Taylor & Francis
health**sciences**

Kinematics of cycling in relation to anterior knee pain and patellar tendinitis

MARTIN P. BAILEY,[1]* FREDERICK J. MAILLARDET[2] and NEIL MESSENGER[3]

[1]*Chelsea School, [2]Faculty of Science and Engineering, University of Brighton, Eastbourne* and [3]*Centre for Studies in Physical Education and Sports Science, University of Leeds, Leeds, UK*

The coronal and sagittal plane leg movements of 24 experienced male cyclists were assessed using video analysis while cycling on a Kingcycle windload simulator. The cyclists were grouped into those with a history of injury and an asymptomatic group on the basis of self-reported injury status. The ages, cycling experience, competition distances and competition speeds of the two groups were compared using Student's t-test. No significant differences ($P < 0.05$) were found for any of these variables. The maximum and minimum shank adduction, shank adduction velocities, knee flexion and ankle dorsiflexion values were also compared using Student's t-test. Significant differences were found at the point of maximum adduction ($1.9°$; $P = 0.019$) and minimum dorsiflexion ($4.9°$; $P = 0.014$). These differences indicated more dorsiflexion and greater abduction on the part of the symptomatic cyclists, supporting previous research that found that cyclists with a history of injury differ from those without a history of injury in the coronal plane leg movement patterns they adopt. Also, the most extreme medial position of the knee relative to the ankle occurred during knee extension. This supports the potential injury mechanism proposed by Francis (1986), which had previously only been examined using coronal plane kinematics.

Keywords: cycling, injury, overuse, pedalling, video.

Introduction

Overuse knee injuries, such as anterior knee pain, patellar tendinitis, iliotibial band syndrome and collateral ligament sprains, have been reported to occur in approximately 25% of cyclists (Hannaford *et al.*, 1986; Gregor and Wheeler, 1994). Anterior knee pain and patellar tendinitis have been suggested to be the most common injuries, accounting for approximately 60% in total (Holmes *et al.*, 1991; Gregor and Wheeler, 1994). Several articles have been published on overuse knee injuries in cycling and various causes, which could relate to anterior knee pain or patellar tendinitis, have been suggested. For example, several authors have suggested that adopting a low saddle position is likely to increase knee flexion and could predispose cyclists to injury (Dickson, 1985; Mellion, 1991; Gregor and Wheeler, 1994). Generic literature on overuse knee injuries has indicated that anatomical abnormalities, such as patella alta, abnormal vastus lateralis tightness

and excessive Q angles, may be important aetiological factors (Cox, 1985; Percy and Strother, 1985; Garrick, 1989). The Q angle is the angle measured at the centre of the patella between lines linking the centre of the patella to the anterior superior iliac spine and the tibial tuberosity (Garrick, 1989). This surface angle gives an estimation of the lines of pull of the quadriceps tendon and patella tendon on the patella. Anatomical factors, such as an abnormally large Q angle, could potentially predispose cyclists to anterior knee pain and patellar tendinitis by disrupting the knee extensor mechanism. This possibility has been supported to some extent in a cycling-specific investigation by Ruby *et al.* (1992b), who found that anatomical variation among asymptomatic individuals corresponded with variations in knee joint kinetics.

Despite the body of literature relating to overuse knee injuries, relatively few studies have addressed cycling injuries directly. Studies comparing the kinematics of cyclists with a history of injury and asymptomatic cyclists are particularly scarce. Hannaford *et al.* (1986) examined the coronal plane movements of eight cyclists, five with knee pain and three with 'significant' knee movement in the coronal plane. Of the five cyclists

* Address all correspondence to Martin Bailey, Chelsea School, University of Brighton, Gaudick Road, Eastbourne, East Sussex BN20 7SP, UK. e-mail: m.p.bailey@bton.ac.uk

with knee pain, three experienced relief of their symptoms after their coronal plane knee motion had been 'normalized'. The process described by Hannaford *et al.* (1986) involved using a special pedal to re-orient the foot, until the movement pattern demonstrated by the tibial tuberosity of the cyclist resembled a linear path when viewed in the coronal plane. These results appeared to support the theoretical analysis of Francis (1986), who suggested abnormalities of foot or subtalar joint anatomy could lead to abnormal knee movements, thereby predisposing cyclists to injury. The pattern that has been hypothesized to be injurious was summarized by the adoption of a knee position close to the midline of the body when the knee was under an extensor load. This position could theoretically increase the effective Q angle and disrupt the knee extensor mechanism. Disruption to the knee extensor mechanism in runners has been suggested to lead to excessive pressure on the lateral facet of the patella, excessive strain of the medial retinaculum and excessive shear stress in the patella tendon (Cox, 1985). It is possible that similar disruption occurs in some cyclists.

Bailey and Messenger (1995) also compared the coronal plane movements of cyclists with and without a history of injury, using methods similar to those employed to assess subtalar joint motion in running (e.g. Nigg *et al.*, 1978). Their results did not support the theory put forward by Francis (1986) that excessive pronation was a cause of the abnormal movement patterns exhibited by some injured cyclists. However, their results did support the contention that injured cyclists adopt a more medial knee position than cyclists without a history of injury.

