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Biomechanical Analysis of the Basic Classical Dance Jump – The Grand Jeté

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Abstract**—**The aim of this study was to analyse the most important parameters determining the quality of the motion structure of the basic classical dance jump – grand jeté.Research sample consisted of 8 students of the Dance Conservatory in Brno. Using the system Simi motion we performed a 3D kinematic analysis of the jump. On the basis of the comparison of structure quality and measured data of the grand jeté, we defined the optimal values of the relevant parameters determining the quality of the performance. The take-off speed should achieve about 2.4 $m \cdot s^{-1}$, the optimum take-off angle is 28 - 30º. The take-off leg should swing backward at the beginning of the flight phase with the minimum speed of 3.3 $m \cdot s^{-1}$.If motor abilities of dancers achieve the level necessary for optimal performance of a classical dance jump, there is room for certain variability of the structure of the dance jump.

Keywords**—**biomechanical analysis, classical dance, grand jeté, jump

I. Introduction

CLASSICAL dance is a motion art, which is both physically and mentally very demanding. The essence of classical dance is handling a given motion task exactly, in a perfect and at the same time aesthetical way. For the optimal realization endurance, speed, strength and coordination abilities are essential. High flexibility is also a precondition for executing good deal of elements. A dancing motion pattern requires a large number of acquired skills with oftentimes very complex structures. The aim is to describe physical principals which form the fundamentals for understanding the spatiotemporal and dynamic structures of particular dance moves. Needless to say that only the understating of mechanism of motion does not enable the dancer to execute a move which surpasses his motor abilities. Nevertheless, it indicates the way which leads to successful realization of the move. This knowledge also enables to precisely distinguish which aspect of motion is a matter of style and which affect motion in its essence. Science in classical dance is thus crucial and irreplaceable. And for this reason in our research we concentrated on the biomechanical analysis of the structure of a basic ballet jump – the grand jeté.Grand jeté belongs to aerial standing high jumps with one leg take-off and other leg landing. Grand jeté is taught as one of the first high jumps, in the curriculum of 8-year dance conservatories it is included in the fifth grade. The exact execution is described by [1], [2], [3] [4].

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II. Methods

The surveyed group is formed by students of Dance Conservatory in Brno. This group was created with deliberate selection. Eight dancers of the 6th and 7th grade were tested. The relatively low quantity of probands is due to the limited number of students of dance conservatories and the demandingness of collecting and processing data. The average height of the surveyed group was 167.4 cm, the average weight 56.5 kg, the age of the dancers ranged from 16 to 18 and the period of professional dance tuition of the dancers reached 6 to 7 years. We considered the surveyed group of dancers of the Dance Conservatory a homogenous one, as there is an assumption of certain level of motor abilities for admission at this field of study.

With the aid of Simi Motion system we conducted a 3D kinematic analysis of the grand jeté jump. Each tested person performed this jump 3 times with the take-off from the right lower extremity and 3 times from the left lower extremity. Since there was a number of 8 tested persons, we analyzed 48 grand jeté jumps. For capturing the scene we used 2 high-speed synchronized digital cameras Simi Motion Version 7. We processed the recorded data in a Simi Motion program.

We assessed each individual recorded data separately. Subsequently we compared these data with the results of a professional evaluation of the individual jumps which was carried out by doc. Vondrová, expert on classical dance and pedagogue at the Dance Conservatory and Janáček Academy of Music and Performing Arts in Brno. The pattern of optimal execution of the jump was created on the basis of the 3D kinematic analysis of the particular jumps which were rated the best by doc. Vondrová.

III. Results

All dance jumps, as well as grand jeté, consist of 4 phases:

1. preparation
2. take-off
3. flight
4. landing

1. Phase - Preparation

The preparation serves as a run-up. Before the initial jump the dancer gains a certain horizontal velocity, which, in case of effective application, improves the performance of the jump, especially the take-off phase.

