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THE ROLE OF RUNNING MILEAGE ON COORDINATION PATTERNS IN RUNNING

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INTRODUCTION

Running has enjoyed an increase in popularity in the last 3 decades but with increased participation has come an increase in reported running injuries [1, 2]. Injury rates among recreational runners are estimated to be as high as 29.4% with the knee (anterior knee pain (AKP) and illiotibial band syndrome (ITBS)) being the most frequency injured area [1, 3]. Overuse injuries typically result from a combination of training error, anatomical, footwear, training surface and biomechanical factors. There is evidence to suggest that running experience or training volume may also be a factor but there are conflicting views on the relative risks for experiences vs. novice athletes [1,4]. The interaction of running experience/mileage and the mechanics of running is not well understood but may be an important factor for understanding relative injury risk in low vs higher mileage runners.

Running is a multi-segmental motion with many degrees of freedom and thus has a high-dimensional space of potential solutions to attain the same movement goal [5]. A traditional analysis of discrete joint angle values provides little information about the pathway of movement or the relative coordination of limb segment motions utilized to achieve a movement goal. The application of higher-order analysis methods such as principal component (PC) analysis provides a methodology to analyze correlated deviations from a mean movement pattern [6]. It has been hypothesized that disruption or decoupling of the normal coordination of segment movements may be deleterious and related to injury development [7]. The role of running experience on multi-segment movement and coordination patterns is not clear.

Therefore the aim of this study was to test the hypothesis that there are differences in the PC weighting coefficients between the high and low mileage groups indicative of differences in joint kinematic waveform patterns and altered multi-segment coordination.

METHODS

Gait analysis data on two groups of 25 runners each was collected: 1) a low mileage and experience group, who ran a weekly average of less than 15 miles and had no history of higher mileage running (26.3+/- 9.14yrs, 22.9+/-3.0 kg/m2, 7.2+/- 4.6 miles/week; 13 males); 2) a higher mileage group with at least 1 year of experience at mileage > 20 miles week (29.5 +/-10.9 yrs; 22.25 +/-2.2 kg/m2, 33.8+/-14.1miles/week; 13 males). Lower extremity joint kinematics and ground reaction force (GRF) data were captured at 240 Hz with a 9 camera motion analysis system and in-floor force platform. Each subject performed 5 trials at running speed of 3.5 m/s.

For each subject, data were time normalized to 100% of the stance phase and the mean over 5 trials was calculated. Included in the analysis were: 3D GRFs, center of pressure (COP) and 3D motions of the hip, knee, ankle and pelvis. All kinematic and GRF data for a single subject were arranged into a column vector. These vectors were stacked together creating a matrix of data trials. The eigen-vectors and values of the covariance matrix of the data were found. The eigenvalues indicate the amount of variation in the data explained by a given eigenvector (PC). The original data were then transformed into PC-space for further statistical analysis. Each subject's trial vector is represented as a weighted linear combination of the PCs [6].

Statistics: Unpaired Student's t-test and effect size of difference (Cohen's d) were used to test for group differences in the PC weighting coefficients for each component. A threshold of $p< 0.05$ and ES > 0.6 was used to select relevant principal component for further data reduction. A resultant PC vector was calculated as a weighted linear combination of the selected PC. Data were projected onto this new vector and the PC weight coefficients determined for each subject. To visualize differences in the gait characteristics identified by the resultant PC, the normalization step was retraced and the resultant PC vector times the mean weighting factor for each group is added to the mean of the trial vectors.

RESULTS

The projection of the subjects' trial vectors onto the linear combination of PC_8 and PC_{15}, was significantly different between the high and low mileage groups (d= 0.93, p=0.0003). Together these components explained 6.6% of the variance in the data. The difference in gait patterns was interpreted by plotting the portion of the discriminant vector plus the mean trial vector corresponding to each variable (Figure 1). This indicated that the primary differences between groups existed in the transverse plane kinematics of hip and pelvis along with the frontal plane knee kinematics. In conjunction with these kinematic differences there were also differences in the medial-lateral GRF and COP.

Table 1: For the two PC's identified as significantly different between groups the relative variance explain, Cohen's *d*, and p-value.

