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APPLICATION OF PRINCIPAL COMPONENT ANALYSIS IN THE STUDY OF TASKS WITH DIFFERENT MECHANICAL CONSTRAINTS

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This study aims to compare the lower limb kinematics between two landing tasks, using the Principal Component Analysis (PCA) and parametric techniques. Ten male volleyball athletes performed bilateral vertical jumps with single leg or double leg landings. Hip, knee and ankle kinematics were used in the analysis. Statistical analysis was performed in the principal components coefficients (PCC) retained in the PCA and in the parametric variables. Only the first PCC presented differences in the three joints. The minimum peak showed differences in the ankle and knee, the maximum peak was different in the knee and hip and the mean angular displacement showed differences in the three joints. PCA described the differences presented by the parametric variables allowing the identification of the location where the variance between the landing tasks could be better explained.

KEY WORDS: Landing Task, Principal Component Analysis, Biomechanics.

INTRODUCTION: Alterations in the number of mechanical constraints of the biokinematic chain while performing landings after vertical jumps seems to be a determining factor in the behavior of biomechanical variables related to injuries. In many sports, such as volleyball, the landing techniques after specific motor skills are performed unilaterally while about 26% of anterior cruciate ligament (ACL) lesions occur in this type of landing (Krosshaug et al., 2007).

The high prevalence of injuries during the single leg landings (SL) seems to be related to the different behavior of the biomechanical variables compared to double leg landings (DL). Leporace et al. (2010) and Pappas et al. (2007) reported a smaller amont of knee flexion and increased hip flexion during SL compared to DL. However, both studies used parametric kinematic variables, such as maximum angular peak and joint positions during the initial ground contact to compare the tasks. Parametrization techniques extract instantaneous values of signal amplitude, which ignore the pattern of movement. According with Chau (2001) the extraction of these pre-defined parameters is subjective and neglects the temporal information of the kinematic signal, containing limited information about the movement.

To obtain information that describe the main differences between the tasks, it is necessary to consider the whole waveform. The Principal Component Analysis (PCA) is a multivariate statistical technique used to reduce the dimensionality of a data set and to perform the analysis of the complete time series. This method transforms the original signal into a reduced set of uncorrelated data which retains the maximum data variance (Jolliffe, 2002). Additionally, in recent studies, the analysis of the eigenvector in temporal correspondence with the original signal has been used to observe the locations where the main variance of each principal component is explained (McKean et al. 2007; Muniz et al., 2010).

Studies have used PCA to classify movement patterns (O'Coonor & Bottum, 2009), as well as to evaluate treatment effects (Muniz et al., 2010) and to differentiate training status (Donà et al., 2009). However, little is known about the relationship between the classical features of comparison between variables used in several studies, as angular peaks and mean angular displacement (MAD), and the results of PCA. Thus, this study aimed at comparing the lower limb kinematics between two landing tasks, using the Principal Component Analysis (PCA) and parametric techniques, as mean and angular peak; and compare the results of the two analysis. The hypothesis was that both techniques of analysis

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used in this study would show differences between landing tasks; however, the PCA would provide information about where, in the movement cycle, the parametric variables could discriminate the differences found.