2. Phase – take-off

The fundamental condition for the take-off is an adequate stiffness of the surface in relation to which the center of gravity is shifted. In the preparation phase of the take-off there is a decrease in angles among the segments of the take-off leg. Simultaneously with this flexion comes the stretching of the take-off muscles. The elastic force counteracts this stretching and it results in increasing the elastic potential force of he muscles. Consequently it is transformed into kinetic energy. After executing the horizontal velocity acquired by the run-up in inclined direction, it is necessary to lift the take-off leg at its touchdown, while its muscles are contracted by the fictitious force. This work is supported by a swing of the loose leg, possibly the upper extremities too and the consequent shift of momentum to the torso. Thomas [5] conducted a dynamic analysis of the grand jeté jump, where he evaluated the ground reaction forces, moments of forces and moment powers during the landing. The horizontal velocity partially performed in inclined direction is partially manifested as the inertial force in horizontal direction. Grand jeté requires an inclined take-off. According to Kašparová [6] the mechanical principle of the take-off is the initial engagement of the segments which are the furthest from the prop and the take-off completion by the closest ones – the ankle and the metatarsal joints. Further she states a precondition for the effective take-off – the heel in touch with the ground. This way the calf muscle will be contracted no sooner than at the take-off itself. The take-off force, which leads to translational movement, intersects the prop and runs into the center of gravity, which is in front of the prop. This forward shift of center of gravity, thus the angle between the surface and the take-off force, has a direct impact on the size of the elevation angle.In the preparation phase the best dancer landed on the take-off leg from the preparatory hop with a velocity of 2.694 $m \cdot s^{-1}$. The transition from maximum flexion in the hip, knee and ankle joints of the take-off leg to extension completed in the moment of leaving the surface took 0.19 s. The dancer reached a take-off velocity of 2.574 $m \cdot s^{-1}$. The angle of the take-off of the centre of gravity was 43º, 13º off the margin of the optimal angle (28 - 30º). The dancer should therefore ideally take off in a smaller angle, which would help her to create a flatter and longer jump. The take-off velocity was also influenced by the motion of upper extremities, but primarily by the swing of the right lower extremity. The maximum velocity of the ankle of the swinging leg was reached at the point of passing the take-off leg and it was 9.352 $m \cdot s^{-1}$. The velocity of the swinging ankle at the take-off was 3,926 $m \cdot s^{-1}$ (fig. 1).

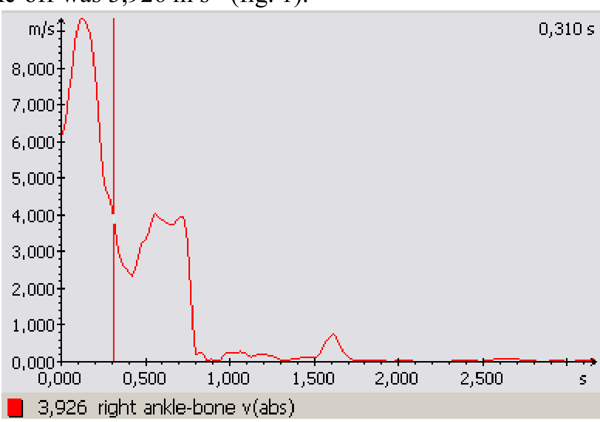

Fig. 1 The velocity of the swinging leg.In the graph the velocity of the take-off leg is marked at the moment of leaving the surface

3. Phase - Flight

After the take-off the support of the body of the surface is broken. With the sum of horizontal velocity and the inclined velocity created by the take-off of the center of gravity, the dancer starts to move up in an take-off angle α and initial velocity v_0. Leško et al. [7] demonstrates that it is but the impulse of force that influences the size of v_0 and as a result the height of the jump too. The horizontal and vertical elements of the quantities describing the movement of the center of gravity are independent from each other. However, the take-off angle depends on the ratio of their magnitude. If we ignore the air resistance, the horizontal element of velocity of motion is a constant value v_{0x}. The magnitude of the vertical element of velocity is variable. At the instant moment when the element of velocity equals zero the body reaches the top peak of its trajectory. At this culmination point of the jump the lower extremities are spread under the angle of 150º [1]. The trajectory in which the center of gravity moves is determined by the magnitude and direction of velocity at the end of the take-off and it is not possible to change it airborne. In his publication Laws [8] emphasizes the creation of illusion of floating, which can be created by a shift of bodily configuration during the flight. Although the center of gravity follows a parabolic trajectory, the relative position of center of gravity to the body can be shifted. At the moment, when the dancer leaves the surface, his upper and lower extremities are rather low and the center of gravity occurs in the abdominal area. When the center of gravity continues to ascend in the parabolic trajectory, the body center of gravity can be elevated by lifting the upper and lower extremities. With optimal timing, an illusion of floating is created. Robertson et al. [9] dealt with the conditions for creating such an illusion of floating. Nevertheless his probands were not able to create such an illusion.