PC#	Eigenvalue/ % variance explained	p-value	Effect size
PC8	4.1	0.005	-0.83
PC15	2.5	0.04	-0.62
PC-resultant	6.6	0.0003	0.93

DISCUSSION

The results of this study supported the hypothesis that systematic differences between low and high mileage runners can be identified using PCA to analyze the interrelation between lower extremity joint kinematics and external forces. Significant differences between low and higher mileage groups were found for two PC. This indicates that the movement patterns of these groups cluster in high-dimensional space and the resultant PC identifies the direction along which there are systematic group differences. This direction represented the pelvic rotation, hip internal rotation, knee ab-adduction and to a lesser degree the medial-lateral GRF and COP.

Biomechanical risk factors identified for the development of AKP and ITBS include the magnitude and/or excursion of the transverse and frontal plane joint kinematics and more specifically increased knee abduction and greater hip internal rotation [8, 9]. In this analysis the higher mileage group showed greater transverse plane pelvic rotation range of motion and greater rotation towards the stance leg during mid-stance (40-60%), smaller hip internal rotation and knee adduction angles in mid-stance and smaller knee abduction angles immediately following foot contact. This suggests the higher mileage runners have a lower risk for AKP and ITBS by virtue of their movement patterns. The athletes in the higher mileage group self-reported no significant history of overuse injury despite some athletes reaching 70 miles/week. No differences were identified through this analysis for the sagittal plane kinematics.

A fundamental aim of this study was to apply the concepts and methods from dynamical systems theory to the study of movement mechanics. Goal directed movements such as running require the integration and coordination of individual segment degrees of freedom into functional units [5, 10]. The application of the PCA to trial vectors consisting of all kinematic variables and time-points provides a method to investigate not only how the individual variables differ by group and but also how the relationship between variables may differ by group [6]. The axes along which the resultant PC vector has non-zero components represent the time-points and movement components that are related in high-dimensional space and together represent a principal pattern within the running stride. Thus this analysis shows that there is coupling between motions at the pelvis, hip and knee in agreement with the literature [9] and for high and low mileage runners this coupling is different and contributes to a different degree (based on the PC coefficients) to the overall motion. This suggests that it is critical to examine the relationships between parts rather than the parts individually.

CONCLUSIONS

The selection of a sagittal plane movement pattern in the higher mileage group that couples with a less 'risky' frontal and transverse plane joint kinematic pattern may reduce injury risk and improve the efficiency of movement. The results from this study suggest that proper running mechanics need to be emphasized or practiced in lower mileage runners if they wish to remain injury free even at high mileages.

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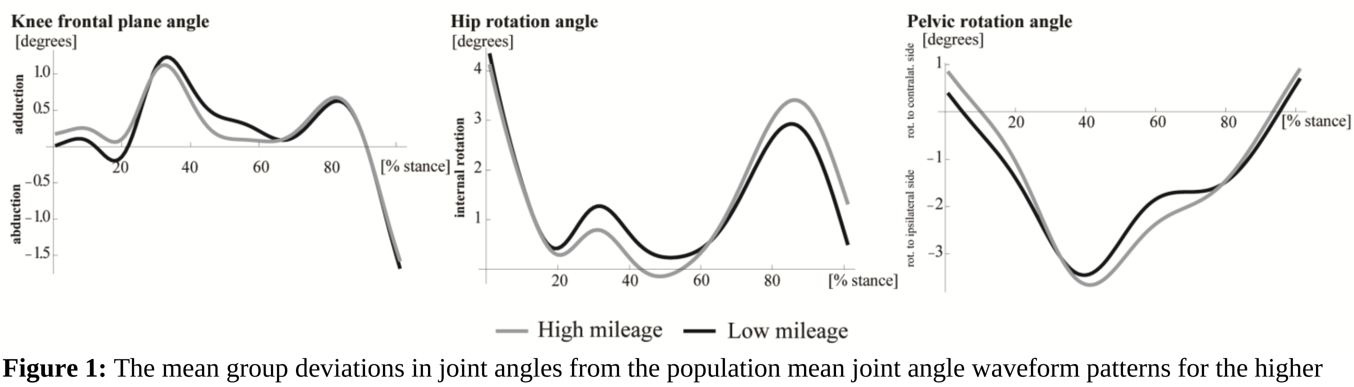

Figure 1: The mean group deviations in joint angles from the population mean joint angle waveform patterns for the higher mileage (Grey) and low mileage (Black) groups. The angles shown are those for which the resultant PC vector had a non-zero value at least 10% of the stance. These deviations from the mean gait have been amplified by a factor of 20 for visualization.