METHODS: Ten young male volleyball athletes (13 ± 0.8 years, 1.69 ± 0.12 m, 60.4 ± 13.3 kg) participated in this study. Responsible for all athletes signed an informed consentiment authorizing the participation of their descendents.This study was approved by the Ethics Committee for Human Research at the State University of Rio de Janeiro (UERJ).
Each subject performed two types of vertical jumps. For each task, the athletes performed the propulsive phase with both legs, followed by single leg (SL) or double leg (DL) landings.
Initially, the athletes performed the tasks in order to familiarize themselves with the movement. After that, each athlete performed six jumps, landing three SL, with the dominant limb, and three DL. The dominant leg was determined as the favorite limb which the subject kicked a ball as far as possible. The order of the landings tasks was randomized.
A camera (Sony DCR HC 46), with a capture frequency of 30 Hz was used to record the images, which allowed achieving 60 frames per second in interlace mode. Spherical reflective markers of 20 mm were fixed at iliac crest, greater throcanter, lateral condyle of the femur, the lateral malleolus, calcaneus and the head of the fifth metatarsal.
After capture, the images were transferred to a personal computer. The raw coordinates of each marker were transformed into 2D coordinates, filtered by a Butterworth low-pass filter of fourth order, applied in the direct and reverse directions, with a cutoff frequency of 6 Hz. The initial ground contact event was identified by a foot-switch FootPress (LaBiCoM®, Brazil) placed in the first metatarsal head of each subject. To normalize the percentage of landing , the samples between the interval of the initial contact and maximum knee flexion were interpolated to 101 values using a Cubic Spline algorithm. Initially, the 2D coordinates were obtained by the SkillSpector Software version 1.2.4 (McLean et al., 2005) and then processed with MATLAB software version 7.8.0 (The Mathworks, USA).
The mean angular displacement (MAD) of hip, knee and ankle in the three jumps on each landing and the maximum and miminum peaks were obtained in the interval between the initial ground contact and the instant of maximum knee flexion.
For PCA, the hip, knee and ankle kinematics signals were organized in three distinct matrices **E** [20 x 101], where each row corresponded to each subject, being the first ten related to SL and the last ten representing to DL, and each column corresponding to the interpolated signals. PCA, according to Jolliffe (2002), was applied to each matrix, separately. For such approach, initially the mean was subtracted from each matrix **E**, after the covariance matrix **S** [101 x 101] was calculated and, finally, the eigenvectors and eigenvalues were estimated from **S** based on a singular value decomposition algorithm. The number of principal components (PCs) retained in the analysis was those showing 95% of cumulative sum from the variance of the original data.
The Wilcoxon Rank Sum test was used to verify differences between the principal components coefficients (PCC) of each landing task retained in the analysis, for the hip, knee and ankle, as well as to compare the maximum and minimum angular peaks and MAD between landing tasks. The level of significance was set to $\alpha = 0.05$.

RESULTS: Two PCs were retained for hip and knee and four PCs were retained in the analysis of ankle, with 97.33%, 96.27% and 97.58% of variance explained, respectively. The first PCC was significantly different for the three joints, with knee showing higher coefficients in the DL ($p = 0.002$) and hip ($p=0.002$) and ankle ($p=0.0039$) for SL. For the coefficients of the others PCs, no significant differences were found ($p > 0.05$).
The loading factor analysis for the first PC indicated that the ankle kinematical differences between the landing tasks are explained at the beginning of the movement. The knee differences could be explained in the intermediate region and for the hip in the final stage (Figure 1).

Regarding the parametric variables (Table 1), statistical differences were found in the ankle ($p = 0.006$) and knee ($p = 0.004$) for the minimum peak flexion; hip ($p = 0.002$) and knee ($p = 0.004$) for the maximum peak flexion and hip ($p = 0.002$) and knee ($p = 0.002$) for the MAD.