In the aerial phase we focused primarily on the time coordination of the movement of upper and lower extremities in consideration of the position of the center of gravity at a given moment. We compared the time sequence, in which certain body elements reached their peaks –head, center of gravity, swinging leg, and upper extremities (figure 2).

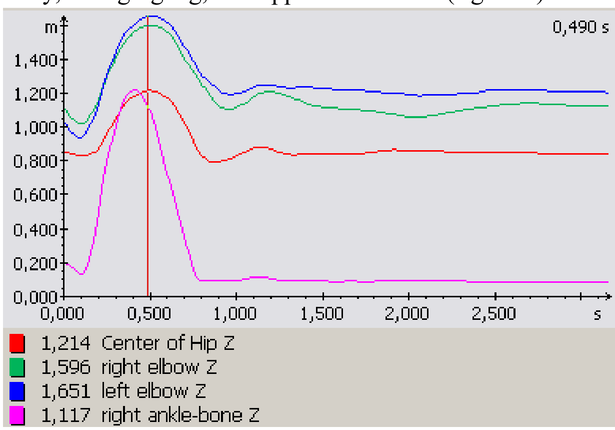

Fig. 2 The graph shows the timing of the peaks of the swinging leg and upper extremities in consideration to the motion of center of gravity

The swinging leg reached its peak 0.08 s sooner than the center of gravity and 0.11 s sooner than the head. The take-off leg stretched backwards while its ankle reached a maximum velocity of 3,422 $m \cdot s^{-1}$. The motion of upper extremities unfortunately did not take any longer than the ascending of the center of gravity, thereby prevented the dancers from creating the illusion of floating.

Further in the aerial phase we compared the period, in which the center of gravity reached its peak with the period when the left and right ankle occurred at the same height (figure 3). The moment when both the ankles reached the same height came 0.09 s later than the peak of the center of gravity (figure 4).

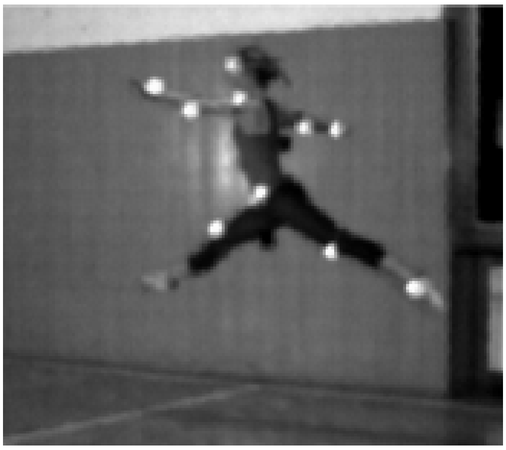

Fig. 3 Grand jeté – micro phase of the flight in the moment, when the ankles are at the same height

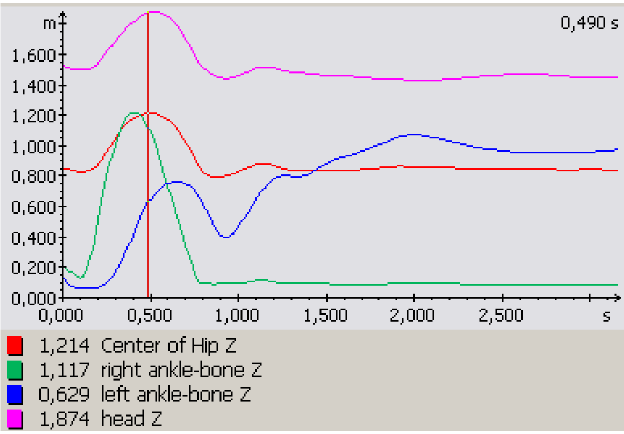

Fig. 4 The Graph shows the timing of motion of the lower extremities in consideration to the motion of the center of gravity and the head

However, it's important to pay attention to the phase of motion of the lower extremities when this moment accurs. Optimum is when the back-stretched lower extremity occurs at its peak. The dancer succeeded in this as the ankle of this lower extremity was consequently raised only by a negligible 1.6 cm. At that moment the magnitude of the angle between the spread lower extremities reached 109.32º, which is not an optimal range.

