MUSCULOSKELETAL ANALYSIS OF TWO BASIC LATIN AMERICAN STEPS

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This study aimed to quantitatively define two basic Latin American steps (Basic Step and Lateral Step) through a biomechanical approach, providing the main events during each step cycle and the key kinematic features related to these movements. The participant was an instructor of the Italian Federation Sports Dance, who performed the movements in the biomechanics laboratory within the "Sport and Anatomy" center, equipped with an 8-camera Vicon IR system and two force plates. The kinematic variables were computed using two OpenSim models: the Rajagopal and the Thoraco-lumbar models. The major differences between the models were observed in the pelvic tilt, while the pelvic list and rotation were quite similar in the waveforms and range of motion during the two dance steps. In addition, the coordination pattern between the lower limbs and the lumbar spine joint angles confirmed their cyclical feature, even though they had different details between the models.

KEYWORDS: BIOMECHANICAL ANALYSIS, OPENSIM, SPORTS DANCE

INTRODUCTION: Latin American dances are popular worldwide because they can be performed by a wide range of people of different ages and training, from amateurs to elite dancers. Previous research has explored the biomechanical analysis of dance, highlighting its applications in both rehabilitation (Carapellotti et al., 2020) and the enhancement of dance performance (Dorosh et al., 2021). Moreover, the integration of virtual reality and machine learning technologies has facilitated the identification of movement patterns and step sequences using biomechanical methods, paving the way for innovative interactive dance training platforms. This work arose from the need to identify key biomechanical features of basic Latin American dance steps, addressing the existing gap in knowledge regarding the foundational movements that lead to a varied interpretation of their performance. We started focusing on the biomechanical analysis of two fundamental movements in salsa and bachata, namely the Basic Step (BS) and the Lateral Step (LS). Purposely, we leveraged combining experimental motion capture analyses and musculoskeletal (MSK) simulations in OpenSim (Delp et al., 2007). Such simulations are essential tools within the biomechanic community, providing the capacity to estimate quantities that cannot be directly measured by motion acquisition systems, such as muscle forces and joint reaction forces (Seth et al., 2018). Furthermore, selecting the appropriate MSK model is crucial, as different models may provide different results and varying levels of accuracy and details for specific movements. The current study aimed to (i) define the main events that occur during BS and LS cycles, and (ii) extract the key kinematics features of the two steps by means of two full-body OpenSim models: the Rajagopal model (RM) (Rajagopal et al., 2016) and the Thoraco-lumbar model (TLM) (Bruno et al., 2015). These models were chosen to compare their capabilities to catch the kinematics of the pelvis and torso, very active in Latin dances. In the RM the head and torso are a single rigid body, while in the TLM the spine is fully articulated. Therefore, the main differences among inverse kinematic results of the two OpenSim models are discussed and also compared with those from VICON CGM2.5.

METHODS: An expert dancer (male, 50 yo, 65 kg, 165 cm) was equipped with 55 retro-reflective markers, according to the Vicon Full Body CGM2.5 marker set (Armand et al., 2014). Each movement was captured three times, in a single session, with Latin music playing in the background at 35 bpm, so that the dancer could perform the movements more naturally. Marker trajectories were recorded at 100 Hz using 8 Vicon infrared cameras, while ground reaction forces (GRFs) were simultaneously acquired at 1kHz using two AMTI force platforms. Acquired data were processed in OpenSim with the TLM (78 segments and 111 DoFs) and the RM (22 rigid segments and 37 DoFs). To compare the kinematic variables, their sequence of pelvis rotations was changed and adapted to the one of the CGM2.5, i.e. Rotation-List-Tilt.

Each model was scaled according to the anthropometric data of the subject. From the Inverse Kinematics tool, the pelvic joint angles, the lumbar angles (RM) and the intervertebral joint angles (TLM) were obtained and compared over a cycle of each step. A custom MATLAB (R2020b) script was used to analyse data and plot the kinematic variables. No statistical analysis of the data was performed. One cycle is defined by the music 4/4-time signature; 8 beats compose a step cycle. Starting from the position where the feet are parallel with the body upright, the first toe contact corresponds to the first beat of the music for both the BS and the LS. The vertical component of the GRFs (vGRF) was used to detect the contact, assuming a threshold value of the force equal to 25 N. Figure 1 shows the main events for the BS (left) and the LS (right). The BS cycle's events are defined using the feet movements, accompanied by pelvis rotations:

1. Toe contact forward (TCF): the BS cycle begins with the toes of the left (for a man, right for a woman) foot moving and touching the ground forward (backward for a woman), while the opposite foot rests in a standing position (count 1).
2. Opposite step on site (OSS): the weight is transferred, and the opposite foot takes a step but remains in place (count 2).
3. Foot off (FO): the foot comes off the ground.
4. Foot starting position (FSP): the foot returns to the starting position on the ground, aligning the feet so they are parallel (count 3). Pause (count 4).
5. Opposite foot off (OFO): the opposite foot comes off the ground.

