# A Kinematic Comparison of Alterations to Knee and Ankle Angles from Resting Measures to Active Pedaling during a Graded Exercise Protocol

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## Abstract

AU3 Peveler, WW, Shew, B, Johnson, S, and Palmer, TG. A kinematic comparison of alterations to knee and ankle angles from resting measures to active pedaling during a graded exercise protocol. *J Strength Cond Res* XX(X): 000–000, 2012—Saddle height is one of the most researched areas of bike fit. The current accepted method for adjusting saddle height involves the use of a goniometer to adjust saddle height so that a knee angle between 25° and 35° is obtained. This measurement is taken while the cyclist maintains a static position with the pedal at the 6-o′-clock position. However, the act of pedaling is dynamic, and angles may alter during movement. The purpose of this study was to examine the alterations to knee and ankle angle occurring from static measures to active pedaling across intensities experienced by cyclists during a graded exercise protocol. Thirty-four recreational to highly trained cyclists were evaluated using 2D analysis of stationary position and 3 active levels (level 1, respiratory exchange ratio of 1.00, and max). Dependent measures were compared using repeated measures analysis of variance ($p = 0.05$). When examining the results, it is evident that significant alterations to pedal stroke occur from stationary measures to active pedaling and as intensity increases toward maximal. Plantar flexion increased when moving from stationary measures to active pedaling, which resulted in an increase in knee angle. Although still greater than stationary measures, less plantar flexion occurred at higher intensities when compared with lower intensity cycling. Less plantar flexion at higher intensities is most likely a result of application of a larger downward torque occurring because of greater power requirements at higher intensities. There appeared to be greater variability in angle when examining novice cyclists in relation to more experienced cyclists. Although stationary measures are where a bike fit session will begin, observation during the pedal cycle may be needed to fine-tune the riders' fit.

**Key Words** saddle height, seat height, knee angle, cycling, triathlon AU4

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## Introduction

In cycling, properly adjusting the bike to accommodate the rider's specific anthropometrics is a key component for both optimal performance and prevention of injury (3,5,9,11–13,16,17,20). The effect of saddle height on performance and injury prevention is one of the most researched areas related to bike fit (3,5,9,11–13,16,17,20). It has been reported that saddle height should be predicated according to knee angle. Holmes et al. recommend setting saddle height so that the cyclist obtains a knee angle between 25° and 35° to prevent overuse injuries (5). Knee angle is defined as degrees of knee flexion with the anatomical reference position considered zero degrees. For optimal performance, it has been previously accepted to set saddle height using 109% of inseam (3,11,20). However, a series of recent studies demonstrated that these 2 methods produce significantly different saddle heights and that use of a 25° knee angle is optimal for both performance and injury prevention (5,12,13,16,17). In a series of studies conducted by Peveler et al., the use of 109% of inseam resulted in subjects falling outside the recommended 25–35° knee angle approximately 50% of the time (45, 63, 73, and 74%) (12,13,16,17). The method of using 109% of inseam to determine saddle height does not take into account variations in upper and lower leg ratios or the length of the foot, resulting in a wide range of knee angles. The use of a fixed angle for determining the most favorable saddle height for increased performance is based on optimizing muscle length and moment arm, both of which adapt with alteration to knee angle (12,13,16–19).

Adjusting saddle height using the Holmes method requires the use of a goniometer to measure knee angle. During this process, the cyclist maintains a static posture with the crank arm in the 6-o′-clock position and pedal horizontal. However, the act of pedaling is very dynamic with movement occurring at the ankle, knee, and hip. Alterations to ankle angle throughout the pedal stroke have been reported in previous studies (10,11,18,19). Alterations occurring at the ankle could also lead to alterations in knee angle because the pelvis is somewhat stationary on the saddle (10,11,18,19). Although studies have examined alterations to knee and ankle angles at varying saddle heights, to our knowledge, no studies have examined alterations to knee and ankle angles that occur when moving from a stationary measure for bike fit using a 25° knee angle to dynamic pedaling (11,18,19). If significant alterations in angles occur from stationary to dynamic pedaling, then dynamic observations may need to be considered for optimal bike fit. The purpose of this study was to examine alterations to both knee and ankle angle from the stationary measure taken with a goniometer to those that occur during dynamic pedaling across all intensities commonly experienced by cyclists.