4. Phase - Landing

The last phase of the grand jeté is the landing phase, when the body gets into contact with the surface with a one-legged support. At the landing the body is pushed downwards by the momentum, which is important to be controlled by the eccentric contraction of muscles. In order for the muscles to be able to work the most effectively and for the longest period of time, it is necessary that right before the landing the extremity is fully stretched so that its muscles are in isometric tension [6]. The horizontal element of the fictitious forces affecting the center of gravity transfer the axis of the center of gravity to the margins of the floor contact area, which is relatively small at the beginning of the landing, or even behind it. In this case the body starts to descend due to the twisting force of the force of gravity. In order to stop the descending, the dancer must land upon a moderately forward stretched leg in a way that the fictitious forces intersect the center of gravity and without the emergence of the moment of force. According to Tarasov [1] the landing leg should be stretched forward in 45 º, while the other stays stretched backward in a 90º angle from the vertical line. Kašparová [6] reached a conclusion that at the touchdown the decreasing of angles in the joints is initiated in metatarsal, consequently knee and hip joints with a simultaneous breaking of the changes in the ankle joints. Holding the heel above the ground is necessary in order not to reach a sharp impact of the whole foot. The fictitious forces affecting the torso and the upper extremities lead to bending forward the torso, thus disrupting the dynamic equilibrium. That is why the isometric contraction of the back muscles, which immobilize the segments of the body, is necessary.

At the landing phase we concentrated on the angle of landing and its relevant forward stretch of the landing leg. According to the kinogram (figure 5) it is apparent that the landing leg moved in almost the same trajectory as in which the center of the gravity consequently descended. Thus at the moment of landing the fictitious force intersecting the center of gravity aimed almost exactly to place where the foot touched down on the surface. The length of the jump measured from the place, where the dancer took off to the place of landing was 1.27 m. The duration of the aerial phase was 0.44 s.

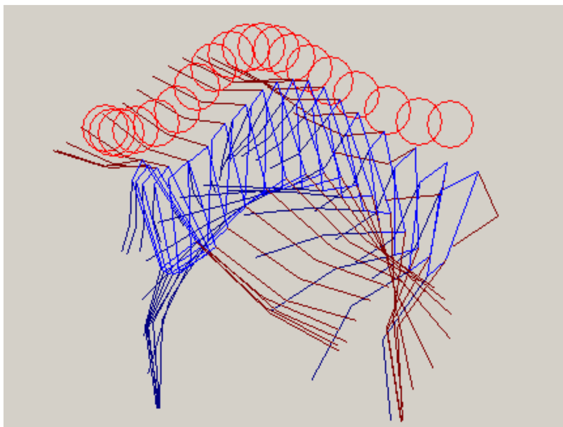

Fig. 5 Kinogram of the grand jeté jump

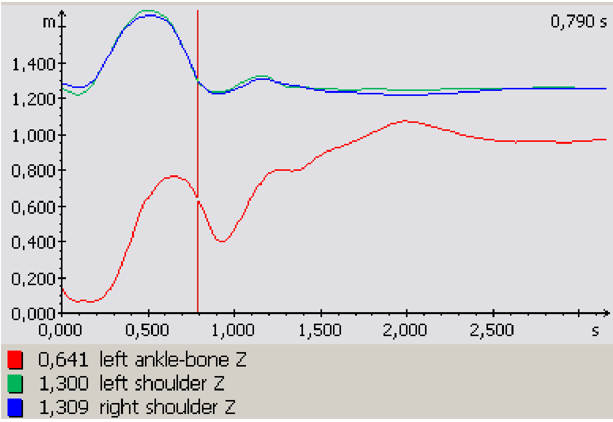

Fig. 6 The graph shows the range of vertical motion of the ankle of the backward stretched lower extremity and shoulders after the landing and touchdown to the whole feet of the standing lower extremity

Further we surveyed the range of motion of the torso and the backward stretched lower extremity during the phase of landing (figure 6). With this dancer we recorded a greater decrease of the backward stretched leg (24 cm) from the moment of touchdown to the whole foot, which cannot be considered an optimal execution. The ankle of the lower extremity, upon which the dancer landed, travelled 0.228 m further, until it stabilized. The aim is to limit this motion to the minimum. In comparison with the rest of measured values at the other dancers, we consider this value acceptable.