Others, notably Ruby and co-workers (Ruby *et al.*, 1992a,b; Ruby and Hull, 1993), have made inferences about injury from measurements of forces applied to the pedal and calculation of internal forces at the knee. As mentioned previously, Ruby *et al.* (1992b) have related variations in anatomy to changes in calculated forces at the knee, in particular the posterior force, extensor moment, varus/valgus moment and axial moment. Ruby and Hull (1993) used similar methods to assess the effects of allowing some freedom of movement in the shoe–pedal interface, and found that allowing some abduction/adduction or inversion/eversion movement at the pedal could reduce some of the calculated knee loads. Unfortunately, the inferences drawn from these studies have not been followed up with direct comparisons of injured and asymptomatic individuals.

Hannaford *et al.* (1986) and Bailey and Messenger (1995) focused purely on the coronal plane, which limited the inferences that could be drawn about the injury mechanism hypothesized by Francis (1986). Further clarification of Francis' (1986) hypothesis would require an understanding of the timing of the medial knee position noted by Bailey and Messenger (1995) in relation to the knee extension/flexion cycle; in particular, whether the medial knee position was adopted in the power phase of cycling, which is usually considered to be from top dead centre of the crank to bottom dead centre. More specifically, peak knee extensor moments have been calculated to occur in the region of 45° after top dead centre (Ruby *et al.*, 1992b; Ruby and Hull, 1993) and 80° after top dead centre (Ericson *et al.*, 1986).

The main aim of the present study was to examine the timing of the medial knee position relative to the ankle, which has been suggested to be a possible cause of overuse knee injuries, such as anterior knee pain and patellar tendinitis (Francis, 1986; Hannaford *et al.*, 1986; Bailey and Messenger, 1995). Previous studies only performed coronal plane analysis, whereas the injury mechanism outlined by Francis (1986) relies on the medial knee position occurring in the power phase of cycling. To determine whether this occurs required examination of kinematics in both the coronal and sagittal plane, which had not been reported in the literature.

Methods

Participants

Twenty-four active male cyclists with at least one year's experience of regular cycling were recruited to the study. Their age, height, body mass, experience and weekly cycling time were 28.0 ± 8.4 years, 1.81 ± 0.09 m, 71.7 ± 5.4 kg, 7.6 ± 5.0 years and 6.7 ± 2.0 h, respectively (mean $\pm s$). All participants completed a written informed consent form and a brief questionnaire relating to their training, competition and injury status. The ethics committee of the Chelsea School, University of Brighton, approved the procedures used in this study.

Video data collection

Markers for digitization were placed on the right side of the participant's body using sites that were visible in the sagittal plane and approximated the centres of rotation of the hip, knee and ankle. These sites were located using the anatomical landmarks suggested by Plagenhoef (1971). Additional sagittal markers were placed over the centres of rotation of the right pedal and crank of the participant's cycle. The coronal plane markers were positioned on the midline of the anterior aspect of the ankle and the tibial tuberosity of the right leg, in accordance with the methods of previous authors (Ericson *et al.*, 1984; Hannaford *et al.*, 1986; Sanderson

et al., 1994). These positions contrasted with the method used by Bailey and Messenger (1995); however, the critical aspect of the coronal plane movement pattern highlighted by their study was the position of the knee with respect to the ankle. The authors considered that markers placed on the anterior aspect of the ankle and the tibial tuberosity would entail a lower risk of systematic error from incorrect marker placement. Similarly, their greater separation, in comparison to Achilles tendon and heel markers, reduced the risk of large operator error in angle measurement. The marker positions are depicted in Fig. 1.

Each participant's own cycle was mounted on a Kingcycle windload simulator (Biotrace, High Wycombe, UK) and the participant was asked to pedal at a cadence of 90 per minute, without any modifications to their normal riding position. The participant selected a gear ratio which elicited a power output of 200 ± 10 W. Data were collected for digitization using two Panasonic (Matsushita, Osaka, Japan) MS2 sVHS cameras, recording at 50 fields per second. One

camera was aligned with the participant's transverse axis to view the sagittal plane. The second camera was aligned with the participant's antero-posterior axis to view the coronal plane. Preliminary experiments had indicated that this approach of using two separate two-dimensional views gave superior accuracy to a two-camera three-dimensional analysis method.

The signals from the two cameras were passed via a Panasonic WJ-MX 30 video mixer to a Panasonic 7350 sVHS video recorder. The mixer was set into the wipe mode, allowing images from both cameras to be placed side by side and synchronized. The resulting video signal complete with time code was recorded onto a sVHS video cassette tape. Before each filming session, two 0.5 m long rods were placed in the position normally occupied by the cycle to allow vertical and horizontal scaling of the video data.