The other five steps are marked by the same events as in the first half of the cycle, with the difference that, in this case, the contralateral foot moves backward (TCB) at about 50% of the cycle (count 5). The BS cycle ends when the initial starting position is achieved (count 7). Finally, pause (count 8). The LS cycle's events are similar apart that the feet move laterally (TCL = toe contact left, TCR = toe contact right) rather than forward/backward.

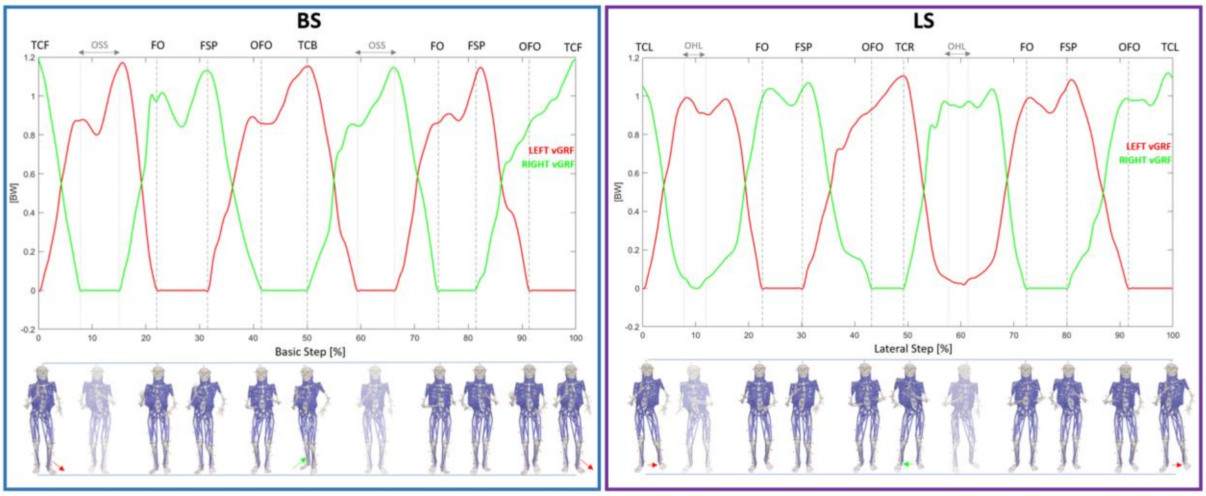

Figure 1: Events detection through vertical Ground reaction Forces (vGRF) expressed in body weight as a function of the BS cycle (left) and the LS cycle (right). (OHL= Opposite Heel Lift).

RESULTS: Kinematics results are reported for one cycle of the BS and the LS. Figure 2 shows the pelvis range of motion (RoM) computed by the RM, TLM and CGM2.5. The pelvic joint angles are quite similar between the models, both in terms of the RoM and kinematic pattern, with the pelvis list (or obliquity) having the biggest excursion during both the BS (-16°÷19°, as min ÷ max values for the CGM2.5 model) and the LS (-18°÷16°). Maximum differences are observed in the pelvic obliquity between the RM and the CGM2.5, reaching 7°, while between the TLM and the CGM2.5 only 2° are found. This is due to a different definition of the reference system of the pelvis in the RM. All models show a cyclic pattern for the pelvis list and rotation, while the pelvis tilt is characterised by a more irregular and asynchronous trend. Figure 3 shows the angle-angle plot describing the coordination between the lumbar rotation angles (for RM) or intervertebral axial rotation angles (for TLM) and the pelvic list, knee flexion-extension (FE) and hip ab-adduction (AA) during both BS and LS. The movement pattern indicates that there is a great coordination between different joints, highlighting the cyclicality of these rhythmic movements.

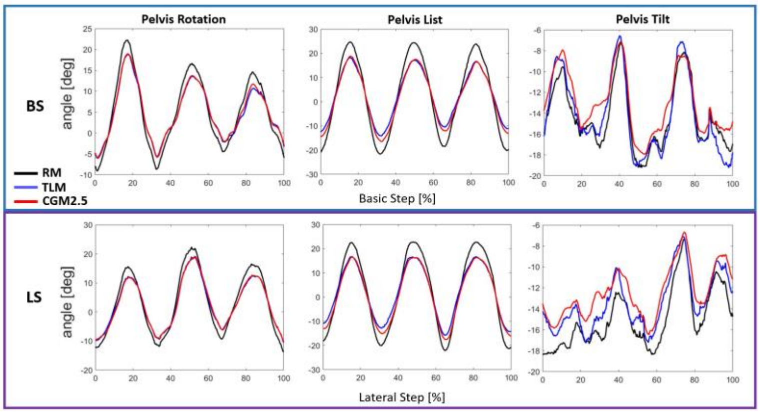

Figure 2: Pelvis joint angles computed by the RM (black line), TLM (blue line) and CGM2.5 (red line) models, during the BS cycle (first row) and LS cycle (second row).

