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The influence of iliotibial band syndrome history on running biomechanics examined via principal components analysis

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ABSTRACT

Iliotibial band syndrome (ITBS) is a common knee overuse injury among female runners. Atypical discrete trunk and lower extremity biomechanics during running may be associated with the etiology of ITBS. Examining discrete data points limits the interpretation of a waveform to a single value. Characterizing entire kinematic and kinetic waveforms may provide additional insight into biomechanical factors associated with ITBS. Therefore, the purpose of this cross-sectional investigation was to determine whether female runners with previous ITBS exhibited differences in kinematics and kinetics compared to controls using a principal components analysis (PCA) approach. Forty participants comprised two groups: previous ITBS and controls. Principal component scores were retained for the first three principal components and were analyzed using independent *t*-tests. The retained principal components accounted for 93–99% of the total variance within each waveform. Runners with previous ITBS exhibited *low* principal component one scores for frontal plane hip angle. Principal component one accounted for the overall magnitude in hip adduction which indicated that runners with previous ITBS assumed less hip adduction throughout stance. No differences in the remaining retained principal component scores for the waveforms were detected among groups. A smaller hip adduction angle throughout the stance phase of running may be a compensatory strategy to limit iliotibial band strain. This running strategy may have persisted after ITBS symptoms subsided.

1. Introduction

Iliotibial band syndrome (ITBS) is a common knee overuse injury afflicting approximately 8% of runners annually. Furthermore, women are two times as likely to sustain ITBS compared to men (Taunton et al., 2002). It has been postulated that ITBS results from repetitive friction of the iliotibial band sliding over the lateral femoral epicondyle during knee flexion and extension (Noble, 1980; Orchard et al., 1996; Renne, 1975). Based on a previous anatomical investigation, the notion of ITBS being a friction syndrome has been challenged (Fairclough et al., 2006, 2007). Instead of limiting sagittal plane knee motion, the iliotibial band serves to stabilize the lateral hip and knee, as well as resist hip adduction and knee internal rotation (Fredericson et al., 2000). Therefore, secondary plane hip and knee biomechanics must be examined to determine associations between biomechanics during running and ITBS.

In addition to lower extremity biomechanics, trunk and pelvis kinematics may be associated with ITBS. It has been postulated that contralateral pelvic drop and trunk lateral flexion away from the stance limb would increase the internal knee abduction moment. An increase in peak internal knee abduction moment may increase the tensile strain experienced by the soft tissue crossing the lateral knee joint such as the iliotibial band (Powers, 2010). However, both runners with previous ITBS and controls lean their trunk towards the stance limb during the stance phase of running (Foch and Milner, in press). Additionally, peak trunk ipsilateral flexion and contralateral pelvic drop were not different between groups. Therefore, it is not unexpected that runners with previous ITBS also exhibited similar peak knee abduction moment compared to controls. Nevertheless, differences in frontal plane biomechanics during running may be detected by examining the entire time-series waveform rather than peak values.

Cross-sectional investigations can provide insight into determining associations in biomechanics during running and their influence on iliotibial band mechanics. It is unknown whether post-injury biomechanics during running reflects runners' biomechanics before their first incidence of ITBS. However, half of runners who have sustained an overuse running injury reported a previous injury to the same anatomical location (Taunton et al., 2003). Although recurrence rates of ITBS are unknown, overuse running injuries commonly recur if underlying causative factors are not addressed. Collectively, the results from cross-sectional

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studies can better inform researchers designing future prospective studies to determine biomechanical causes of ITBS.