Digitization of the videotape was performed using Kine software (Bartlett and Bowen, 1993) on an Acorn
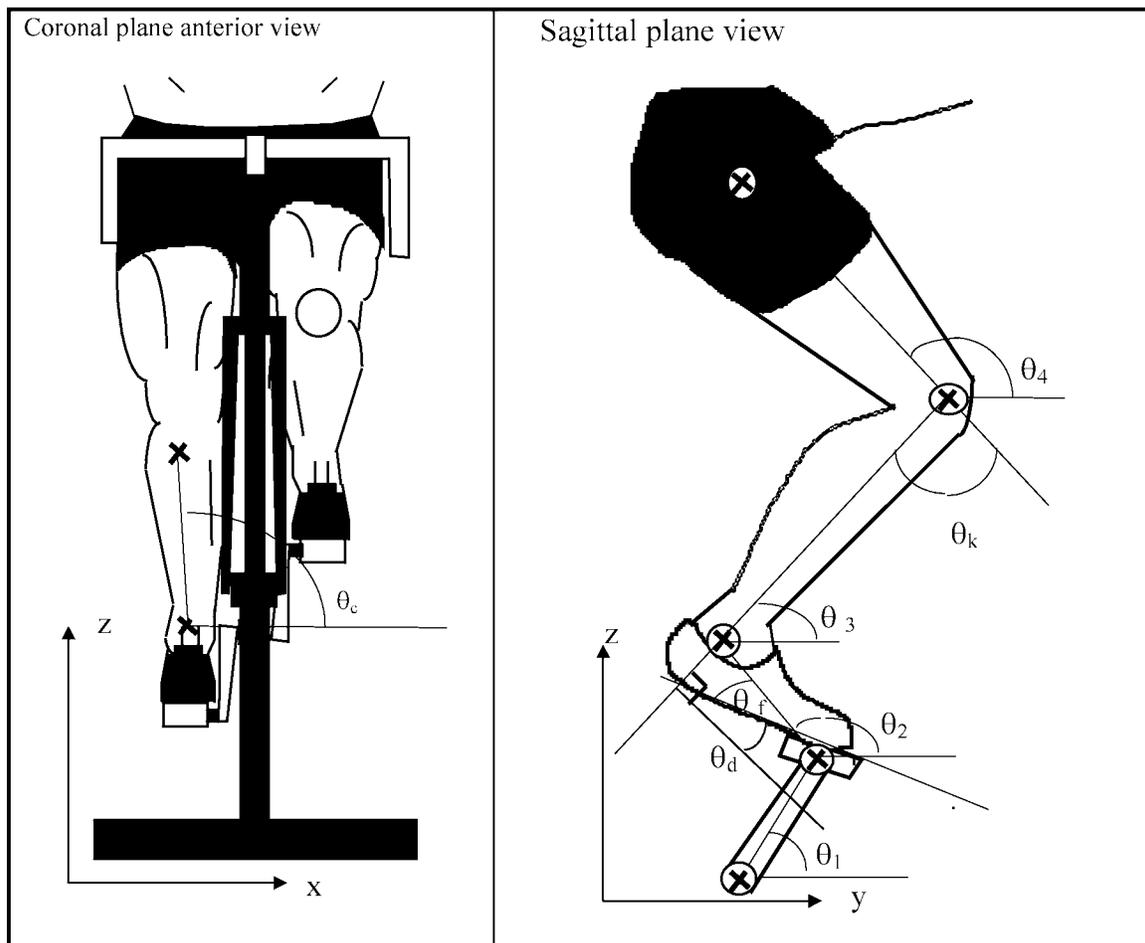
Fig. 1. Schematic illustration of the markers and angle definitions for the video analysis.

Archimedes (Acorn Computers, Cambridge, UK) 440/ 1 microcomputer running a RISCOS 3 operating system (Acorn Computers, Cambridge, UK). The video data from both systems were imported from the sVHS tape to the computer via a Panasonic AG 7550 sVHS video recorder, a Panasonic WJ-MX 30 video mixer and an Arvis AR VC2 digitizer board (A.T. Baldwin, Manchester, UK). Three pedalling cycles were digitized with each movement sequence being initiated from the point at which the pedal passed the cycle seat tube. Only the second of the three pedalling cycles was used for analysis; the first and the third cycle were used as padding to minimize any end-point errors from smoothing. After digitization, the data were smoothed using the Kine system's generalized cross-validated quintic spline routine.

The coronal plane shank angle relative to the right horizontal (θ_c) was calculated from the horizontal positions of the ankle (x_a) and tibial tuberosity (x_t), along with the known separation of the markers (l_{sc}), to prevent parallax errors arising when the lower leg was not parallel with the coronal plane. A correction was also applied to allow for perspective errors as the markers moved closer to or further away from the camera. Figure 1 depicts the angle definitions.

To allow the angle of the shank to approximate an anatomical definition (as adduction angle), the adduction angle (θ_a) was defined as:

$$\theta_a = \theta_c - \pi/2$$

With this definition, when the shank was positioned vertically in the coronal plane (θ_a was zero), a positive angle indicated adduction (a lateral position of the knee relative to the ankle) and a negative angle indicated abduction (a medial position of the knee relative to the ankle).