## Methods

### Experimental Approach to the Problem

A graded exercise protocol was chosen to slowly progress the subjects from low to maximal intensity to cover the full spectrum of pedaling intensities typically experienced by cyclists. The subjects participating in this study concluded the graded exercise protocol at varying levels. Because of a wide range of fitness levels, the final graded exercise protocol level completed by each individual subject ranged from level 3 to level 10. To conduct a meaningful analysis, measures relative to intensity were chosen to compare alterations to knee and ankle angles across intensities. Three different intensity levels were chosen for comparison. Graded exercise protocol level 1 was chosen to represents low intensity for all the subjects. The level where the subject reached a respiratory exchange ratio (RER) of 1.00 was chosen as a nonsubjective measure to represent a level similar to race pace. The level where the subject reached maximal exertion was chosen because it represents the subject's maximal pedaling ability at a fixed cadence and given resistance.

For the purpose of this study, the Holmes method was used to measure knee angle, which is defined as degree of knee flexion with the anatomical reference position considered zero degrees. Alterations to ankle angle were measured using movement of the foot in relation to horizontal to minimize measurement errors. An increase in angle in relation to the horizontal from stationary measures corresponds to an increase in plantar flexion, whereas a decrease in angle would indicate increased dorsiflexion. The use of the subject's personal shoes and clipless pedals maintained the foot in a relatively fixed position with no foot movement fore and aft on the pedal.

### Subjects

The subjects consisted of 34 recreational to highly trained cyclists (male = 28, female = 6), based on the $\dot{V}O_2max$ scores that ranged from 33.60–70.00 ml·kg$^{-1}$·min$^{-1}$. Full descriptive statistics for total subjects and all subgroups are given in Table 1. T1
Testing was conducted during race-ridding season. Approval for this study was obtained through the local institutional review board, and all the subjects completed an informed consent before participation. A physical activity readiness questionnaire and a health status questionnaire were used to screen for individuals who may be placed at increased risk during strenuous exercise. Those found at an increased risk were excluded from the study per American College of Sports Medicine's guidelines (1). AU5

The subjects reported to the laboratory with their personal cycling shoes and clipless pedals. The cyclist's pedals were placed on the cycle ergometer to allow for a more stable platform during the graded exercise protocol. The subjects cycled in their normal cycling attire. To promote optimal performance and ensure accurate measurements, the subjects were instructed to abstain from training at least 1 day before the performance trial.

### Procedures

The subjects completed a graded exercise protocol conducted on a Monark 894E cycle ergometer (Monark Exercise AB, Vansboro, Sweden). The 894E was equipped with an FSA SLK race saddle (Full Speed Ahead, Mukilteo, WA, USA) and the Monark variable seat post (Monark Exercise AB). The race saddle was used to better represent the saddles commonly equipped on cyclists' personal bikes. The Variable

**Table 1.** Physical characteristics of subjects ($n$ = 34).*

| | | $\dot{V}O_2max$ (ml·kg$^{-1}$·min$^{-1}$) | Weight (kg) | Height (cm) | BF (%) | Age (y) |
|---|---|---|---|---|---|---|
| Men | ($n$ = 28) | 56 ± 8 | 80 ± 10 | 179 ± 6 | 14 ± 5 | 31 ± 6 |
| Women | ($n$ = 6) | 45 ± 6 | 57 ± 7 | 167±10 | 21 ± 3 | 37 ± 6 |
| Top 10 | ($n$ = 10) | 64 ± 3 | 74 ± 5 | 181 ± 7 | 11 ± 4 | 32 ± 7 |
| Bottom 10 | ($n$ = 10) | 48 ± 6 | 85 ± 13 | 179 ± 5 | 17 ± 6 | 32 ± 7 |

*BF= body fat.

seat post was used to allow precise millimeter adjustment to saddle height. During the graded exercise protocol, level 1 began at 1 kilopond (kp) and increased by 0.5 kp every 2 minutes until volitional exhaustion. The subjects were required to maintain 90 rpm or higher throughout the graded exercise protocol (7). Achievement of $\dot{V}O_2$max was determined by a heart rate equal to or greater than age-predicted maximum, a respiratory exchange ratio ≥1.15, or a $\dot{V}O_2$ plateau with increasing workload was attained (8).

