SYMCOMP 2019
Porto, 11-12 April 2019
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KINEMATICS OF A CLASSICAL BALLET BASE MOVEMENT USING A KINETIC SENSOR

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Keywords: Biomechanics, Movement Analysis, Image Processing, *Kinetic* Sensor

Abstract *Dance is an art form considered a language since it can sometimes reflect a population's culture or even a celebration that accompanies humanity from its earliest times and which requires from performers a high physical and emotional dexterity. It is expected that the dancer performs rigorous and repetitive technical movements that often lead to painful injuries, resulting in 56% of classical ballet dancers will suffer from some type of musculoskeletal injury.*

Due to this high number of injuries, it is essential to study and analyse base movements for this type of dance in order to prevent injuries and to optimize the dancer's choreography and productivity. These movements are precedents of more complex movements. In this work, the study of a base dance movement, the Echappé Sauté, using biomechanical techniques is carried out to study the kinematics of the movement.

For the data collection, three dancers voluntarily participated and the movements were capture using a 2nd Generation Kinect camera that allows the capture of 3D movement. The biomechanical analysis was performed using the IpiSoft software and a manual procedure was used to perform a 2D biomechanical analysis based on the assumption that the dance movements for this study occur only in one plane. The results were compared to show the adequacy of the use of the Kinetic sensor for 3D dance movement analysis.

1. INTRODUCTION

Dance is an art form considered as a language because it can reflect the culture of a population or even a celebration that accompanies humanity from its earliest times [1]. In the sixteenth century, the Classical *Ballet* emerges in France, which marks the Renaissance period and leads its practitioners to acquire demanding physical and emotional skills. Over time, these abilities have revealed certain damaging aspects since they can lead to painful injuries for the dancers. Performing a choreographic piece requires the dancer to have a very demanding physical and emotional dexterity. The dancer must be able to perform technical movements in a rigorous and repetitive way, which can cause painful injuries, admitting that 56% of classical *Ballet* practitioners will suffer from some type of musculoskeletal injury [2].

Due to the high number of injuries, using Biomechanics in the study and analysis of base movements that are precedents of more complex movements in this type of dance may provide relevant information in order to prevent injuries and to optimize the dancer's productivity.

Also, the success of a performance depends on a subjective appreciation of the audience but the act of the performance depends on the physical and mental form of the dancer as well as its preparation and training to perform and interpret the choreography. In this sense, alternative forms of dance assessment may serve to support the training and preparation of the dancers.

Biomechanics combines principles that govern mechanics in the study and characterization of a movement. In the study of human movements, capturing images of movement and measuring forces and muscle function allows conclusions to be drawn about the way the movement develops. In the case of dance, this information can be used by the dancer to understand its weaknesses, enhance their technical abilities and / or promote the prevention of injuries that affect these professionals and are responsible for shorter careers. On the other hand, on the teachers' side, it allows to plan and develop specific exercises and training programs to overcome the physical difficulties, improve technical execution and predict the occurrence of injuries of an aspiring dancer. The articulation of the movements performed with the correct technique will be closer to the artistic and choreographic ideals and a smaller number of injuries will represent a greater availability of the dancers to the realization of a greater number and more diversified style of performances and, possibly, a more versatile dancer.

For the biomechanical analysis, it is usual that the movement in study is recorded using several cameras such that all the relevant points on the body are present in the recording. Nowadays, a single camera can be used if it also uses an infrared sensor and an infrared light emitter. The Kinect sensor was developed by Microsoft Company as an accessory to XBOX 360 [3] and its main function is facial recognition and the ability to recognize the user’s joints [4]. The *Kinetic* sensor combines the high definition images with the information from the infrared sensor and emitter to obtain the depth of the space where the object moves [5]. Thus, it is possible to reconstruct a movement in three dimensions.

In this work, a *Kinetic* sensor is used to record a *ballet* movement that is considered to exist in a plane, such as a vertical jump. The movie is digitized and a biomechanical analysis of the whole body is performed using *iPi Mocap Studio* [8] and its *Biomech Add-On* [9]. The position data obtained is used to compute the velocity vector with two- and three- coordinates. The objective is to compare the results obtained by considering the depth or disregarding it. If the movement in study evolves in plane, the depth could be disregarded. However, if there is movement on the third axis, considering only the other two will lead to loss of information and the results will not be able to accurately obtain the correct body information.