The crank (θ_1), foot (θ_2), shank (θ_3) and thigh angle (θ_4) time series were exported from the Kine software for the sagittal plane analysis. These time series were used to derive the knee and ankle angles that were chosen to define the pedalling techniques of different riders. The knee angle (θ_k) was calculated as shown below:

$$\theta_k = \theta_4 - \theta_3$$

A knee angle of zero was considered to be fully extended, positive knee angles indicated flexion at the knee and negative knee angles indicated hyper-extension. The ankle angle (θ_d) was calculated as shown below to allow the angle to be expressed with respect to dorsiflexion of the ankle. In the equation below, θ_f represents a correction angle to account for the angle between the foot angle, as defined by the positions of the ankle and pedal markers, and the sole of the shoe:

$$\theta_d = \theta_2 + \theta_f - \pi/2 - \theta_3$$

This definition gave a zero angle when the foot was perpendicular to the lower leg, while a positive angle indicated relative dorsiflexion and a negative angle indicated relative plantar flexion at the ankle.

Data analysis

The cyclists were divided into two groups – those with a history of injury and those without a history of injury – on the basis of self-reported injuries that had occurred within the last 2 years. This was considered to be the maximum acceptable time for accurate recall of the injury. Injury was defined as pain that had caused the cyclist to reduce or cease training for at least 1 week or seek medical advice. If the injury was associated with a crash or other traumatic event, the cyclist was excluded from the study. Similar definitions and recall time periods have been used previously in retrospective studies of injury without any reported problems (Jacobs and Berson, 1986; Bailey *et al.*, 1996). The demographic variables of the two groups were compared using two-tailed, two-sample *t*-tests, to establish whether they could be considered comparable in these terms.

The maximum and minimum values of θ_a, θ_k and θ_d from the two groups were then compared using two-sample *t*-tests. The final statistical comparison made was of the first derivative of θ_a with respect to time. This variable was obtained from the smoothed data using a second central difference formula. This comparison was also made using a two-sample *t*-test. Published literature on cycling has indicated that less shank adduction, greater dorsiflexion (Francis, 1986) and greater knee flexion (Dickson, 1985; Mellion, 1991) could predispose cyclists to anterior knee pain or patellar tendinitis. Running literature (e.g. Messier and Pittala, 1988) has indicated that the angular velocity of coronal plane variables may be higher in symptomatic individuals. Consequently, one-tailed tests were used for these variables. Two-sample *t*-tests were deemed to be appropriate, as the skewness, kurtosis and heteroscedasticity of the data sets were within acceptable tolerances according to the methods and definition of Vincent (1995). Statistical significance was set at $P < 0.05$. Root mean square differences of θ_a, θ_k and θ_d were calculated for the two groups, as a qualitative indication of the variation between groups across the pedal cycle. Graphical representations of θ_a, θ_k, θ_d and the first derivative of θ_a were produced. To aid interpretation, means (represented by dotted lines) and error ranges (represented by solid lines) are shown in the figures. The darker lines indicate the results for the symptomatic group. The error range was calculated as ± one standard error of the mean calculated for that point.

Results

Of the 24 cyclists, 14 had no history of injury and 10 reported a history of injury to the right leg or both legs. Seven cyclists were considered to have suffered from anterior knee pain, two were considered to have suffered from patella tendinitis and one had experienced both conditions. None of the cyclists reported their injuries to be associated with trauma or disclosed a history of injury without symptoms in the last 2 years. Consequently, all participants were retained in the analysis. The means and standard deviations of variables that related to these cyclists' competitions, ages and cycling experience are shown in Table 1. No significant differences ($P < 0.05$) were found between these demographic variables for the two groups when two-tailed two-sample Student's t-tests were applied. The actual P-values for the comparisons are shown in Table 1.

Figures 2–5 compare the results for the previously injured cyclists with those for the cyclists without a history of injury in terms of the mean angles and the adduction angular velocities observed throughout one pedal cycle. Throughout the figures, the movement patterns for the cyclists with a history of injury are represented by the darker set of lines. Figure 2 shows the adduction angles for the two groups. The mean for the cyclists without a history of injury appeared to vary around a neutral position, whereas the previously injured cyclists retained an abducted shank position throughout the pedalling cycle. When analysed quantitatively, the root mean square difference of the means was found to be 2.5°, which in combination with Fig. 2 illustrates that, on average, the previously injured cyclists' position was 2.5° more abducted. This greater abduction indicated a more

medial knee position relative to the ankle. One-tailed, two-sample t-tests revealed the maximum value of the adduction angle to be significantly lower in the previously injured group ($-1.9°$) than in the group without a history of injury ($1.2°$) ($P = 0.019$, effect size = 0.90). The difference between the minimum values was not statistically significant, with values of $-4.3°$ and $-2.5°$ for the previously injured group and the group without a history of injury, respectively ($P = 0.063$, effect size = 0.64).

