COMPARISON OF PEAK LUMBAR LORDOSIS BETWEEN SOME BASIC MOVEMENTS OF RHYTHMIC GYMNASTICS

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To assist coaches in managing gymnasts, a good knowledge of the movements most likely to cause back pain is required. In rhythmic gymnastics (RG), this can be considered as identifying movements involving very high lumbar curvatures. To quantify the lumbar lordosis during some basic RG movements (*ring*, *penché*, *penché with rotation*, *split leap*, *turning split leap*, and *front* and *back walkovers*), eight gymnasts were enrolled and a 3D motion analysis was performed based on motion capture data, a musculoskeletal model and low-dose biplanar radiographs for model personalisation purposes. The *ring* and both the *front* and *back walkovers* were the movements studied involving the lumbar spine in extension the most but also resulting in the highest dispersion between gymnasts. Hence, future works should investigate the causes of this greater dispersion.

KEYWORDS: lumbar, gymnastics, kinematics

INTRODUCTION: Back pain is prevalent among women practising rhythmic gymnastics (RG) (Caine & Nassar, 2005; Kruse & Lemmen, 2009; Purcell & Micheli, 2009). Frequent repetition of movements requiring extreme lumbar extensions places major stress on the lumbar spine and may result in overuse injuries such as intervertebral discs degeneration or micro-traumatic pathologies such as isthmic lysis and spondylolisthesis (Kruse & Lemmen, 2009; Purcell & Micheli, 2009). Maintain gymnast health is therefore a major issue, particularly in high-level practice where in the search for performance the increasing training load is challenged by the induced increased risk of overuse injury. Consequently, practicing more smartly seems crucial and requires a more detailed knowledge of the relative impact of the frequent repetition of each type of RG movement on the lumbar spine. In this way, the identification of the RG movements increasing the most the stress in the lumbar spine could help the medical staff and coaches to address recommendations.

As lumbar extension is known to increase the stress in the lumbar spine (d'Hemecourt & Luke, 2012; Hall, 1986; Kruse & Lemmen, 2009), peak lumbar lordosis could be considered as a good indicator to identify movements that are more at risk of lumbar spine injury. Therefore, the objective of this study was to quantify the maximum of lumbar lordosis reached during basics RG movements performed by eight gymnasts in order to distinguish which ones are significantly more prone to overstress the lumbar spine. Basic RG movements studied, which have been previously selected with coaches as being representative of the discipline and consistent with measurement protocol, were: *rings*, *penchés*, *penchés with rotation, split leaps*, *turning split leaps*, *front walkovers* and *back walkovers.*

METHODS:

Participants: After receiving ethical agreement for the study (number: 2018-A01926-49), eight young RG athletes, all training in French national training centres (at least 15 hours per week for the youngest), consented to participate in the study. Gymnasts were 15 years old in average (range: 12 to 18 years old). Their masses were 46 ±12 kg (range: 33 kg to 63 kg) and their heights were 1.59 ±0.08 m (range: 1.44 to 1.69 m).

Data Collection: Gymnasts underwent a motion capture session that took place in a motion analysis lab equipped with a dedicated RG floor. Reflective markers (82 in total) were placed on the segments of the gymnasts: 38 on their lower limbs, 5 on their pelvis, 4 on the spine (L5, T12, T8 and C7), and the 35 others on the upper limbs and the thorax. The three-dimensional location of the markers was tracked at 200 Hz by a 14-cameras optoelectronic motion capture system (Vicon system, hardware: 1.3/2.2 Vero cameras; Nexus 2 software; Oxford Metrics, UK). Each gymnast made a static acquisition in upright standing posture and then performed successfully from one to five repetitions of each of the 7 RG movements studied (Figure 1A). After the motion capture acquisitions, gymnasts underwent micro-dose biplanar radiographs (EOS system, EOS imaging, France) in the EOS recommended neutral standing upright posture, while still being equipped with the reflective markers of the motion capture system.

