PRINCIPAL COMPONENT ANALYSIS OF KNEE ANGLE WAVEFORMS DURING RACE WALKING

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This study aimed at understanding whether principal component analysis (PCA) may be useful to characterize race-walkers abilities at different performance levels. Seven young race-walkers of national and international rank were recruited. PCA was applied for classifying and detecting the structure of knee sagittal angle. This statistical technique allowed extracting multidimensional features that capture the greatest variation in race walking data. The scores, i.e. the projections of the original data on the components, revealed to be good discriminative factors for performance level detection. Finally, the underlying linear structure of the principal components provided a biomechanical interpretation of motor skill. The best athletes were able to correctly lock the knee during the mid-stance; the worst ones tended to bend the knee prematurely.

KEY WORDS: PCA, race walking, technique, pattern characterization.

INTRODUCTION

Biomechanical studies have become an important tool not only in clinics but also in sports, for both trainers and athletes. Kinematic and kinetic analyses attempt to capture the athlete's actual motor characteristics to evaluate the correctness and proficiency of the movement and to prevent possible injuries. In such an analysis, it is important to take into account bio-variability. While in clinics increased variability in the parameters could be associated to decreased stability in performing a movement (Heiderscheit, 2000; Hausdorff 2005), in sports it is still not clear how this parameter may affect athletes' performance. It could be related to a form of instability or loss of ability of the athlete (Bartlett, 2004), or to a compensatory purpose in finding an optimal solution to altered situations (Hamill, 2006). This study addressed kinematic and kinetic variability during race walking. Race walking (RW) was chosen as the means of investigation due to its unique peculiarities. This discipline has specific constraints imposed by two rules: first, the athlete must maintain the contact with the ground at all times; second, the knee of the supporting leg has to be kept straight from the foot contact with the ground until the trunk passes over the leg. These rules generate very particular biomechanical and coordination demands and make this motor task appear as a stereotyped skill, particularly interesting for bio-variability analyses. Furthermore it has strong analogies with normal walking, one of the most studied movements in literature. Functional data analysis, an emerging statistical technique in biomechanics data elaboration, was adopted. Deluzio et al. (1997) introduced Principal Component Analysis (PCA) to evaluate kinematic and kinetic gait waveform measures. Multivariate covariance analysis was applied also by Sadeghi et al. (2002) in the analysis of sagittal moments at the hip, knee and ankle during stance phase. Recently, Donoughe et al. (2006) used functional data analysis in a clinical study on subjects with a history of Achilles tendon injury. Concerning the sports field, the same technique was used by Ryan (2006) in the study of kinematic vertical jump data, to differentiate some developmental stages of this motor task. The aim of the present study was to gain more insight into the application of PCA in the study of kinematic and kinetic data of race walking. In particular we tried to explore PCA potential in characterizing race walkers abilities for different performance levels, by focusing our attention on the flexion-extension knee angle.

METHOD

Data Collection: Four male (64 ± 2.4 kg, 180.8 ± 9.1 cm) and three female (50.7 ± 6.8 kg, 167.3 ± 5 cm) racewalkers of national and international class were recruited for this study, training at least 6 training sessions a week on a regular basis. A stereophotogrammetric system (ELITE 2002, BTS, Milan, Italy) composed by 8 cameras (100Hz) and a force plate (AMTI OR6-7-1000, Watertown, USA) (500Hz), were used to acquire the race walking (RW) movement. The SAFLo marker-set (Frigo, 1998) was adopted because it revealed to be the most suitable protocol to reliably detect lower limb joint angles on the sagittal plane without altering natural movement. As many as 20 suitable race walking trials across a 12m long walkway were performed by each athlete. Only the stance phase of every acquisition was used. **Data Analysis:** Ground reaction force, lower limb (hip, knee, and ankle) joint angles, joint moments and powers were evaluated. PCA was then applied for data reduction, detection of differences among athletes from different levels and assessment of the most significant pattern modes. At first, mean was subtracted from each of the data dimensions, then covariance matrix was calculated and, finally, eigenvectors and eigenvalues were estimated from it. Data were then reconstructed on the eigenvectors accounting for at least 95% of the total variance, thus extracting underlying meaningful features while reducing noise**.** Principal component scores, i.e. the projections of the original data on the new components, proved to be useful indexes for athletes' skill recognition. A hierarchical cluster technique was adopted to characterize different skill levels.

RESULTS AND DISCUSSION

The knee flex-extension is a fundamental aspect of RW technique. Its control is referred to by one of the two defining rules and, consequently, it is very important for the athlete's characterization. Therefore, the attention of the present study was focused on the knee sagittal angle. Athletes were numbered in decreasing order, according to their performance level, considering trainers' indications and race results (personal best in 20 km events*:* subj1=19:58:00; subj7=24:04:51). Race walkers were divided in three groups (LEVEL1=athletes [subj1;subj2]; LEVEL2=athletes [subj3;subj4;subj5]; LEVEL3=athletes [subj6;subj7]). From a qualitative analysis of sagittal knee angle during stance phase, different anomalous patterns characterized the best two athletes, while the other ones had similar behaviours; from this simple graphical evaluation, it was quite difficult to interpret the biomechanical differences among race walkers. PCA was then applied to each class of subjects. The first component resulted to be similar for all the athletes, representing the common knee sagittal angle trend. The percentage of variability explained by the first components is summarized in Figure 1 for the three classes. The more regular increment of the best athletes may be explained by a personalized and refined interpretation of the movement. Further investigating these two components, they proved to be good discriminators for performance level detection. Hence, we performed a hierarchical clusterization of all the data, enforcing a subdivision into an increased number of clusters. With the use of four clusters, the scores of the second and third principal components allowed to differentiate the best athletes (subj1;subj2) from the other ones. Results are shown in Figure 2. Athletes '1' and '2' had high positive PC3 scores, subjects '3','4' and'5' had positive PC2 scores, while '6' and '7' had negative scores both for PC2 and PC3. In order to analyze the biomechanical aspect of these results, we considered the graph of the influence of PC2 and PC3 on the mean knee sagittal angle. It consisted in the plot of the overall mean function of all the acquired race walking trials and the functions obtained by adding (subjects with positive scores) and subtracting (subjects with negative scores) a suitable multiple of the principal component in question. This considerably clarified the effects of the two components on every athlete.