Figure 3 illustrates that the angular velocities of the shank in the coronal plane were broadly similar for the two groups throughout the pedal cycle. The maximum values were $0.20 \text{ rad} \cdot \text{s}^{-1}$ and $0.27 \text{ rad} \cdot \text{s}^{-1}$, respectively, for the previously injured cyclists and those without a history of injury, suggesting the peak rate of
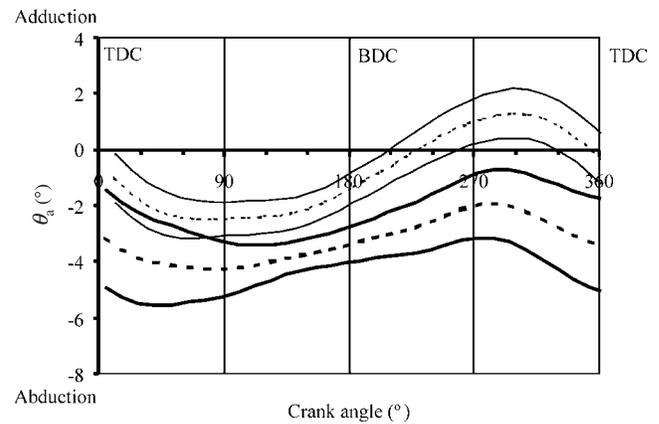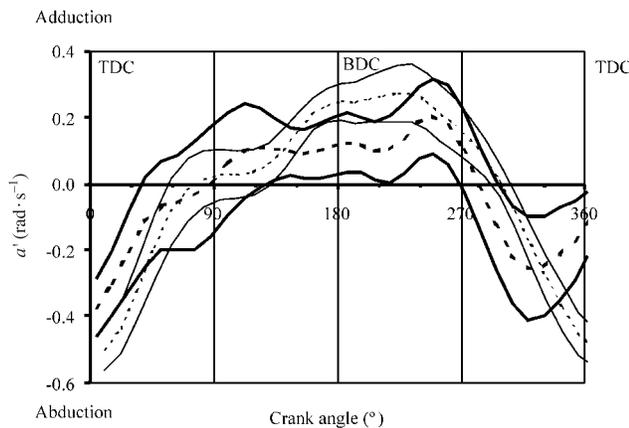

Fig. 2. Comparison of adduction angles for previously injured cyclists and those without a history of injury (asymptomatic) (mean ± standard error). Fine dotted line = asymptomatic mean; darker dotted line = previously injured mean. TDC = top dead centre; BDC = bottom dead centre.

Table 1. Competition status, age and experience for the previously injured cyclists and those without a history of injury, showing means, standard deviations (*s*), *t*-test probabilities (*P*) and effect sizes (ES)

| Group | Height (m) | Mass (kg) | Longest competition | | Average competition | | Age (years) | Experience (years) |
			Distance (km)	Speed ($\text{km} \cdot \text{h}^{-1}$)	Distance (km)	Speed ($\text{km} \cdot \text{h}^{-1}$)		
Injured								
Mean	1.76	72.3	93.9	36.6	53.6	38.7	28.7	8.0
s	0.09	5.2	31.4	3.3	21.3	3.7	4.8	5.4
Asymptomatic								
Mean	1.84	70.4	128.7	36.7	63.6	38.5	27.7	7.4
s	0.08	2.9	70.1	2.8	33.2	3.6	10.1	4.9
P	0.5	0.5	0.18	0.95	0.43	0.9	0.79	0.78
ES	0.89	0.48	0.69	0.03	0.4	0.06	0.13	0.12

lateral knee movement relative to the ankle was higher in the cyclists without a history of injury. However, the difference was not found to be significant ($P = 0.31$, effect size $= 0.21$). The comparison of the means of the minimum values showed the mean value for the previously injured cyclists to be -0.38 rad $\cdot$ s^{-1} and for the cyclists without a history of injury -0.49 rad $\cdot$ s^{-1}. These values suggested the peak rate of medial movement of the knee was higher in the cyclists without a history of injury; however, the difference in the means was not significant ($P = 0.12$, effect size $= 0.48$).

Fig. 3. Comparison of angular velocity of the shank in the coronal plane for previously injured cyclists and those without a history of injury (asymptomatic) (mean $\pm$ standard error). Fine dotted line = asymptomatic mean; darker dotted line = previously injured mean. TDC = top dead centre; BDC = bottom dead centre.
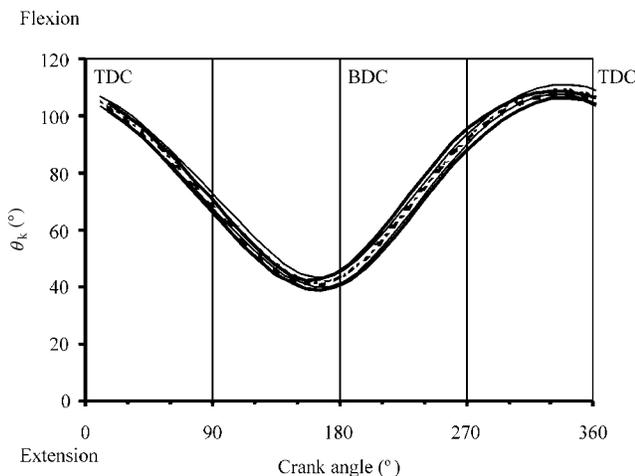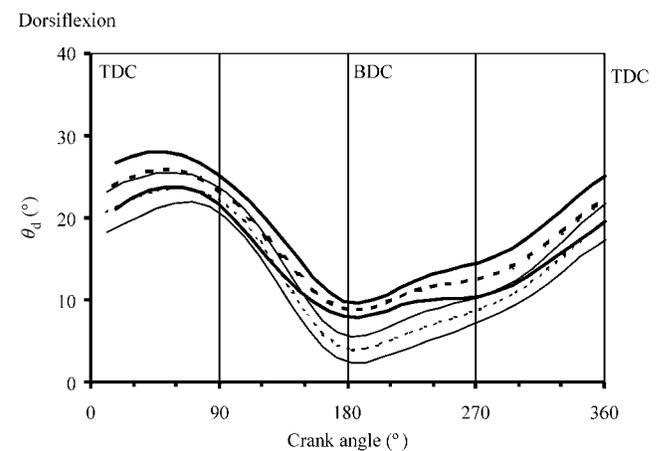

