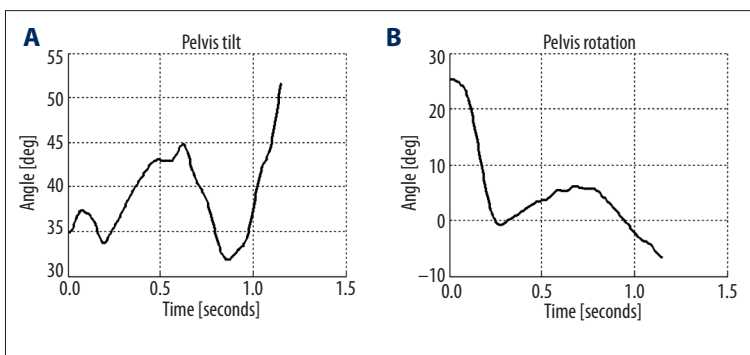


Figure 5. (A, B) Line graph of pelvis tilt angle in the sagittal plane and pelvis rotation in relation to the vertical axis of a dancer (female dancer results).

The usage of force plates allowed us to establish ground reaction forces (GRF) acting during the landing phase that followed the performed movement.

Based on the results of the measurements, it was possible to assess movements performed by the dancers by analyzing the line graphs of GRF and line graphs of angles in lower limb joints. This paper concentrates on the analysis of the "stag

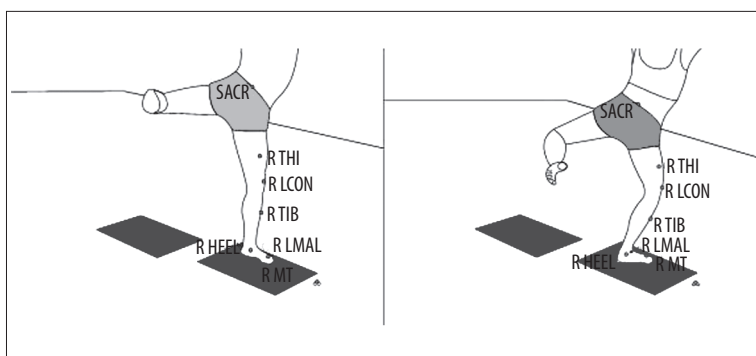


Figure 6. Distinctive lower limb arrangement during the landing phase of the "stag jump" modern dance movement.

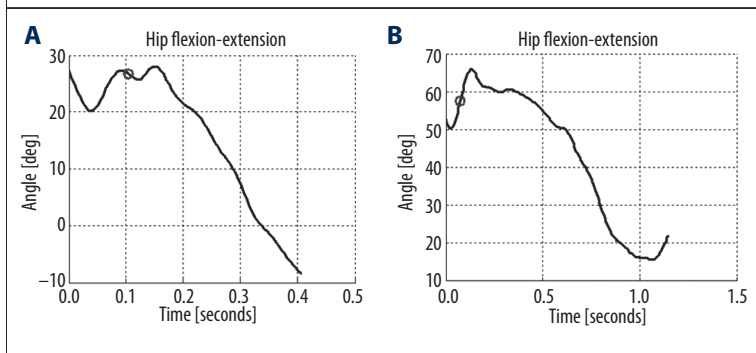


Figure 7. Line graph of hip joint angle in the flexion-extension plane: (A) male dancer, (B) female dancer. Mark indicates the moment of peak vertical reaction.

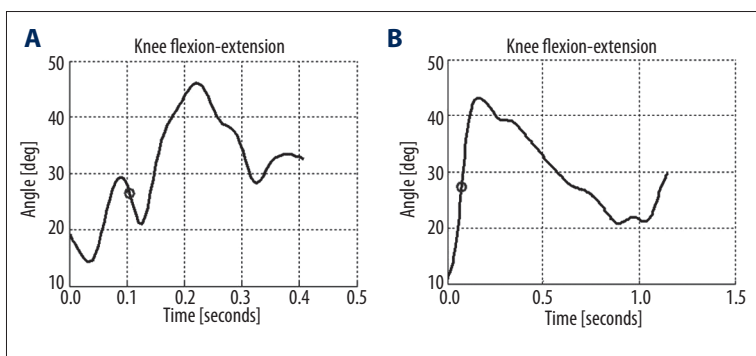


Figure 8. Line graph of knee joint angle in the bending-extending plane: (A) male dancer, (B) female dancer. Mark indicates the moment of peak vertical reaction.