Before conducting the graded exercise protocol, the saddle height was set using the Holmes method (5). A manual goniometer (LeMond Fitness Inc., Woodinville, WA, USA) was used to set saddle height at a 25° knee angle. Each arm of the goniometer measured 34 cm from the center of the axis bolt to the end of the arm. The subjects pedaled until they obtained a comfortable riding position and then stopped at the bottom of the pedal stroke in the 6-o′-clock position. The pedal was then adjusted so that it was positioned horizontal. The clipless pedal systems used by the cyclists allow for very minimum foot movement during the measuring process. Boney landmarks (lateral femoral condyle, lateral malleolus, and greater trochanter) were located on the right leg using palpation, and reflective markers were placed on each landmark. Palpation and marking occurred with the pedal in the 6-o′-clock position to optimize measurements in that position. In relation to "normal" shorts, cycling shorts permit very little movement of material throughout the pedal stroke and allowed for ease of palpation and placement of markers. During measurement, the pedal was set at horizontal, which was considered the neutral position. The axis of the goniometer was centered on the lateral femoral condyle, with the stationary arm pointing downward toward the lateral malleolus of the ankle and the moveable arm pointing upward to the greater trochanter at the hip. All measurements were taken by the primary investigator and repeated until 3 consistent measures were obtained to assure accuracy.

A 2D video analysis system, MaxTRAQ Pro (Innovision Systems, Columbia, MI, USA), was used for kinematic measures occurring on the sagittal plane. Reflective markers and a Sentech STC-TB33USB-ASH camera (60 Hz) equipped with infrared lights (Innovision Systems were used during recording to allow for autotracking during later analysis. For each level, video recordings were taken 20 seconds before increasing resistance level during the graded exercise protocol. The subjects were instructed to remain seated throughout the graded exercise protocol.

Recorded video at stationary, level 1, RER of 1, and max were chosen to examine alterations in the knee and ankle angle. The stationary video was used to standardize for 2D video measurement and was designated as control for comparison of the other 3 conditions. Knee and ankle measurements were taken at the 6-o′-clock position during 3 different revolutions and then averaged. Knee angle measurements were taken using lines drawn from the reflective marker located on the lateral malleolus to the reflective marker on the lateral epicondyle to the reflective marker on the greater trochanter using the 2D software. Ankle angle was measured as alteration from horizontal using lines drawn with the 2D software.

### Statistical Analyses

Angles at the knee and ankle were compared between stationary, level 1, RER of 1, and max. Within-subjects comparisons were made for the total group ($n = 34$) and subgroups (male [$n = 28$], top 10 performing men and bottom 10 performing men). Statistics were not run for women ($n = 6$) because of low numbers. The top 10 men were defined as those with the top 10 highest $\dot{V}O_2$max scores and the bottom 10 men were defined as those with the lowest 10 $\dot{V}O_2$max scores. In all the groups, means were compared using analysis of variance and an alpha priori of 0.05. The interclass correlation coefficients were as follows: overall knee = 0.246, overall ankle = 0.381, male knee = 0.695, male ankle = 0.740, top 10 knee = 0.299, top 10 ankle = 0.815, bottom 10 knee = 0.742, and bottom 10 ankle = 0.691.

## Results

The complete results are given in Table 2. For the overall group ($n = 34$), stationary knee angle was significantly lower in relation to level 1 knee angle ($p < 0.001$), knee angle at RER of 1.00 ($p < 0.001$), and knee angle at the maximal level T2

**Table 2.** Dependent variables for alteration to knee angle.*

| | | Stationary | Level 1 | RER of 1.00 | Max |
|---|---|---|---|---|---|
| Overall | ($n = 34$) | 28.17 ± 3.16 | 35.41 ± 4.48† | 33.44 ± 4.26†‡ | 33.21 ± 5.39†‡ |
| Male | ($n = 28$) | 28.17 ± 3.32 | 35.90 ± 3.67† | 33.87 ± 3.37†‡ | 33.72 ± 5.27†‡ |
| Top 10 | ($n = 10$) | 27.25 ± 2.74 | 35.48 ± 2.03† | 33.03 ± 2.24†‡ | 30.76 ± 5.29‡ |
| Bottom 10 | ($n = 10$) | 29.53 ± 3.00 | 36.58 ± 4.34† | 34.73 ± 4.93† | 35.96 ± 6.12† |

*RER = respiratory exchange ratio.
†Significant difference in relation to stationary ($p < 0.05$).
‡Significant difference in relation to level 1 ($p < 0.05$).