Data processing: As 3D kinematics of the spine during gymnastics movements cannot be determined directly from the motion capture data, a three-dimensional linked-segment full-body model has been developed using the open-source musculoskeletal simulation software OpenSim (Delp et al., 2007). The model was based on the full-body model of Raabe and Chaudhari (2016) with a fully articulated spine based on the model of Bruno et al (2015). A body-specific coordinate system was defined for each vertebra in order to calculate directly the lumbar lordosis that was defined as the angle between the sacral endplate (body S1) and the first lumbar vertebra (body L1).
This generic model was then scaled to each gymnast through proportional coefficients for each segment based on distances between specific markers from the static acquisition. The eight scaled models were then personalised to each gymnast for the pelvis and thoraco-lumbar spine. To this end, 3D-reconstructions of the pelvis and vertebrae were performed based on EOS radiographic images. Then, the 3D surface meshes of the pelvis and vertebrae were used to personalise the model in terms of geometries and intervertebral joint centres locations (located in the middle of the intervertebral discs as in the model of Bruno et al (2015)). The locations of the markers placed on the pelvis and vertebrae were also personalised for each gymnast based on markers identification on biplanar EOS images.
Then, joints kinematics during RG movements were determined using a multibody kinematics optimization algorithm implemented in OpenSim 3.3 software (Delp et al., 2007). Bodies kinematics were then calculated from inverse kinematics results in order to get position and orientation of each body of the model during movements. The time courses of the lumbar lordosis were then calculated from S1 and L1 kinematics. For interpretation, a *zxy* rotation sequence was used, corresponding to flexion/extension then lateral bending then axial rotation, to determine the flexion-extension angle (first angle of the rotation sequence) between S1 and L1 (Figure 1B).
Time courses of lumbar lordosis were obtained for each trial and the maximum values of lumbar lordosis reached during the acquisitions of each movement were considered to calculate the mean peak lumbar lordosis reached by each gymnast for each movement. Given the objective of this study and the low number of participants, non-parametric statistical tests for paired data of Wilcoxon (rank sum test) were then conducted. The significance level was chosen at $\alpha=0.05$ and every probability (p-values) was reported.

RESULTS: Figure 1 (A) shows the typical time courses of the lumbar lordosis associated with illustrations of the key postures of the gymnast during the RG movements. This enables to visualise both the instants of peak lumbar lordosis occurrence and the associated general postures.

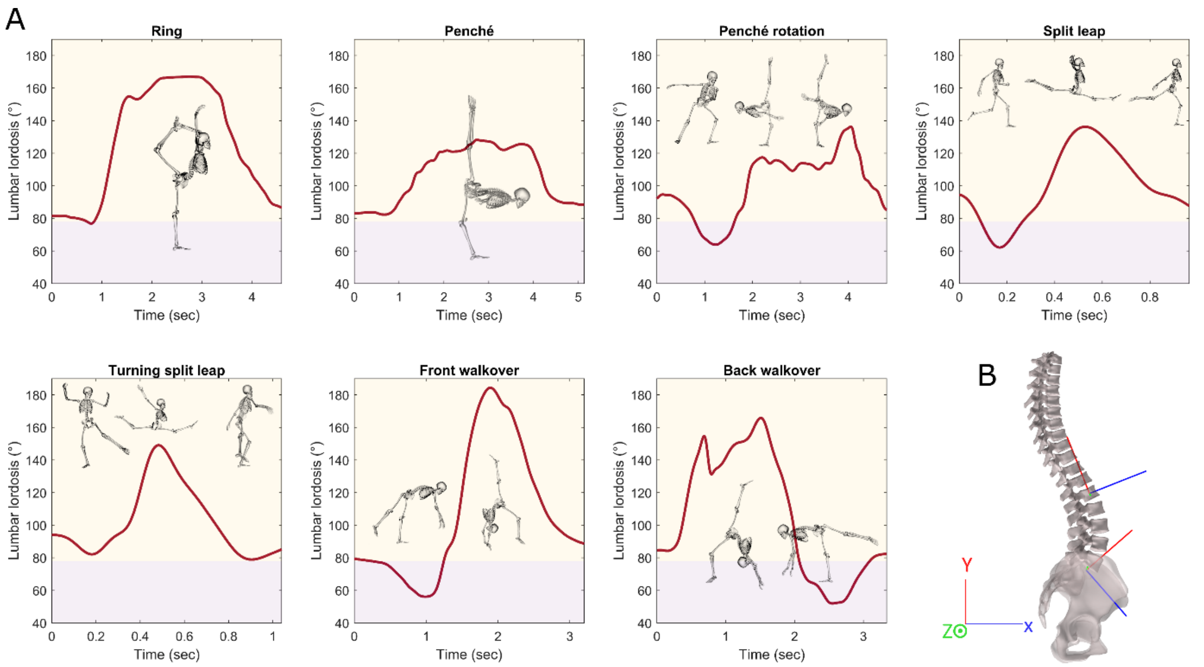

Figure 1: (A) Example of typical time courses of lumbar lordosis for one participant. The yellow (respectively purple) area indicates the lumbar spine is in an extension (respectively flexion) posture. Those areas were determined based on the calculation of the lumbar lordosis in neutral posture from the static acquisition in neutral upright standing posture (ie, 78° for this participant). Regarding the evolution, an increase (respectively a decrease) of the lumbar lordosis means a lumbar extension (respectively flexion) movement. (B) thoraco-lumbar spine and pelvis geometries showing S1 and L1 coordinate systems used to calculate lumbar lordosis.