2. METHODS

2.1. Selection of the movement

To perform a *Ballet* movement, a dancer is required to perform technically demanding movements and challenging training sessions. It is important to understand each movement in detail from the beginning to its completion and it may be accomplished using biomechanics. The variety of movements in *Ballet* is a combination of basic movements and positions that follow certain rules: each movement of the arm is constructed from a basic position of arms and each movement of the leg is developed from one of the five fundamental positions of the feet [6].

The jumps in the Classical *Ballet* are of most importance in terms of biomechanical analysis, not only for their repetition that sometimes leads to the appearance of associated injuries, but also for the magnitudes of forces that are produced that can surpass in a large scale the body mass of the subject. To perform a jump, it is required that the dancers have extreme joint amplitudes and large muscular capabilities that result in mechanical stress in the soft tissues and adjacent bones. This is reflected in ligament and joint lesions that occur more frequently in the lower limb [6].

The progression of a jump in *Ballet* can be divided in three components: the *Ballon*, which is related to the resistance of the jump actions; the turn-out, described as the maximum external rotation of the leg in relation to the hip joint; and finally, the *demi-plié*, which results from a semi-flexion of the knees with the heels on the ground. The jump is then the result of a combination of force and elasticity in order to facilitate the impulsion and reception with respect to the ground [6].

The *Echappé Sauté* is one of the basic jumps in the Classical *Ballet* where the dancer jumps into the air by pushing both legs from the ground in a closed position (the first or fifth position) and slides both feet out and lands in an open position of the feet (the second or forth position) [6]. As the movement of this jump involves the whole body and is mainly a vertical jump, it was selected for this study.

2.2. Participants

For this study, three participants, students of the School of Dance of the Polytechnic Institute of Lisbon, performed the *Ballet* movement. The participants were asked to execute a sequence of jumps. The requirements for the selection of the participants were defined as:

- Age between 18-21 years old
- Practitioners of artistic dance for at least 5 years

Table 1 presents the characteristics of the participants.

Participant	Gender	Height [m]	Weight [kg]	Shoe Size [EU size]
1	Female	1,60	59	36
2	Female	1,63	55	37
3	Male	1,77	70	43

Table 1. Characteristics of the participants.

2.3. Motion Capture

The *Microsoft Kinect* sensor was launched in 2010 as an accessory to the *Xbox 360* with the goal of making the most appealing and interactive gaming experience [3]. It consists of an RBG colour camera, infrared sensor, an infrared light emitter and four microphones, since it also allows voice recognition, and in its main functions are the ability to recognize joints of its user and facial recognition [4]. With the infrared sensors and emitters it is possible to establish a relationship between a point of the image collected and its distance from the sensor, thus providing coordinates in three-dimensional space (introduction of the Z coordinate in relation to the X and Y -coordinates already achieved with RGB camera) [3,4].
The participants performed a sequence of four jumps of the type selected for the study and the movement was captured by using the *Kinetic* sensor and the *iPi Recorder* software [7]. To analyse the images from the *Kinetic* sensor, a specialized software was used, *iPi Mocap Studio* [8] and its *Biomech Add-On* [9]. With this software, it is possible to obtain the information of position, velocity and acceleration over time for the movement. Because the movement chosen is performed mainly on the sagittal plane, it is possible to analyse the movement considering only one plane. Thus, this study focused on the positions and velocities of some chosen points on that plane, considered relevant for the analysis of the movement. The software obtained the velocities using the three axis and with the manual method, the velocities were computed using the information of the positions of the points considering only the two axis of the principal plane of motion.

3. RESULTS

Taking in consideration that the *Echappé Sauté* is one of the basic jumps in the Classical *Ballet*, and that besides the legs, also the arms and the torso are contributing to the jump, the biomechanical analysis was performed to the whole body. The results presented in this work focus on the movement performed by the male participant and correspond to the movement analysis of the ankle, the elbow and the top of the head. Due to the behaviour obtained for those points, it was decided to obtain the information regarding the movement of the body’s centre of mass and of the lower leg segment to further improve the knowledge about the influence of the depth in this jump.