Previous cross-sectional investigations have implemented discrete analysis of peak variables to investigate factors associated with ITBS (Ferber et al., 2010; Grau et al., 2011). However, analysis of discrete variables is not sensitive to differences in the underlying movement pattern within a biomechanical waveform. Potentially, a more comprehensive waveform analysis would be able to characterize differences during running among runners with different ITBS injury status. Therefore, a principal component analysis (PCA), which captures the time-varying movement pattern of a waveform, may provide deeper understanding of injury risk factors (Kipp et al., 2011). PCA can be used to identify underlying patterns within angle and moment time-series curves based on the retained principal components. Previous research has shown that analysis of discrete variables was not able to discriminate between workers who developed low back pain and those who did not (Wrigley et al., 2005). However, the principal components derived from a PCA were able to identify differences in the kinematics and kinetics of lifting technique before low back pain developed (Wrigley et al., 2005). Additionally, PCA was able to detect differences in knee biomechanics during a run and cut task between genders that analysis of discrete variables did not (O'Connor and Bottum, 2009). Collectively, the results of these studies suggest that a PCA may enhance our understanding of biomechanical factors that are associated with previous ITBS. Therefore, the purpose of this cross-sectional investigation was to determine whether women with previous ITBS exhibited differences in kinematics and kinetics during running compared to controls using a PCA approach.

2. Methods

2.1. Participant details

Approval for all procedures was granted by the Institutional Review Board. Forty female runners between the ages of 18 and 45 provided informed written consent prior to participating. Other data obtained from these runners have been reported previously (Foch and Milner, in press). Participants were excluded if they answered 'yes' to any question on a Physical Activity Readiness-Questionnaire (PAR-Q) (Thomas et al., 1992) or previously sustained a major lower-extremity injury. Answering 'yes' to a question on the PAR-Q indicated that the participant currently had heart and/or orthopedic problems that limited her ability to exercise. A running history questionnaire was then completed by each participant. All participants were running a minimum of 24 km wk^{-1} (previous ITBS: median = 29.7 km wk^{-1}; range = 24–85.3 km wk^{-1}; controls: median = 32.2 km wk^{-1}; range = 24–80.5 km wk^{-1}). Forty female participants were equally divided into two groups: previous ITBS and controls (Table 1). Runners with previous ITBS reported that they had been diagnosed by a health care professional (medical doctor, physical therapist, or athletic trainer) and had been running pain free for at least 1 month prior to data collection.

2.2. Data collection

Participants wore running shorts, a tank-top, and neutral laboratory footwear (Bite Footwear, Redmond, WA, USA) for the overground running trials (Barnes et al., 2010). Passive reflective markers were placed on the right lower-extremity for controls. Data were collected on the previously injured lower-extremity in the ITBS group. If both sides were injured previously, then data from the right side were collected. Joint coordinate systems were defined by placing passive reflective markers over anatomical landmarks on the lower extremity of interest and trunk (Grood and Suntay, 1983). The anatomical landmarks were: acromion processes, superior iliac crests, greater trochanters, lateral and medial femoral epicondyles, lateral and medial malleoli, and first and fifth metatarsal heads. Molded thermoplastic shells with four non-collinear markers were positioned over the posterior pelvis and posterolaterally on the proximal thigh and distal shank (Cappozzo et al., 1997). The shells on the thigh and shank were secured to the segment via neoprene wraps and hook and loop tape (Manal et al., 2000). Rear-foot motion was indicated by placement of three non-collinear markers directly on the heel. Markers were placed on the manubrium, sternal body, seventh cervical vertebra, and tenth thoracic vertebra to indicate trunk motion. A static calibration trial was recorded with participants standing on a foot placement template. The standardized foot position was 0.17 m between heel centers at an angle of 14° between the anteroposterior axes of the feet (McIlroy and Maki, 1997). After the calibration trial was recorded, all anatomical markers were removed.

Overground running trials were collected while participants ran along a 17 m runway at a velocity of 3.5 ± 0.18 m s^{-1}. A nine-camera motion capture system (Vicon, Oxford Metrics, Centennial, CO, USA) sampling at 120 Hz recorded marker trajectories. A force plate located in the middle of the runway was synchronized with the motion capture system (AMTI, Inc., Watertown, MA, USA) and sampled at 1200 Hz. Two photocells linked to a timer were placed three meters apart on either side of the force plate to monitor running velocity. Five acceptable trials were collected, in which participants maintained the specified running velocity and landed on the force plate without altering their stride.