IV. Discussion

The amount of acquired data from the analysis – 48 grand jeté jumps – enables the evaluation of the most common mistakes that the dancers made while performing the jump.

In the phase of the take-off it was primarily not using the full potential of the take-off leg, mainly the calf muscle, where the dancers did not jump off the whole foot. From the preparation jump, they touched down just upon the half of the foot, thus decreasing the rebound, consequently the take-off velocity and the duration of the aerial phase too. The next drawback is the slow swing of the lower extremity into the forward stretch, which decreases the momentum of this lower extremity and so there is less transition of the momentum to torso at this moment. Some dancers executed the swing fast enough, but were not able to coordinate it with the take-off of the other leg. In most of the cases the take-off occurred later than in an optimal case. Also the take-off leg often executed the take-off under a greater than optimal angle. As a result of this departure in direction of the take-off force and of the mentioned delayed completion of the lower extremity take-off, all the dancers (with one exception) took off under a greater angle than the optimal 28 - 30º, meaning too perpendicularly upwards. Some dancers, during the swing of the arms, were not able to maintain the elegant and aesthetic motion in accordance of the rules of classical dance.In the aerial phase the fast swing of the take-off leg to the backward stretch is the most fundamental. Here we also recorded most drawbacks, which have a considerable impact on the position of all bodily segments during the aerial phase. If the dancer performs a slow swing to a backward stretch, the forward stretched leg descends too much. Then the forward stretched leg is too low, whereas the other leg is just ascending to the backward stretch. We can see some overturn of the lower extremities instead of a simultaneous swing-apart. As a result the height, at which the ankles meet, is too low. The difference is very clearly depicted in the graphs (figure 7 a, b). In graph a) the ballet dancer timed the moment where the ankles are at the same height optimally. This moment occurred almost at the same time when the center of gravity reached its maximum; the swinging leg was at the initial phase of descending and the take-off leg close to reaching its peak. In graph b) we can see that the velocity of the back swing was not sufficient and thus the backward stretched leg did not reach the necessary height. There is a substantial difference between the peak reached by the take-off leg and the swing leg. The quality of the aerial phase was often limited by a small spread of the lower extremities. In the take-off and aerial phase there is a perceptible wrong twist of the shoulders or the pelvis. The axis of the arm and pelvis should stay perpendicular to the direction of motion.

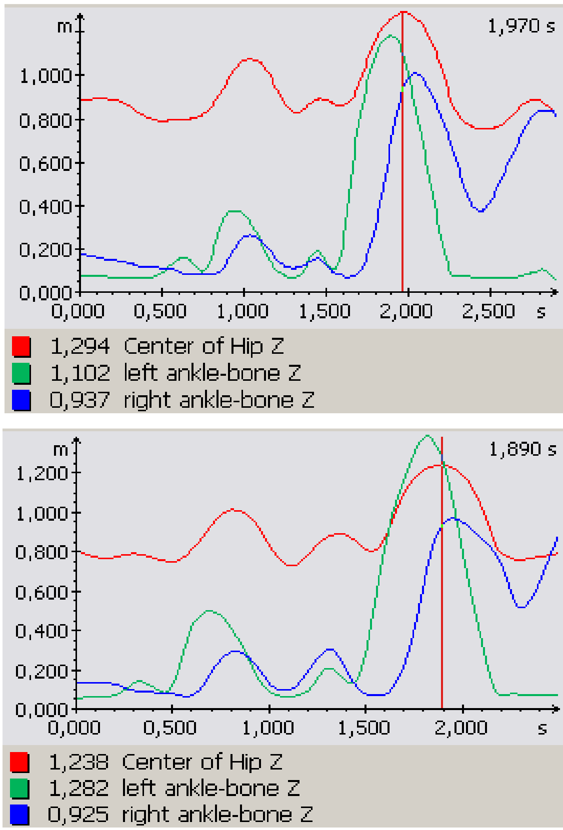

Fig. 7 a) optimal timing of the motion of lower extremities; b) wrong timing of the motion of the lower extremities of the grand jeté