3.1. Top of the head

As it is considered that the *Echappé Sauté* is a jump on a plane, the highest point on the head

will have a motion that is mainly vertical and on the plane of the jump. The positions of the top of the head point obtained by the *iPi Mocap Studio* software on the plane of the jump are presented in Figure 1 and it shows that the movement of this point is primarily on the vertical axis, although there is a dislocation of about 10 cm on the horizontal axis. This reflects the fact that during the performance of the four jumps the participant actually did not keep in place and moved on the plane of motion. The evolution of the positions of the top of the head point over time is presented in Figure 2 for each individual axis. The movement on the horizontal axis, the x-axis shown in red, is not completely linear as was discussed on the previous figure. The evolution on the vertical axis, the y-axis shown in green in Figure 2, has the expected oscillatory motion for the type of jump with slight variations on the peak value obtained for each jump. If the z-axis is considered, in blue in Figure 2, the evolution over time of this point reflects the fact that, in the performance of these jumps, there will be movement in the z-axis, and the motion will not be exactly in plane.
Regarding the speed of the top of the head point, the values obtained by the *iPi Mocap Studio* software are presented in Figure 3 in blue and the values obtained from the positions on the xy-plane are shown in red. There is a good correlation between the two methods and apparently only in the beginning of the motion is there a significant difference between the two curves, but if the difference between the speed obtained from the two methods is plotted as presented in Figure 4, it is possible to observe that the difference can take values of up to 0.6 m/s to the value of the speed obtained using the three coordinates of the point. However, there is a small delay between the two curves that might be responsible for the observed differences.

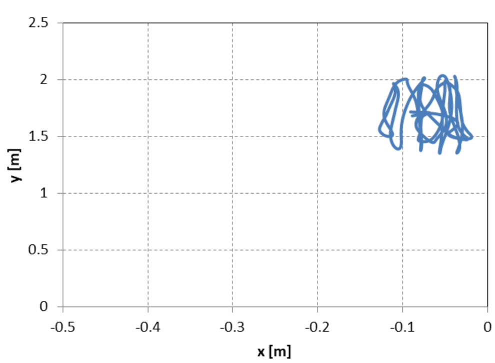

Figure 1. Trajectory of the top of the head point in plane xy.

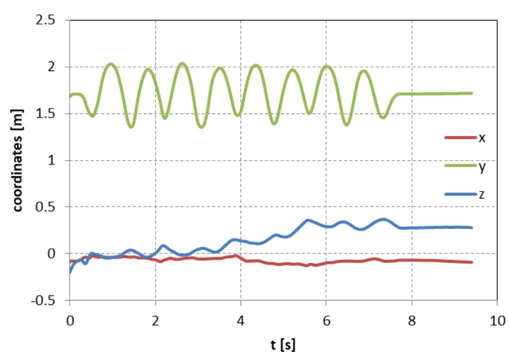

Figure 2. Trajectory evolution of the top of the head point on each 3D axis.

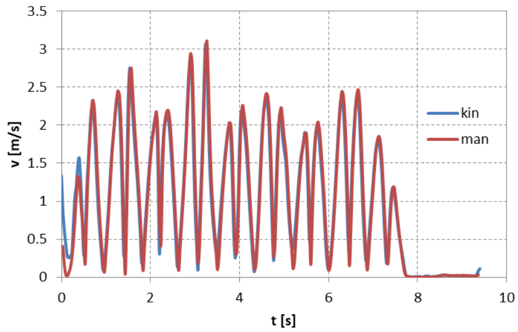

Figure 3. Speed of the top of the head point.

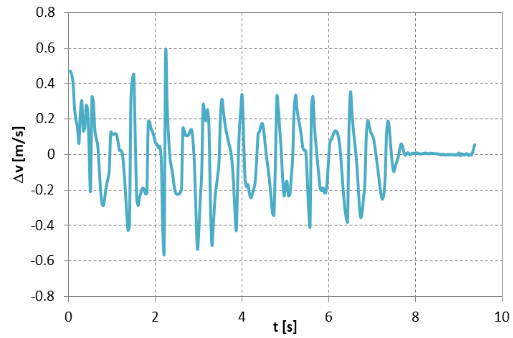

Figure 4. Difference of speed of the top of the head point obtained by the two methods.