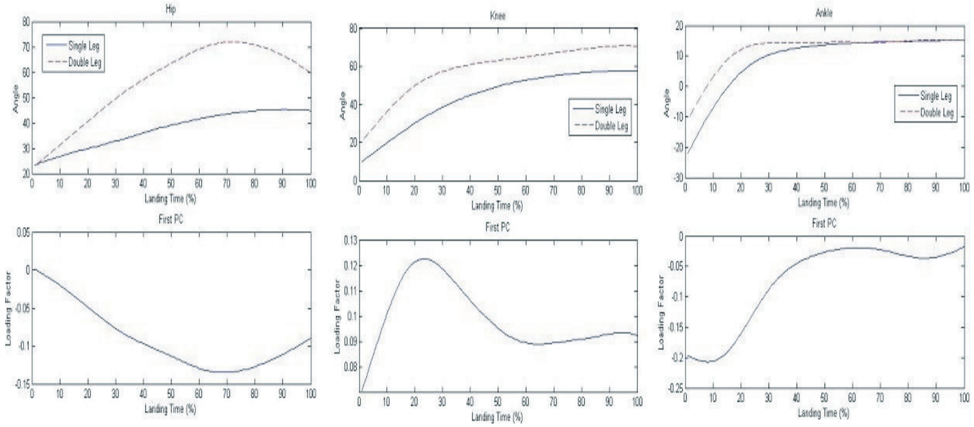

Figure 1: Above: Kinematic behavior of the hip, knee and ankle, respectively, in the SL (continuous) and DL (dotted). Below: Loading Factor of the first principal component of the hip, knee and ankle, respectively.

Table 1
Minimum, maximum and mean (standard error) values of the angular behavior of the three joints during single leg (SL) and double leg (DL) landings.

Joint	Minimum		Maximum		Mean	
	SL	DL	SL	DL	SL	DL
Hip	23.3(2.2)	23.0(2.7)	46.2(3.2)	72.3(4.2)**	37.6(2.5)	56.5(2.5)**
Knee	9.9(1.5)	20.8(3.1)**	58.4(1.9)	71.5(2.2)**	44.2(1.7)	58.9(2.0)**
Ankle	-21.9(1.9)	-10.8(2.3)**	16.6(1.1)	18.3(0.8)	9.3(0.8)	12.2(0.8)

** $p < 0.01$ in relation to the single leg landing.

DISCUSSION: In this study, kinematics variables from lower limbs between SL and DL landings were compared, using PCA and classical parametric techniques, such as the MAD and maximum and minimum angular peaks. It was motivated by the fact that much of the literature consists of reports of investigations in which it was used the classical parameters described above. However, the results provided by that type of analysis has little practical applicability, since, in general, it is not known what location of the movement cycle is explaining the differences observed. Landing tasks were chosen as dependent variables because during these tasks the minimum and maximum angular peaks occur, respectively, at the beginning and at the end of the cycle, while the MAD corresponds to the overall behavior of each joint during the cycle.

The results of this study confirmed the hypothesis initially proposed. The MAD showed significant differences for the hip and knee joints during the two landing tasks. Such results are related with the statistical differences found in only the first PCC suggesting, therefore, that the first eigenvector contained the most relevant informations relating to the differences between the two tasks. Thus, only the loading factor of the first PC was used to observe the location in which the differences could be explained.

The parametric analysis evidenced differences for the ankle and knee joints for the minimum peak, while differences were found in the hip and knee joints for the maximum peak (Table 1). Such results were confirmed in the first eigenvector analysis (Figure 1) by evidencing the most variance at the beginning of the landing cycle for the ankle joint (10% initial), at the end

for the hip (around 70%), while the knee showed the greatest difference between 20% and 30% of the cycle. No parametric variable was able to describe this kinematical behavior exactly. Rather, significant differences in knee kinematics were identified for all parametric variables used in this study.
Another interesting aspect arising from the loading factor interpretation was the sequence in which the differences occur during SL and DL landings. As described above, the first eigenvector analysis evidenced that the ankle presented the main differences between landings at the beginning of the movement followed by the knee and, finally, the hip. This may have occurred because the absorption of the mechanical loads from the ground impact after the landing is expressed distal-proximally. Based on this information, it is possible to suggest that the joints kinematics are modified during SL and DL landings, in order to compensate for differences in mechanical loads, that, according to Pappas et al. (2007), are commonly presented in these tasks. However, this hypothesis needs further studies to be confirmed.

CONCLUSION: With the use of PCA it became possible to identify all the differences obtained with the parametric variables and it was still possible to identify the location in the landing cycle where the differences between tasks could be explained. It is proposed for future studies comparing the PCA and parametric variables in other fields, like sports skills, which could explain the main variables related to performance improvement and injury prevention.

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