In the final phase of the grand jeté jump the most important thing is to gain balance as fast as possible and keep it. Some dancers touched down upon a tilted lower extremity. In that case the fictitious force does not intersect the place of contact of the foot with the surface, but in front of it instead. Thus the moment of force is created and the dancer tends to fall forward. As a result she makes a few minor skips in order to get into a balanced position. The comparison is shown in figures 8a, b. In figure 8a we can see a too much tilted lower extremity, upon which the dancer lands. In figure 8b the forward stretch of the leg is optimal.

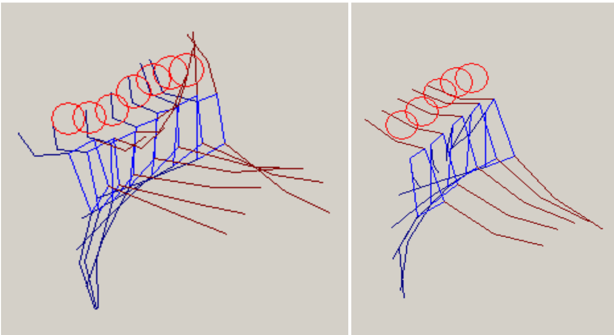

Fig. 8 a) wrong touchdown b) optimal touchdown

The next frequent drawback that we observed appeared at the backward stretched leg, which often descended to low due to the inertia, also the torso bend forward too much. This negative phenomenon is caused by insufficient muscle tonus holding the lower extremity in the backward stretch and the erector spinae muscles.

V. Conclusion

In the conducted 3D kinematic analysis we determined the kinematic parameters characterizing the spatiotemporal structure of the basic jump of classical dancing – the grand jeté. Jumps and their particular phases, which the experts evaluated as incorrectly performed, also appeared in our 3D kinematic analysis as under average. According to the comparison of the quality of structure of the measured values of the relevant parameters of the jumps we managed to determine the basic requirements for performing the grand jeté. The object of the dancers should be the longest possible trajectory of flight, creating the the illusion of floating in the proximity of the peak of the parabolic trajectory in which the center of gravity moves and a stable touchdown without any excessive moves. The 3D kinematic analysis implies that the following parameters have a direct impact on the accomplishment of the given requirements: the acquired take-off velocity and the angle of take-off, mutual coordination of the motion of upper and lower extremities and their timing in consideration with the motion of the center of gravity in the aerial phase and the range of motion of the torso and the backward stretched leg in the phase of landing. On the basis of the results of the 3D kinematic analysis we specified the optimal values of these basic parameters. We reached a conclusion that the velocity of the ankle of the swinging leg should reach 8,5 $m \cdot s^{-1}$ at its peak. This fast swing must be supported by a fast extension of the take-off leg. The take-off velocity of the center of gravity should reach the minimum value of 2,4 $m \cdot s^{-1}$. As for the angle of take-off, we believe that it is possible to perform high-quality jump, if the departure from the optimal take-off angle (28 - 30º) is no more than 8º. In the beginning of the aerial phase the take-off leg performs a swing into a backward stretch. The ankle should reach the maximum velocity of at least 3,3 $m \cdot s^{-1}$. If all these phases are executed in an acceptable quality, the phase of landing will most probably be optimal, because in a dynamic balance the ankle does not have to adjust to so much disruptive movement. A jump can be accepted as optimal, if the ankle does not travel further than 0.22 m.

All the acquired results point to the fact that the realization of the jumps has more individual biomechanical solutions. First and foremost they depend on the conditioning and coordination dispositions of the dancers, but on additional factors too. If these motor abilities reach a high level necessary for a well-performed jump, there is a certain variability of the structure of the dance jump within optimal solution to the given motion task.

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