3.2. Elbow

During the jump, the arms perform a motion that contributes to the impulse for jumping and the elbow has mostly a parabolic movement in the xy- plane, as it is possible to observe in Figure 5. Observing the movement of the elbow on each axis in Figure 6, the movement out of plane is seen by the evolution on the z-axis that has a variation of about 0.6 m between the smallest and the highest points. Also, the motion is not exactly in plane as the movement on the x-axis shows with deviations of about 0.3 m. On the vertical plane, the elbow point follows the expected pattern for a series of vertical jumps. This behaviour of the elbow is expected as the arms are the body segments that perform most movement out of the xy-plane in this jump.

In terms of the speed, the overall evolution is similar as can be observed in Figure 7 but on closer inspection there are considerable deviations between the speeds computed using the velocity components on the x- and y- axes and using the three axes. The maximum deviation is about 5 m/s as can be observed in Figure 8.

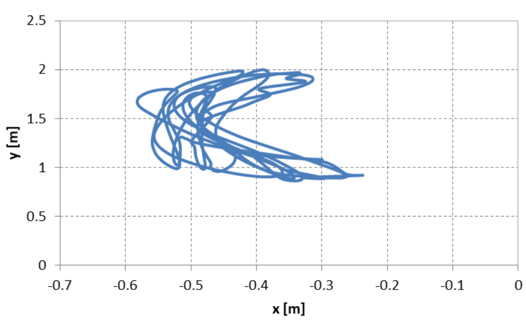

Figure 5. Trajectory of the elbow point in plane xy.

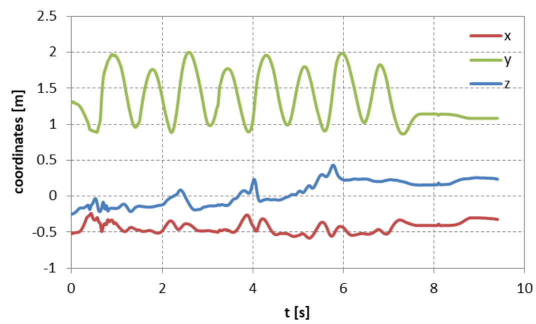

Figure 6. Trajectory evolution of the elbow point on each 3D axis.

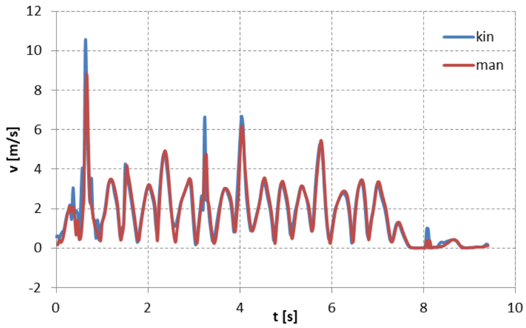

Figure 7. Speed of the elbow point.

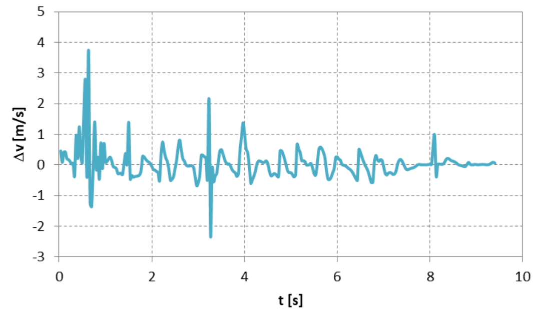

Figure 8. Difference of speed of the elbow point obtained by the two methods.

3.3. Ankle

The jump performed is divided in two stages, the first is a vertical jump during which the legs open and land with the feet apart; the second is a vertical jump starting in the end position of the previous stage and closing the legs during the jump and landing with the feet close together in a similar position as the starting position. This motion of the feet is reflected in Figure 9, where the repetition of the jump is also observed. Considering the different axes, the movement of the ankle point, presented in Figure 10, shows clearly that for this point the motion was not performed in plane as the z-axis has an irregular behaviour and a maximum deviation of 0.5 m. In the x-axis, there is also increased movement with a maximum deviation of 0.5 m.