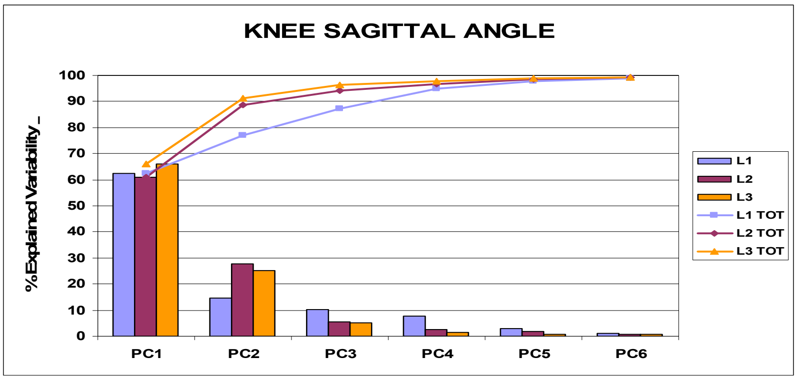

Figure 1: Percentage of explained variability (relative, bars, and cumulative, lines)

Athletes ‘1’ and ‘2’ with positive PC3 scores (Figure 3b - dash green line), tended to hyperextend the knee during mid-stance (17%-50% stance). Athletes ‘3’,’4’ and ’5’, with positive PC2 scores (Figure 3a - dash green line), manifested a larger knee flexion in the terminal stance (50%-83% stance) and pre-swing phases (83%-100% stance). Athletes ‘6’ and ‘7’ showed negative scores both for PC2 and PC3 (Figure 3a,3b – dot red lines), which corresponded to an inversion of behaviour: the knee was more extended during loading response (0%-17% stance) and more flexed during midstance.

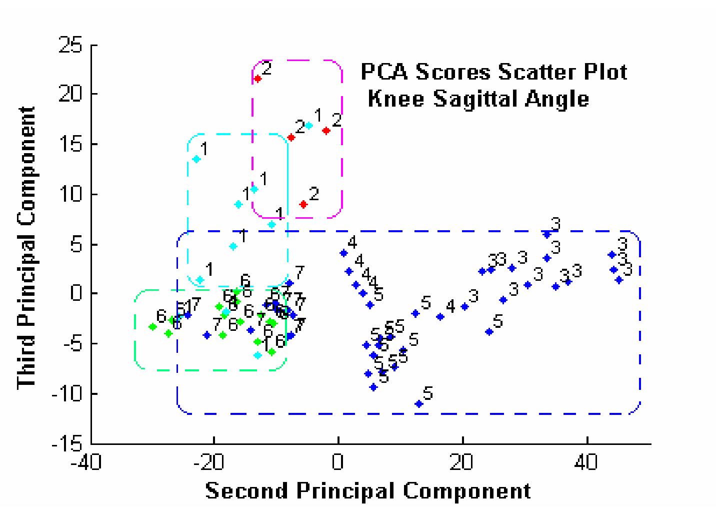

Figure 2: principal component scores for all the trials of all the subjects (PC3 vs. PC2); athletes were numbered in decreasing order, according to their performance level.

PCA revealed to be a promising technique for the reduction and analysis of data. It permitted to classify each athlete according to his skill level, based on a critical and peculiar aspect of the motor task: the knee sagittal angle. By applying a hierarchical cluster technique to the principal component scores, classification of the athletes was in agreement with the trainers' one and with race walkers personal best performances. A biomechanical interpretation of the analyzed knee sagittal angle components gave indications on the most peculiar characteristics of the athletes.

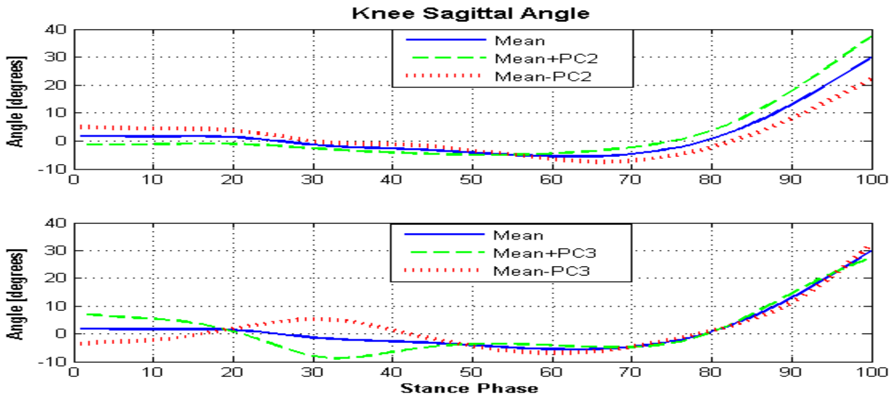

Figure 3: The mean knee sagittal angle curve and the effects of adding (green) and subtracting (red) a suitable multiple of each PC curve: (a) PC2; (b) PC3

CONCLUSION

The application of PCA proved to be a useful tool to classify athletes according to their performance level and to characterise their biomechanical behaviour. A future study on all the measured variables could allow to better inspect PCA potential in characterizing race walkers abilities.

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