Fig. 4. Comparison of knee flexion angles for previously injured cyclists and those without a history of injury (asymptomatic) over one pedal cycle (mean $\pm$ standard error). Fine dotted line = asymptomatic mean; darker dotted line = previously injured mean. TDC = top dead centre; BDC = bottom dead centre.

Figure 4 demonstrates that the mean knee flexion angles for the two groups of cyclists were similar. The root mean square difference between the two means was $2.0°$; unlike the adduction angle, the differences between the two data series were not in a constant direction throughout the pedal cycle. The maximum values were $107.4°$ for the previously injured group and $109°$ for the group without a history of injury, a difference that was not statistically significant ($P = 0.215$, effect size $= 0.35$). The minimum values were $40.7°$ for the previously injured group and $41.5°$ for the group without a history of injury, a difference that was also not statistically significant ($P = 0.373$, effect size $= 0.13$).

Figure 5 shows the mean ankle dorsiflexion angles for the two groups of cyclists exhibited similar patterns. However, throughout the pedal cycle the previously injured cyclists demonstrated between $2°$ and $5°$ more ankle dorsiflexion than the cyclists without a history of injury, with a root mean square difference of $3.5°$. The difference in maximum values was not statistically significant ($P = 0.233$, effect size $= 0.35$), with the previously injured group maximum being $25.9°$ and the maximum for the group without a history of injury being $23.6°$. The difference in the minimum values was significant, with the previously injured group mean being $8.8°$ and the mean for the group without a history of injury being $3.9°$ ($P = 0.014$, effect size $= 1.09$).

Discussion

In any study of injury, assessment of the causality of any statistically significant findings is difficult because of the

Fig. 5. Comparison of dorsiflexion angles for previously injured cyclists and those without a history of injury (asymptomatic) over one pedal cycle (mean $\pm$ standard error). Fine dotted line = asymptomatic mean; darker dotted line = previously injured mean. TDC = top dead centre; BDC = bottom dead centre.

large number of variables that could have an effect. Differences between groups could theoretically be due to the causes of injury or an adaptation in technique resulting from injury. However, the results of the present study did provide support for the theoretical mechanism of injury first proposed by Francis (1986), by providing a link between previous kinematic (e.g. Bailey and Messenger, 1995) and kinetic studies (e.g. Ruby *et al.*, 1992b).

Coronal plane results

The phasing and amplitude of the mean adduction angle data for the two groups of cyclists were similar. However, the previously injured group showed between 1.5° and 3.8° less adduction throughout the pedal cycle, indicating a more medial knee position relative to the ankle. At the point of maximum adduction, the previously injured cyclists demonstrated a significantly less adducted position and in fact remained in an abducted position. The hypothesized cause of anterior knee pain and patellar tendinitis described in the Introduction, which was based on the work of Francis (1986), was that the risk of anterior knee pain and patellar tendinitis would be increased if the shank was in an abducted position when a knee extensor moment was generated. An abducted shank position places the knee in a medial position with respect to the ankle, which has the potential to disrupt the knee extensor mechanism.

The greatest abduction occurred at 83° and 88° after top dead centre for the previously injured group and the group without a history of injury, respectively. It can be seen from Fig. 4 that the participants were approximately half-way between their most flexed and most extended knee angles at that point in the pedal cycle. Figure 4 also shows the cyclists were demonstrating knee extension. Further support for the knee extensor musculature being active in the region of 80–90° after top dead centre has been provided by Ruby *et al.* (1992b) and Ericson *et al.* (1986). Ruby *et al.* (1992b) observed the maximum mean knee extensor moment of their participants to be approximately 38 N·m, at 45° after top dead centre. However, in the region of 80–90° after top dead centre, the knee extensor moment was still relatively high at approximately 22 N·m. Ericson *et al.* (1986) found the maximum of the mean extensor moments to be approximately 30 N·m. The maximum values occurred in the region of 80–90° after top dead centre. These authors' results indicated that at the point of greatest shank abduction observed in the present study, the cyclists' knees were not only extending as demonstrated by the present study, but also their extensor musculature was likely to be active. The results of the present study, therefore, provide a link between previous studies where only coronal plane movement was investigated (e.g. Bailey and Messenger, 1995) and those which gave an indication of the point in the pedal cycle where the knee extensor musculature was active (e.g. Ruby *et al.*, 1992b). This link serves to support the theoretical injury mechanism proposed by Francis (1986).