**Table 3.** Dependent variables for alteration to ankle angle.*

| | | Stationary | Level 1 | RER of 1.00 | Max |
|---|---|---|---|---|---|
| Overall | ($n = 34$) | 15.37 ± 4.16 | 26.88 ± 4.58† | 22.53 ± 5.58†‡ | 23.08 ± 6.26†‡ |
| Male | ($n = 28$) | 15.48 ± 4.28 | 27.05 ± 4.25† | 22.22 ± 5.92†‡ | 23.00 ± 6.66†‡ |
| Top 10 | ($n = 10$) | 13.67 ± 3.67 | 26.75 ± 3.52† | 21.48 ± 3.19†‡ | 22.41 ± 3.22†‡ |
| Bottom 10 | ($n = 10$) | 17.38 ± 3.84 | 27.76 ± 4.36† | 25.35 ± 5.27†‡ | 27.06 ± 6.34† |

*RER = respiratory exchange ratio.
†Significant difference in relation to stationary ($p < 0.05$).
‡Significant difference in relation to level 1 ($p < 0.05$).

recorded ($p < 0.001$). Level 1 knee angle was significantly higher in relation to knee angle at RER of 1.00 ($p = 0.003$) and knee angle at maximal level recorded ($p = 0.016$). There was no significant difference between a knee angle at RER of 1.00 and knee angle at maximal level recorded ($p = 0.711$). Stationary ankle angle was significantly lower in relation to level 1 ankle angle ($p < 0.001$), ankle angle at an RER of 1.00 ($p < 0.001$), and ankle angle at maximal level recorded ($p < 0.001$). Level 1 ankle angle was significantly higher in relation to ankle angle at an RER of 1.00 ($p = 0.002$) and ankle angle at maximal level recorded ($p$ =0.009). There were no significant differences between an ankle angle at an RER of 1.00 in relation to ankle angle at maximal level recorded ($p = 0.307$; Table 3).

Within the male group ($n = 28$), stationary knee angle was significantly lower in relation to level 1 knee angle ($p < 0.001$), knee angle at RER of 1.00 ($p < 0.001$), and knee angle at maximal level recorded ($p < 0.001$). Level 1 knee angle was significantly higher in relation to knee angle at RER of 1.00 ($p = 0.003$), and knee angle at maximal level recorded ($p = 0.034$). There was no significant difference between a knee angle at RER of 1.00 and knee angle at maximal level recorded ($p = 0.841$). Stationary ankle angle was significantly lower in relation to level 1 ankle angle ($p < 0.001$), ankle angle at an RER of 1.00 ($p < 0.001$), and ankle angle at maximal level recorded ($p < 0.001$). Level 1 ankle angle was significantly higher in relation to ankle angle at an RER of 1.00 ($p < 0.001$), and ankle angle at maximal level recorded ($p = 0.006$). There were no significant differences between an ankle angle at RER of 1.00 in relation to ankle angle at maximal level recorded ($p = 0.213$).

Within the top 10 male group, stationary knee angle was significantly lower in relation to level 1 knee angle ($p < 0.001$) and knee angle at an RER of 1.00 ($p < 0.001$). There was no significant difference between the stationary knee angle and a knee angle at max level (0.088). Level 1 knee angle was significantly higher in relation to knee angle at RER of 1.00 ($p = 0.039$) and knee angle at maximal level recorded ($p = 0.038$). There was no significant difference between a knee angle at RER of 1.00 and knee angle at maximal level recorded ($p = 0.159$). Stationary ankle angle was significantly lower in relation to level 1 ankle angle ($p < 0.001$), ankle angle at an RER of 1.00 ($p < 0.001$), and ankle angle at maximal level recorded ($p < 0.001$). Level 1 ankle angle was significantly higher in relation to ankle angle at an RER of 1.00 ($p < 0.001$), and ankle angle at maximal level recorded ($p < 0.001$). There were no significant differences between an ankle angle at RER of 1 in relation to ankle angle at maximal level recorded ($p = 0.169$).

For the bottom 10 men, stationary knee angle was significantly lower in relation to level 1 knee angle ($p = 0.002$), knee angle at RER of 1.00 ($p = 0.031$), and knee angle at maximal level recorded ($p = 0.017$). There were no other significant differences in any other measure of knee angle. Stationary ankle angle was significantly lower in relation to level 1 ankle angle ($p < 0.001$), ankle angle at an RER of 1.00 ($p = 0.003$), and ankle angle at maximal level recorded ($p = 0.004$). Level 1 ankle angle was significantly higher in relation to ankle angle at an RER of 1.00 ($p = 0.007$). There were no other significant differences in ankle angle.