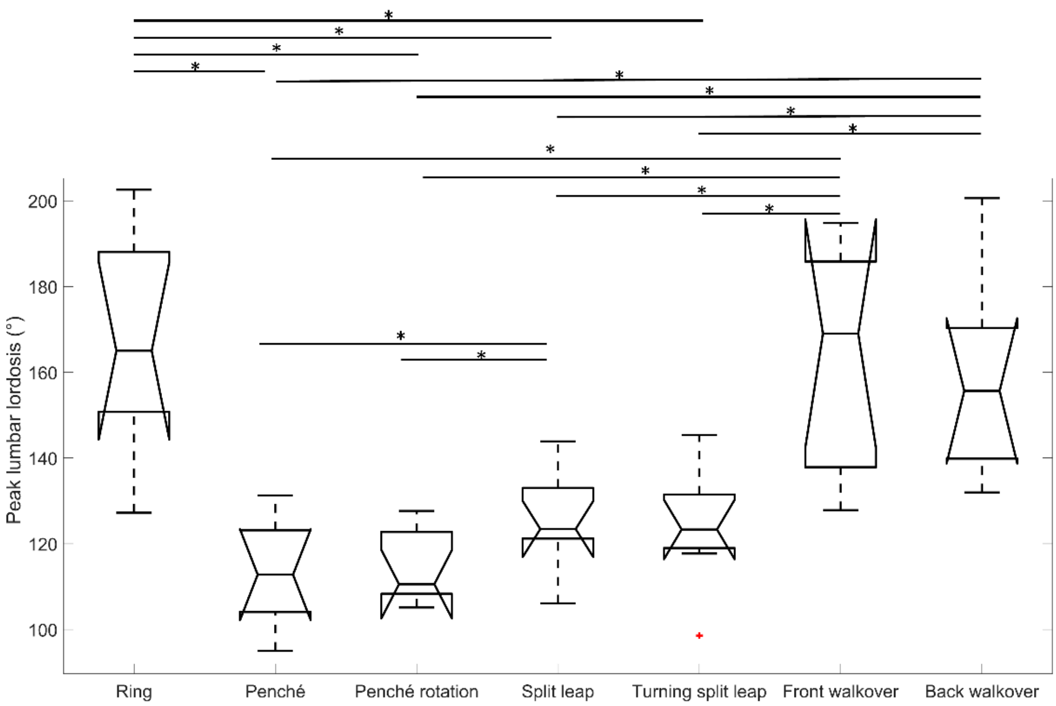

Figure 2: Box plots representing peak lumbar lordosis according to the RG movements.

For each movement, peak lumbar lordosis of the whole cohort are reported on figure 2 as box plots. Results showed that the *ring* along with the *front* and *back walkovers* required significantly highest lumbar lordosis (mean: 167°±25°, 164°±26° and 158°±23°, respectively) than the *split leap*, the *turning split leap*, the *penché with rotation* and the *penché* (mean: 126°±11°, 124°±14°, 115°±9° and 113°±12°, respectively) ($p \in$ [0.01-0.02]). In addition, peak lumbar lordosis observed during the *split leap* were also significantly higher than during the *penché* and the *penché with rotation* (p=0.02 in both cases). Other differences were not significative at the α=0.05 threshold.

DISCUSSION: Peak lumbar lordosis were reported for each movement and the Wilcoxon non-parametric statistical tests for paired data were carried out to compare the movements.
The *ring* along with the *front* and *back walkovers* appeared to be the movements requiring the most lumbar extension. Although, the peak lumbar lordosis of the *split leap* was in average 25% lower than the one reached during the *ring*, it remained in average 10% higher than the one reached during the *penché*. Considering that high lumbar extensions increase the stress in the lumbar spine, quantifying the peak lumbar lordosis reached during basic RG movements enabled to identify that the *rings* and the *walkovers* (front and back) would induced more stress in the lumbar spine than the *penchés* and the *split leaps* (both with rotation or not).
However, this study is not free of limitations. First, to reinforce its statistical power, more gymnasts should be enrolled. However, evident differences already appeared between movements as well as a high variability between gymnasts, in particular for movements requiring the most lumbar extension. Hence, it would be beneficial in a future study to investigate whether the level of lumbar curvature for these movements is related with a success or a failure with respect to the Code of Points or with differences in the strategy of movement execution, in particular regarding the relative use of other joints. Secondly, the seven movements studied only represent a small portion of all possible RG movements. However, their diversity (statics or dynamics, with or without jump, with or without rotation) would enable coaches to estimate the level of stress induced by movements with similar postures. Thirdly, the lumbar lordosis values computed during the movement directly rely on the definition of the three-dimensional linked-segment full-body model used. However, the personalisation process of the model should have prevented from model inaccuracies.

CONCLUSION: To our knowledge, this study is the first to quantify lumbar lordosis during seven RG movements. It thus enabled to distinguish which of the RG movements are significantly more prone to overstress the lumbar spine and provide consequently coaches with a more detailed knowledge of the risk for the lumbar spine associated with the frequent repetitions of certain types of RG movements.

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