The computed speed, presented in Figure 11, has a similar evolution but there are several occasions where the dissimilarities are clear. Figure 12 shows the deviation is at times about 1.2 m/s, showing that effectively the movement of the ankle point is considerably influenced by the z-axis.

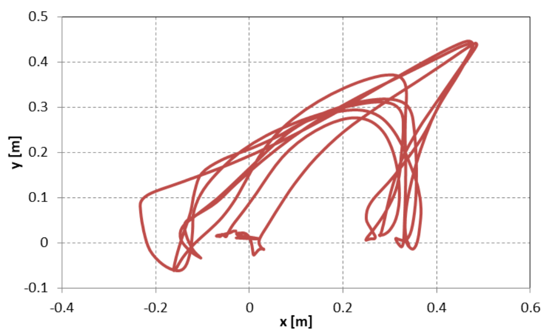

Figure 9. Trajectory of the ankle point in plane xy.

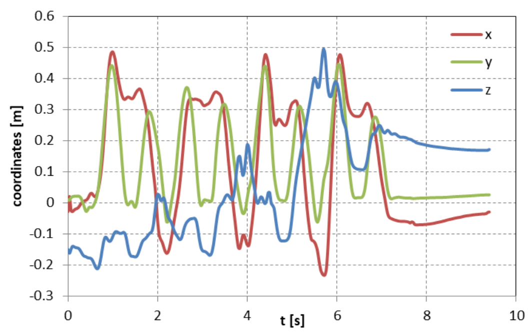

Figure 10. Trajectory evolution of the ankle point on each 3D axis.

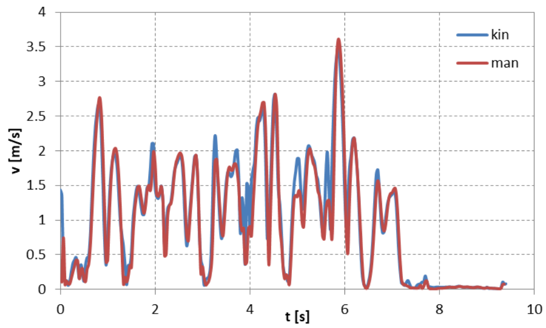

Figure 11. Speed of the ankle point.

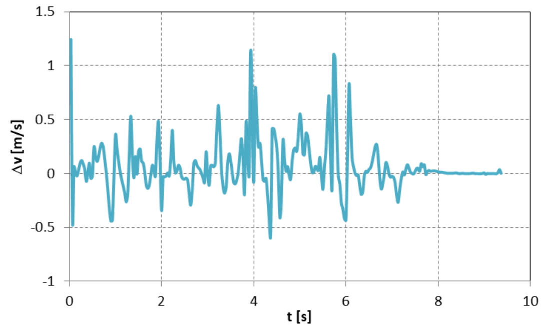

Figure 12. Difference of speed of the ankle point obtained by the two methods.

3.3. Depth influence

The jump performed is a sequence of two vertical jumps, in the first of which, the executer opens the legs and lands with the feet apart, and in the second, the executer closes the legs and lands with the feet close together, returning to the starting position. This should be a jump where most of the motion is performed on a plane, but there is effectively movement on the perpendicular to the plane where the jump is executed, as the results presented show.

Looking at the movement of the centre of mass of the body, presented in Figure 13, the motion that occurs in the z-axis clearly shows that this is a three- dimensional motion and not a motion in plane. Thus, although the general representation of the movement can be obtained using two dimensions, there is information being lost. This is even truer if the body segments are considered. To exemplify, the length of the forearm segment was computed using the position information of its extremities for each frame. Figure **14** shows the results of the computation if the depth is considered (Lxyz) or not (Lxy). It is clear that while the segment maintains its length when using the three dimensions, the length of the segment varies greatly when only two dimensions are considered.