## Discussion

The purpose of this study was to measure the alterations to knee and ankle angle that occur during motion in comparison to stationary measures. When examining the results, it is evident that significant alterations to pedal stroke occur from stationary measures to active pedaling dependent on increased intensity. When examining the results for the total group, there appears to be a distinct pattern. All 3 measures for knee angle and ankle angle were significantly higher in relation to stationary measures. This represents a common pattern seen in cycling where the cyclist will pedal plantar flexed during the pedal stroke (10,11,18,19). An average increase of 36.39% in plantar flexion from stationary to pedaling corresponded to an average 17.20% increase in knee angle. An average 15.15% increase in dorsiflexion from level 1 to an RER of 1 and max corresponded to an average decrease of 5.89% in knee angle.

When examining the relationship between alterations to knee and ankle angle from stationary, there are 3 main considerations: (a) Cyclists contact the bike at the handlebars, saddle, and pedals, with weight distributed between these 3 points. (b) Pelvis position on the saddle changes very little when cycling on flat terrain and the use of clipless pedals maintains the cyclist's foot in a relatively fixed position. (c) The distance from the pedal axle in the 6-o′-clock position to the top of the saddle for a given subject does not alter. When plantar flexion occurs at the ankle, knee angle must also alter, because of the pelvis maintaining a stable position with little movement on the saddle and the cycling shoe being locked in the clipless pedal.

It is also feasible that the alteration to knee and ankle angle, which occurred from stationary position to pedaling, could be a result of the cyclist's attempt to obtain a specific knee angle through the use of plantar flexion. There appears to be training specificity to cycling position in that cyclists adapt to the specific position in which they train and race (2,4,14,15). Although not directly measured, it is feasible that cyclists in this study could alter ankle angle in an attempt to obtain knee angles similar to those in which they are accustomed.

Interestingly, level 1 knee and ankle angles were significantly higher in relation to pedaling at a higher intensity (RER of 1.00 and max). Although all 3 dynamic measures were significantly higher than stationary, greater dorsiflexion was present at an RER of 1.00 and Max in relation to level 1. This could be because of the greater power required to maintain 90 rpm against greater resistance. This is further supported by the fact that there were no significant differences found between an RER of 1.00 and Max. The results support the findings of earlier research conducted by Kautz et al. who examined the effect of increased workload at a fixed cadence (90 rpm) on a cycle ergometer (6). The cyclists performed at a lower workload (~60% of $\dot{V}O_2max$) and a work load that simulated race pace (~90% of $\dot{V}O_2max$). The larger workload resulted in a significant increase in torque during the downstroke of the pedal cycle. The researchers determined that the cyclists responded to the increased workload using 2 basic techniques. Half the subjects ($n = 7$) responded to the greater workload by applying a larger downward torque and producing significantly greater dorsiflexion during the downstroke. The greater dorsiflexion resulted in alterations to tangential force throughout the pedal stroke. The other half ($n = 7$) did not significantly alter ankle angle and produced a slightly greater downward torque. During this study, 70.59% of the subjects demonstrated greater dorsiflexion in response to the increased workload. One of the main differences between the 2 studies is that Kautz et al. adjusted the ergometer to mimic the cyclists' personal bikes, whereas this study used a set knee angle of 25°. A set knee angle during this study could have resulted in the larger percentage of cyclists who used dorsiflexion in response to the increased workload. It has not been determined as to which response is most optimal for improved performance.

When examining the male subgroup, the results followed the same pattern as the overall subject pool. This relationship could be accounted for because the male subgroup accounted for 82.35% of the total number of subjects. The low number of female participants prevented a meaningful comparison for detection of gender differences.