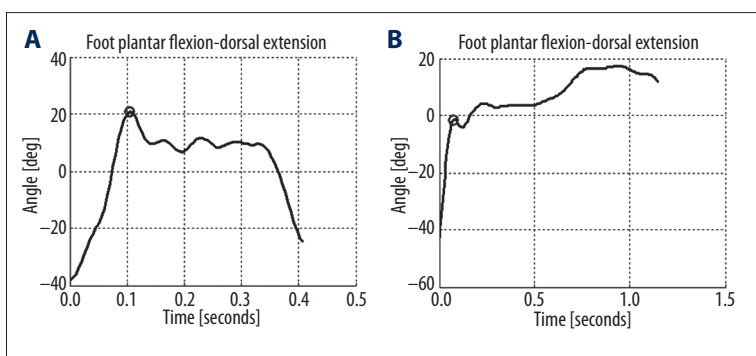


Figure 9. Line graph of ankle joint angle in the plantar bending – dorsal bending plane: (A) male dancer, (B) female dancer. Mark indicates the moment of peak vertical reaction.

jump" movement performed by 2 modern dancers – a woman and a man. The following diagrams (Figures 3–10) present the results of measurements performed on modern dancers.

The pelvis rotation in relation to the long axis of the body was 30° for the female dancer and 25° for the male dancer. Pelvis

tilt in the sagittal plane is significant during the entire landing phase and fluctuates between 32° and 50° for the female dancer and 21–31° for the male dancer. Both pelvis rotation in relation to the vertical axis and pelvis tilt in the sagittal plane result from specific positioning of the non-supporting limb (Figure 6).

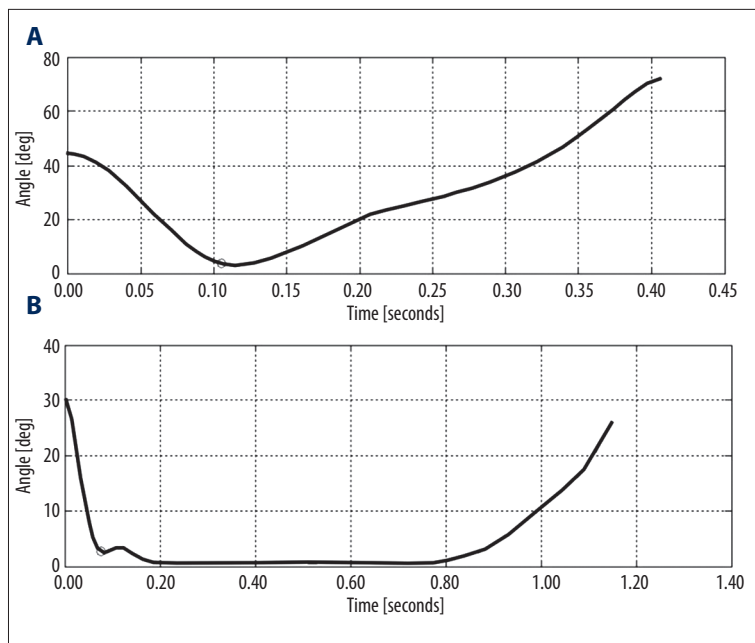


Figure 10. Line graph of foot angle in relation to the ground: (A) male dancer, (B) female dancer. Mark indicates the moment of peak vertical reaction.

The line graph of joint angles in the sagittal plane (Figures 7 and 8) shows that they are similar in shape but differ in the range of motion (ROM). This is especially true in the hip joint angle (Figure 7). The ROM in the hip joint is 50° for the female and 36° for the male. In the knee joint (Figure 8), ROM is 32° for the female dancer and 31.7° for the male dancer. ROM of ankle joint (Figure 9) in the sagittal plane was 60° for the female dancer and 59° for the male dancer.

Discussion

This study allowed us to describe the way a dancer positions (coordinates) the body during landing that follows a dance movement and the forces that act on the lower limb. The values of the vertical component of ground reaction reached the levels that equaled almost 4 times the body weight of man and a little over 3.2 times the weight of woman. Considering that the values of reaction in the lower limb joints exceed the values of ground reaction [19,20], one can observe the loads that a dancer's musculoskeletal system is exposed to. Such high loads are a frequent cause of injuries to dancers, as well as musculoskeletal problems that dancers already suffer from during their careers.