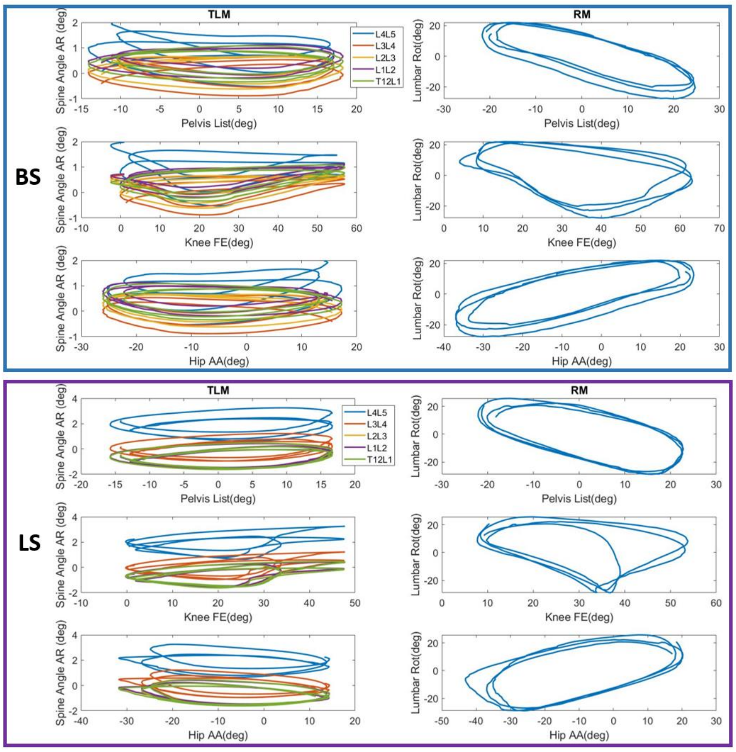

Figure 3: Angle-angle plot describing the joint coordination between the TLM lumbar spine Axial Rotation (on the left)/ RM Lumbar Rotation (right) and pelvis list (first row), knee FE (second row) and hip AA (third row) during the BS and the LS.

DISCUSSION: The study aimed to provide a scientific foundation for quantitatively defining the BS and LS in Latin American dances and to analyse the difference of kinematic results obtained from two full-body OpenSim models and the VICON CGM2.5 model. First of all, the main events of the BS and LS were identified from vGRFs, video and music timing. Both the BS and the LS showed similar kinematic features: the peaks of the pelvic list and rotation occurred at the same temporal events (after every 33% of the cycle), emphasising the same precisely executed rhythm in both movements. In general, the coordination pattern between the different joints was mostly elliptical in shape, demonstrating the cyclic nature of these dance steps. An exception was observed in the coordination between knee and lumbar spine angles during the LS, due to a greater phase shift between knee flexion peaks and lumbar spine axial rotation peaks. In addition, the low coordination variability between the lower limbs and the lumbar spine joint angles may be due to a more consistent or regulated performance. The high mobility of pelvis and spine, and the ability to move them rhythmically and fluidly in this type of dance are key factor differentiating expert dancers from novices. For this reason, the study focused on pelvis joint angles and lumbar spine movements, emphasizing the need for precise models to capture the complex motions inherent in Latin dancing. Regarding the pelvis joint angles, the TLM and CGM2.5 showed a more similar RoM with respect to the RM, which overestimated both pelvis rotation and list. This difference is due to a different definition of the pelvis reference system in the models. Furthermore, the RM provided only lumbar angles (lumbar extension, bending and rotation), describing the trunk-head (child) orientation with respect to the pelvis (parent), through a 3 DoFs joint. In contrast, the TLM offered a more in-depth view by modelling the intervertebral joints as spherical joints, allowing for detailed analysis of segmental movements in the thoracic and lumbar spine, such as the joint coordination between each intervertebral angle and pelvic list, knee FE and hip AA during both the BS and the LS. For this reason, the TLM could be suitable in providing valuable insights that can potentially inform both training and injury prevention strategies for dancers. However, the marker set used for this study cannot guarantee that these values are accurate and reliable. Moreover, it should be verified whether the use of a complete marker set (e.g., with markers placed along the entire length of the spine) could give appreciably different results.

CONCLUSION: In this paper, we investigated two basic steps of Latin dance, the basic and the lateral steps, mimicking a standard gait analysis. The kinematic features obtained from OpenSim models and VICON CGM2.5 were compared, in particular for pelvis angles. Results were very comparable, apart from an off-set due to a different reference system of the pelvis adopted in the Rajagopal OpenSim model. Moreover, the use of a model with an articulated spine (TLM) enabled some important coordination between joint angles to be revealed, although the reliability of the intervertebral joint angles should be still verified. This confirms that the choice of the MSK model is important and depends on the purpose of the study. In conclusion, the study poses the basis for a scientific approach to Latin dance, which can be helpful to both practitioners and instructors. In the future, further tests will involve experts and novices, male and female dancers, with also an evaluation of the main muscles involved.

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