As evident in Table 1, the top 10 group differed from the bottom 10 group in physiological measures. Although the 2 groups are age matched, there is an apparent difference in weight, body fat percentage, and $\dot{V}O_2max$. When examining alteration to knee and ankle angles within the top 10 and bottom 10 subgroups, the pattern represented the overall group with a few alterations. In the top 10 and bottom 10 groups, both knee and ankle angles were significantly different in relation to stationary measures. The exception was that there was no difference in stationary and max knee angle in the top 10 group. It is possible that the power requirements at maximal effort for this group resulted in greater dorsiflexion. The top group demonstrated the same differences between level 1 measures and RER of 1.00 and max measures for both knee and ankle angles. However, in the bottom group, there were no significant differences in knee angle between level 1 and RER of 1.00 and max and only a significant difference in ankle angle between level 1 and an RER of 1.00. This greater variability expressed with the bottom 10 may be a result of less optimal muscle recruitment patterns (2). Chapman et al. concluded that novice cyclists expressed significantly greater muscle coactivation and greater variability in muscle activation in relation to highly trained cyclists (2). Increased cycling experience may result in neuromuscular adaptations ultimately resulting in decreased coactivation and less variability leading to greater economy during the pedal cycle. The result could also be because of lower power requirements per stroke at an RER of 1.00 and max observed in the bottom 10 group. The lower power requirements may not result in the greater dorsiflexion seen in the top 10 group. When examining the top 10 and bottom 10 groups, 90% of the top 10 group responded with greater dorsiflexion, whereas 60% of the bottom 10 group responded with greater dorsiflexion. There appeared to be greater variability in the in the bottom 10 group as some presented with greater plantar flexion at the higher workloads. The difference could also be generated because of variations in muscle recruitment patterns between novice and experienced cyclists. Experienced cyclists could have learned to adopt the use of dorsiflexion in response to the greater power requirements associated with higher workloads. Chapman et al. concluded that muscle recruitment patterns were highly dependent upon cycling level and that those with greater experience were more economical in regards to muscle recruitment patterns in cycling (2).

The stationary angles were measured using the MaxTRAQ 2D video analysis system to standardize for comparison with angles during motion. The mean knee angle for the stationary position was 28.17 ± 3.16, which differed slightly from the measure of 25° taken with the manual goniometer. Measurements were taken multiple times by a bike fit expert with 11 years of experience. The difference could have occurred because of the length of the goniometer arms. From the center of the goniometer, each arm measured 34 cm, which did not reach the reflective markers placed on the bony landmarks at the lateral malleolus and greater trochanter. Although not measured during this study, the use of a goniometer with extendable arms could help alleviate human error when aligning the goniometer. The difference in measurement could have also occurred because of the process of tagging the center of the reflective markers during the 2D analysis process. However, the possible difference between the 2 measures was the rationale for using the 2D stationary analysis for comparison with measurements during active cycling.

## Practical Applications

Overall, the results demonstrate that observation of dynamic pedaling may be needed because of significant alterations to knee and ankle angles, which occur during active pedaling. Bike fit sessions are typically conducted with the cyclists in a stationary position. Although stationary measurements are supported in the literature and are initially important in the bike-fitting process, this study supports the use of dynamic measures in such a process, too. It is apparent from the results of this study that alterations to knee and ankle angle do occur during active pedaling and that angles alter as resistance to pedaling increases. The practitioner should be aware of these alterations to adjust fit based on each individual's anthropometrics and pedaling style.

It is also apparent from the results that cyclists with less experience will demonstrate greater variability in pedal stroke vs. more experienced cyclists. Optimizing bike fit with a novice cyclist may be more problematic because of the greater variability in pedal stroke and therefore require more time. However, experienced cyclists may present with less variability during the pedal cycle leading to more accurate measurements and resulting in fewer adjustments during the fitting process.

This study demonstrates that the use of video analysis should be included as a component of the bike-fitting process. Video analysis allows the practitioner to analyze the kinematics of the pedal stroke frame by frame to examine movement at the knee and ankle not normally observed by the human eye during active cycling. The system enables precise measurement during cycling performance, thus accounting for measurement differences between static posture and active pedaling. This is extremely important when one considers that the most appropriate bike 'fit' should be derived from a functional position, not a static one. This recommendation does not negate the importance of initiating saddle height adjustment using stationary methods established by previous studies. Instead it is suggested to augment the established methods to optimize the bike-fitting process. Because the prevalent recommendations, based off current literature, involve knee angles based on static measures, there are currently no performance or injury prevention recommendations based on dynamic knee and ankle angles. It is understood that saddle height is only 1 component of bike fit and adjustment of other bike fit variables could contribute to dynamic changes in knee angle. Although not explored in this study, saddle height may affect movement in the frontal plane as well and should be explored.

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