Ground reactions measured during the landings of classical dancers in other studies were even higher than in modern dancers (2.65 BW for females and 3.7 BW for males) [2,21]. It is directly related to the requirements imposed on the technique of dance movements, which are much more rigorous in classical dance.

Interestingly, the landing phase durations in this movement are very short. The impulsive character of the peak vertical component of ground reaction acting on feet during the landing phase that follows a ballet jump poses the greatest risk of joint injury, beginning with the lowest joints – metatarsal and ankle joints [22].

The short time allowed for the performance of a movement and the need to immediately transition to the following one leave dancers extremely little time to coordinate the entire body and prepare for receiving the huge loads observed. The requirement to perform each dance movement strictly according to the rules considerably limits the ability to properly absorb the impact during landing. This is why it is so important to define the best way (from the biomechanical point of view and taking into account the artistic design) to perform individual dance movements by dancers. It is obvious that the maximum value of the vertical component of GRF depends on the way dancers will use their feet as a form of biological shock absorbers.

The following observations can be formulated on the basis of the analysis of joint angles and GRF peaks.

At the moment the foot contacts the ground, it remains in plantar flexion in a manner that only the toes are in contact with the ground. When the vertical component of ground reaction reaches its maximum, the foot is resting flat on the ground (parallel to the ground). Therefore, the center of mass is transferred from toes and metatarsus to the vicinity of the ankle joint, which decreases the moment of vertical ground reaction forces (and thus the forces generated by muscles working around the ankle joint). In addition, the flat positioning of the

foot lowers the center of the ankle joint, shortening the moment arms of the components acting in the horizontal plane.

When the vertical component of GRF reaches its peak, thighs and shins assume almost vertical positions. This leads to the conclusion that when the greatest loads act on the limb, these will be mostly compressive loads, for which the long bones of the lower limb are well prepared (they possess the best strength in the longitudinal direction).

The analysis of foot angle in relation to the ground shows that after landing on his toes, the male dancer bends his foot dorsally and for a short period of time (about 0.2 s) puts weight on the entire foot and then stands on the toes. The female dancer lands in a different manner – after touching the ground with the toes, she puts weight on the entire foot and keeps the foot in this position throughout most of the support phase.

Conclusions

Modern dance generates many potentially dangerous situations for the locomotor system. One of the most significant factors that lead to injuries is high dynamic loads (forces) of an impact nature that occur particularly during the landing phases of numerous expressive jumps.

Peak forces are generated over a very short time period, which makes coordinating such movement structures very difficult. It is important to realize that these forces are transmitted via the relatively small surface of the dancer's feet that are only weakly protected by characteristic footwear – the forefoot region and toes.

Properly mastering movement technique is tremendously important in minimizing injuries. Many publications on injury prevention emphasize that proper technique is fundamental in preventing injuries [16,23]. The knowledge of dynamic loads acting on the dancer's body and kinematics of movement may represent a significant contribution in the description of the proper technique of dance movements.

The following values that best describe the landing phase of the "stag jump" were established:

- loads transmitted to the dancer's foot;
- line graphs of joint angles in the lower limb;

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- changes in position of the foot in relation to the ground;
- values of joint angles, as well as the angle between the foot and the ground when the highest value of the vertical component of ground reaction occurs.

This allowed us to analyze the influence of movement technique on the values of external loads (GRF).

Analysis of the conducted research reveals significant differences in the technique of the same dance movement. Research by Orishimo et al. [24], as well as Broner and Ojofeitimi [17], suggests that these differences in technique probably do not due to the dancer's sex, professional experience, or educational path of the dancer. The female dancer went through all levels of ballet education in Poland (Primary and Secondary National Ballet School), and the male dancer began his education as an adult at the DanceWeb workshop in Vienna. However, such a conclusion needs to be confirmed by further research with a larger sample.

Hamilton et al. observed correctly that certain dance movements can be mastered only until puberty, when the body can still be "molded" [25].

During the next phases of research, the results of these measurements will be used to determine loads transmitted by musculoskeletal system when performing dancing movements. For this purpose, a mathematical model of lower limb movement will be prepared, allowing us to determine the forces generated by muscles and the forces transmitted by joint surfaces. The values thus obtained will complement the results of the research.

On the basis of these results, works are being conducted in cooperation with ballet teams, choreographers, and dance teachers to devise training methods using the methodology and the potential of a biomechanical laboratory. These training methods would be aimed preventing injury and physical overload, as well as increasing dancers' knowledge of biomechanics and kinesiology of the locomotor apparatus in dancing.

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