Table 1
Mean (standard deviation) of participant demographics in the previous iliotibial band syndrome (ITBS) and control groups. Each group was comprised of 20 participants.

Demographics	Previous ITBS	Controls	*P* value
Age (years)	26.0 (5.6)	23.7 (5.5)	0.187
Height (m)	1.67 (0.04)	1.68 (0.06)	0.809
Mass (kg)	58.8 (7.4)	58.9 (5.7)	0.955
Weekly distance run (km wk^{-1})	41.8 (25.1)	38.6 (18.2)	0.645

2.3. Data reduction

Data were reduced in Visual3D (C-Motion, Rockville, MD, USA). Kinematics and ground reaction forces were filtered with a 4th order Butterworth filter at a cut-off frequency of 8 Hz (Bisseling and Hof, 2006). Joint angles were determined using a Cardan X–Y–Z (mediolateral, anteroposterior, and vertical) rotation sequence (Wu and Cavanagh, 1995). Trunk and pelvis segments were computed with respect to the laboratory coordinate system. The laboratory coordinate system was defined at the posterior left corner of the force plate. Inverse dynamics were computed using a standard Newton–Euler approach. Moments were expressed as internal moments and were normalized to body mass and height (O'Connor and Bottum, 2009). A vertical ground reaction force threshold of 20 N was used to determine the onset and end of stance. The five waveforms of interest were: frontal plane trunk, pelvis, and hip angles and knee moment, as well as transverse plane knee angle.

2.4. Principal components analysis

Stance phase of the overground running trials was time normalized to 101 points. The angle and moment data for each participant were an ensemble average of the five trials. For each of the five angle and moment waveforms of interest, a data matrix was created. The 101 data points comprised the columns and 40 participants comprised the rows of each matrix ($X_{40\times101}$). The PCA approach used in the current investigation was based on a methodology described previously (Wrigley et al., 2006). The mean was computed for each column of the respective matrix. Then, the mean of each column was subtracted from each row in its respective column. The mean centered matrices were transformed into principal components using an eigenvector decomposition method on the input's covariance matrix ($C_{101\times101}$). The PCA produced the eigenvectors ($V_{101\times101}$) and eigenvalues ($L_{1\times101}$). The eigenvector matrix consisted of the coefficients for each of the 101 principal components which defined a new coordinate space for the original waveform data (Wrigley et al., 2006). The eigenvalue matrix indicated the relative contribution each principal component had on the total variance in the data. For each matrix, the first three principal components were analyzed. Principal component score matrices ($Z_{40\times101}$) were then computed by multiplying the mean-centered input matrix by transposing the eigenvector matrix:

$$Z_{40\times101} = (X_{40\times101} - (1_{40\times1} \times \bar{x}_{1\times101})) \times V'_{101\times101} \quad (1)$$

where $\bar{x}_{1\times101}$ is each time normalized data point. The principal component scores represented how closely a runner's waveform matched the shape of its respective principal component (Wrigley et al., 2006).

To determine if the retained principal components represented the original data adequately, a residual analysis was performed using the *Q*-statistic (Jackson, 1991). The *Q*-statistic is the sum of the squares of the residuals between participants' original waveform and the reconstructed curve based on the retained principal component (Wrigley et al., 2006). A *Q*-critical value (Q_α) was calculated using an alpha level of 0.05 from a *t*-distribution (degrees of freedom = 39, $Q_\alpha = 2.0211$) (Wrigley et al., 2006). *Q*-critical indicated whether the number of retained components reconstructed the original data adequately. For each participant, a *Q*-statistic value lower than Q_α indicated that the original data were represented adequately by the retained principal components (Jackson, 1991).

To aid in the interpretation of the principal components, the influence of a principal component on the combined groups' ensemble mean waveform was