The difference in the most abducted shank angle adopted by the two groups in the present study was 1.8°. This was not found to be significant, as large inter-individual variations in shank angle occurred in the area of the pedal cycle where the minimum shank angles were observed. The large inter-individual variation was evidenced by larger standard errors noted in this region of the pedal cycle (see Fig. 4). However, the effect size for the *t*-test of 0.64 indicates a moderate difference between the two groups (Cohen, 1988). This effect size, in conjunction with the relatively consistent difference between the two groups across the pedal cycle and the significantly different values at maximum adduction provide some evidence to support a relationship between shank abduction under load and anterior knee pain/patellar tendinitis. Ideally, further study of the mechanical factors that could be related to the aetiology of anterior knee pain and patellar tendinitis in cycling would involve combined kinematic and kinetic assessment. This would enable the combination of coronal plane movement and knee extensor moments, which have been hypothesized to be related to injury (Francis, 1986), to be more firmly established or refuted.

The findings of the present study provide a link between previous studies of coronal plane cycling kinematics and sagittal plane cycling kinetics (e.g. Bailey and Messenger, 1995; Ruby *et al.*, 1992b), and also corroborate the analysis of coronal plane movements in cycling conducted by Bailey and Messenger (1995). Similar magnitudes and directions of the differences between the previously injured cyclists and those without a history of injury were demonstrated by both studies. There was some difference in the mean positions of the results between the two experiments, with the present experiment showing less adduction for both groups. This difference in mean position could be due to a systematic difference arising from the different marker positions used for the experiments. Bailey and Messenger (1995) investigated subtalar joint motion as evidenced in the coronal plane, using markers on the rear of the shoe and the Achilles tendon. The method used was similar to that used for many running studies (e.g. Nigg *et al.*, 1978). The method in the present study followed that of several previous investigations of cycling (Ericson *et al.*, 1984; Hannaford *et al.*, 1986; Sanderson *et al.*, 1994), with coronal plane markers placed on the midline of the ankle and in the tibial tuberosity.

Differences in coronal plane shank velocities between the previously injured group and the group without a history of injury were generally small, as might have been expected given the relatively consistent differences between the angle measurements. The greatest velocities might have been expected to occur for the previously injured group, on the basis of studies of coronal plane movements in running (e.g. Messier and Pittala, 1988). However, this was not the case; the greatest velocities were produced by the cyclists without a history of injury.

Knee flexion results

The knee angles were very similar between the two groups of cyclists. No differences were observed in the magnitudes or phasing that could not easily be attributed to measurement or sampling error. This was evidenced by the statistically insignificant differences between the maximum and minimum values of knee flexion. The effect sizes were small (0.13) and small to moderate (0.35), respectively, for the comparison of minimum and maximum knee flexion (Cohen, 1988). These results provided little support for the concept that increased knee flexion increases injury risk (Dickson, 1985; Mellion, 1991; Gregor and Wheeler, 1994). Technique errors such as using a low saddle height, which could lead to greater knee flexion, would perhaps be more likely to occur in less experienced cyclists than those observed in the present study.

Ankle dorsiflexion results

The angles of dorsiflexion were generally quite similar between the two groups of cyclists. Neither group adopted a position of relative plantar flexion at any point in the pedal cycle. Although a 'toe-down' foot position was adopted at times by some cyclists, the amount of knee flexion that is retained throughout the pedalling cycle prevented relative plantar flexion of the ankle. The dorsiflexion was greatest for both groups in the region of the pedal cycle where a considerable knee extensor moment was likely to be present (Ericson *et al.*, 1986; Ruby *et al.*, 1992b). Maximums were found at 52° and 59° after top dead centre, respectively, for the previously injured group and the group without a history of injury. The previously injured group demonstrated 2.3° more dorsiflexion at maximum. However, this difference was not found to be statistically significant and the effect size was only low to moderate (0.35), so this factor does not appear to be a strong indicator of injury risk. In contrast, the minimum dorsiflexion angle of the previously injured cyclists was signifi-

cantly greater than that of the group without a history of injury, with a difference of 3.8° and a large effect size (1.09). Statistically, this indicates a strong predictor of injury risk, although there is no rationale currently for dorsiflexion at crank bottom dead centre to relate to anterior knee pain or patellar tendinitis. The mechanisms linked to anterior knee pain and patellar tendinitis were related to phases of the pedal cycle where the knee extensor musculature was active. However, at crank bottom dead centre, there is no evidence of an extensor moment; in fact, significant knee flexor moments have been noted in this region of the pedal cycle (Ruby *et al.*, 1992b; Ruby and Hull, 1993).

Conclusions

The differences in coronal plane shank angle between the previously injured group and the group without a history of injury were in line with the results of previous studies (Hannaford *et al.*, 1986; Bailey and Messenger, 1995). This support arose from the consistently greater abduction shown by the cyclists with a history of injury, which was found to be significant at the point of maximum adduction. The support for previous research and the injury mechanism proposed by Francis (1986) would have been greater if the difference between the groups had been significant at the point of greatest abduction.