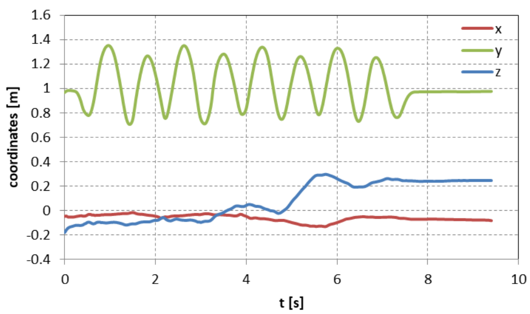

Figure 13. Trajectory evolution of the centre of mass on each 3D axis.

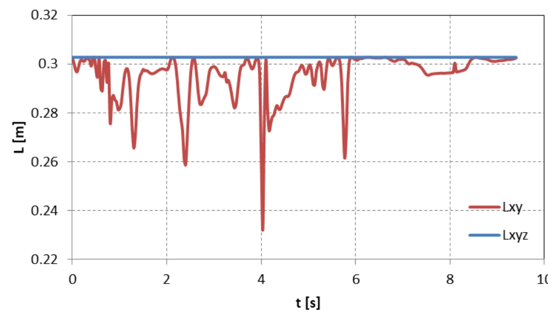

Figure 14. Length of the forearm segment obtained by the two methods.

4. CONCLUSIONS

When a movement is considered to develop in a plane, it is usual that its study focus on the information on that plane. If only two- dimensions are considered in the analysis, information regarding the third axis and its influence on the overall motion is lost. The influence of considering the biomechanical analysis of movement using two- or three- dimensions is explored in this work.

For this study, a basic *Ballet* jump was considered, the *Échappé Sauté*, as it is mainly a vertical jump with movement of the arms and legs. Three participants were asked to perform a sequence of *Échappé Sautés* and the motion was captured using a *Kinetic* sensor and the *iPi Recorder* software.

The motion was digitize and analysed using the *iPi Mocap Studio* and its *Biomech Add-On*, and the positions, velocities and accelerations of several body points were obtained. Using the position's information, the coordinate on the vertical plane were considered to compute a two-dimensional velocity vector. Using this vector, a comparison was made with the velocity vector obtained by the software.

The results for three body points were presented, the top of the head point, the elbow and the ankle. The movement of all these points show that although the movement in study is executed mainly in the vertical plane, there is considerable movement on the third axis, leading to a loss of information when the study only takes into account the information on two axes. Also, there is some movement on the horizontal axis, especially relevant when considering the top of the head point, showing that although this point should have only a vertical motion, during the execution the participant was not able to maintain the same position.

To further investigate the influence of the third axis, the motion of the centre of mass was considered. On a vertical jump, the centre of mass has a vertical motion and it does not show movement on the horizontal plane. However, in the motion in study, the centre of mass showed movement in all axis, revealing that in this jump there is considerable motion out of plane and that disregarding the depth, contributes to a loss of information on the overall motion.

To illustrate the effect of the loss of information, the length of the forearm segment was computed for the motion. This study showed that if the computation uses only the information of the vertical plane, the segment does not maintain the same length during the motion analysis, which is not accurate. Using the three coordinates of the points, the segment does not change its length during the motion analysis.

This study illustrates that even when the movement in analysis is considered as a movement in plane, there is information to be obtained by considering the three-dimensional motion. The two- dimensional motion analysis is simpler and may be useful for generic overall information of the movement, but using the information on the three axes will obtain more accurate results, as expected. Thus, the three- dimensional analysis of movements is more adequate even when the movement occurs in one plane. When considering the two-dimensional analysis of such movement, it may be considered adequate as long as the spatial uncertainty is presumed as part of the analysis.

Regarding the application to dance, the plane information is relevant as it can give a general idea of the performance. If the aim is to obtain information on the individual performance to analyse the positioning and deviations from the considered correct execution, the analysis should take in consideration all axes to ensure all motion is accurately obtained.
On an overall perspective, the use of the *Kinetic* sensor allows for a simpler configuration of the motion capture apparatus, as it is able to capture the motion considering the depth, thus exempting the use of more cameras.

ACKNOWLEDGMENTS

The authors would like to acknowledge the support of Polytechnic Institute of Lisbon through the IDI&CA 2017 grant for project IPL/2017/EBME/ISEL, and the support of FCT through IDMEC under LAETA project UID/EMS/50022/2019.

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