The observed trend for a more medial knee position to be adopted by previously injured cyclists could not be conclusively attributed to a cause or effect of injury on the basis of these results, because of the retrospective nature of the study. However, there was a logical rationale for a medial knee position with respect to the ankle disrupting the knee extensor mechanism by effectively increasing the Q angle. There was no clear rationale for the medial knee position being a response to injury, which reduces the stress to the knee extensor mechanism.

The observation of greater dorsiflexion by the previously injured cyclists had no strong rationale to relate it to anterior knee pain or patellar tendinitis. The point at which a significant difference occurred was at a phase in the pedal cycle where a knee flexor moment has been found (Ruby *et al.*, 1992b; Ruby and Hull, 1993). This finding may warrant further investigation.

Several authors (Dickson, 1985; Mellion, 1991; Gregor and Wheeler, 1994) have suggested that overuse knee injuries such as anterior knee pain and patellar tendinitis could be related to excessive knee flexion resulting from a low saddle height. No support for this concept was obtained in the present study.

References

Bailey, M. and Messenger, N. (1995). Coronal plane kinematics of cycling and their relationship to injury. *Journal of Sports Sciences*, **14**, 3–4.

Bailey, M., Dew, M. and Moore, A. (1996). A comparative analysis of the incidence of overuse knee injuries in triathletes, runners and cyclists. *British Journal of Therapy and Rehabilitation*, **3**, 537–542.

Bartlett, R.M. and Bowen, T.M. (1993). *Kine System User Guide*. Alsager: Manchester Metropolitan University.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioural Sciences*. Hillsdale, NJ: Lawrence Erlbaum.

Cox, J.S. (1985). Patellofemoral problems in runners. *Clinics in Sports Medicine*, **4**, 699–716.

Dickson, T.B. (1985). Preventing overuse cycling injuries. *Physician and Sportsmedicine*, **17**, 197–202.

Ericson, M.O., Nisell, R. and Ekholm, J. (1984). Varus and valgus loads on the knee joint during ergometer cycling. *Scandinavian Journal of Sports Sciences*, **6**, 39–45.

Ericson, M.O., Bratt, A., Nisell, R., Arborelius, U.P. and Ekholm, J. (1986). Power output and work in different muscle groups during ergometer cycling. *European Journal of Applied Physiology*, **55**, 229–235.

Francis, P.R. (1986). Injury prevention for cyclists: a biomechanical approach. In *Science of Cycling* (edited by E.R. Burke), pp. 158–184. Champaign, IL: Human Kinetics.

Garrick, J.G. (1989). Anterior knee pain (chondromalacia patellae). *Physician and Sportsmedicine*, **17**, 75–84.

Gregor, R.J. and Wheeler, J.B. (1994). Biomechanical factors associated with shoe/pedal interfaces – implications for injury. *Sports Medicine*, **17**, 117–131.

Hannaford, D.R., Moran, G.T. and Hlavac, H.F. (1986). Video analysis and treatment of overuse knee injury in cycling: a limited clinical study. *Clinics in Podiatric Medicine and Surgery*, **3**, 671–678.

Holmes, J.C., Pruitt, A.L. and Whalen, N.J. (1991). Cycling knee injuries. *Cycling Science*, **3**(2), 11–14.

Jacobs, S.J. and Berson, B.L. (1986). Injuries to runners: a study of entrants to a 10,000 metre race. *American Journal of Sports Medicine*, **14**, 151–155.

Mellion, M.B. (1991). Common cycling injuries, management and prevention. *Sports Medicine*, **11**, 52–70.

Messier, S.P. and Pittala, K.A. (1988). Etiologic factors associated with selected running injuries. *Medicine and Science in Sports and Exercise*, **20**, 501–505.

Nigg, B.M., Eberle, G., Frey, D., Luethi, S., Segesser, B. and Weber, B. (1978). Gait analysis and sports shoe construction. In *Biomechanics VI-A* (edited by E. Asmussen and K. Jorgensen), pp. 303–309. Baltimore, MD: University Park Press.

Percy, E.C. and Strother, R.T. (1985). Patellalgia. *Physician and Sportsmedicine*, **13**, 43–59.

Plagenhoef, S.J. (1971). *Patterns of Human Motion*. Englewood Cliffs, NJ: Prentice-Hall.

Ruby, P. and Hull, M.L. (1993). Response of intersegmental knee loads to foot/pedal platform degrees of freedom in cycling. *Journal of Biomechanics*, **26**, 1327–1340.

Ruby, P., Hull, M.L. and Hawkins, D. (1992a). Three-dimensional knee joint loading during seated cycling. *Journal of Biomechanics*, **25**, 41–53.

Ruby, P.R., Hull, M.L., Kirby, K.A. and Jenkins, D.W. (1992b). The effect of lower limb anatomy on knee loads during seated cycling. *Journal of Biomechanics*, **25**, 1195–1207.

Sanderson, D.J., Black, A.H. and Montgomery, J. (1994). The effect of varus and valgus wedges on coronal plane knee motion during steady rate cycling. *Clinical Journal of Sport Medicine*, **4**, 120–124.

Vincent, W.V. (1995). *Statistics in Kinesiology*. Champaign, IL: Human Kinetics.