# Effects of Saddle Height on Economy and Anaerobic Power in Well-Trained Cyclists

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## Abstract

Peveler, WW and Green, JM. Effects of saddle height on economy and anaerobic power in well-trained cyclists. *J Strength Cond Res* 25(3): 629–633, 2011—In cycling, saddle height adjustment is critical for optimal performance and injury prevention. A 25–35° knee angle is recommended for injury prevention, whereas 109% of inseam, measured from floor to ischium, is recommended for optimal performance. Previous research has demonstrated that these 2 methods produce significantly different saddle heights and may influence cycling performance. This study compared performance between these 2 methods for determining saddle height. Subjects consisted of 11 well-trained ($\dot{V}O_2max = 61.55 \pm 4.72$ ml·kg$^{-1}$·min$^{-1}$) male cyclists. Subjects completed a total of 8 performance trials consisting of a graded maximal protocol, three 15-minute economy trials, and 4 anaerobic power trials. Dependent measures for economy ($\dot{V}O_2$, heart rate, and rating of perceived exertion) and anaerobic power (peak power and mean power) were compared using repeated measures analysis of variance ($\alpha = 0.05$). $\dot{V}O_2$ was significantly lower (reflecting greater economy) at a 25° knee angle ($44.77 \pm 6.40$ ml·kg$^{-1}$·min$^{-1}$) in comparison to a 35° knee angle ($45.22 \pm 6.79$ ml·kg$^{-1}$·min$^{-1}$) and 109% of inseam ($45.98 \pm 5.33$ ml·kg$^{-1}$·min$^{-1}$). Peak power at a 25° knee angle (1,041.55 ± 168.72 W) was significantly higher in relation to 109% of inseam (1,002.05 ± 147.65 W). Mean power at a 25° knee angle (672.37 ± 90.21 W) was significantly higher in relation to a 35° knee angle (654.71 ± 80.67 W). Mean power was significantly higher at 109% of inseam (662.86 ± 79.72 W) in relation to a 35° knee angle (654.71 ± 80.67 W). Use of 109% of inseam fell outside the recommended 25–35° range 73% of the time. Use of 25° knee angle appears to provide optimal performance while keeping knee angle within the recommended range for injury prevention.

**Key Words** seat height, Wingate, triathlon, cycling position, peak power

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## Introduction

In cycling, properly adjusting saddle height is vital for both injury prevention and optimal performance (7,10,13–16,19,20). The Hamley and the Holmes methods are the only 2 techniques for adjusting saddle height evaluated and published in scientific literature (7,10,14–16,19,20).

Hamley and Thomas (7) recommended use of 109% of inseam for optimal cycling performance. During their study, inseam was measured from ischium to floor, multiplied by 1.09, with the result used to determine saddle height measured from the center of the pedal axel (at the bottom of the stroke) to the top of the saddle. This use of inseam measurement to adjust saddle height for optimal performance has been validated by other researchers (14,20).

The Holmes method is recommended for injury prevention (10). A saddle that is set too high can lead to anterior knee pain and a saddle height that is set too low could lead to posterior knee pain (10,13). To avoid either extreme, Holmes et al. (10) recommended using a saddle resulting in a knee angle between 25 and 35°, with the pedal located at the bottom of the pedal stroke. This range is recommended by Holmes et al. (10) for injury prevention only and performance was not evaluated.

Recent research has demonstrated that the Hamley and Holmes methods often produce dissimilar saddle heights within a given individual (15,16,19). In previous research from our laboratory, we compared methods of setting saddle height and found that using 109% of inseam fell outside the recommended 25–35° knee angle 63, 45, and 74% of the time in 3 studies, respectively (15,16,19). A possible reason for the wide range of saddle heights, produced by using 109% of inseam, is that this measure does not take into account individual variations in femur, tibia, and foot length. These individual variations cannot be accounted for by inseam alone, resulting in the wide variations in knee angles recorded in the previously mentioned studies (15,16,19). In contrast, a 25° knee angle will consistently yield a 25° knee angle, as it is independent of anatomical variations among individuals.

In 2 previous studies, we examined the difference in performance when using the Hamley and Holmes methods (15,19). The first study examined the effect of saddle height on anaerobic power during a 30-second Wingate trial (19).

In this study, subjects fell outside the recommended 25–35° knee angle range 45% of the time when using 109% of inseam to set saddle height. This led to a significant decrement in anaerobic power for those who fell outside the recommended 25–35° knee angle in comparison to performance at a 25° knee angle. No significant difference in performance was found when comparing a 25° knee angle to a 35° knee angle. In the second study, we examined the effect of saddle height on economy between the Hamley and the Holmes methods (15). It was determined that cyclists were more economical at a saddle height set using a 25° knee angle vs. a 35° knee angle and 109% of inseam (15).

These 2 previous studies examined the effect of saddle height on performance in both noncyclists and cyclists (15,19). The economy study consisted of 10 noncyclists and 5 cyclists with a mean $\dot{V}O_2max$ of 55 ± 6 $ml \cdot kg^{-1} \cdot min^{-1}$ and a range of 49–63 $ml \cdot kg^{-1} \cdot min^{-1}$ (15). Only 3 of the 5 subjects obtained a $\dot{V}O_2max$ greater than 55 $ml \cdot kg^{-1} \cdot min^{-1}$. The specificity of a cyclist's training position can affect cycling performance (5,9,17,18). Chapman et al. (5) demonstrated that muscle recruitment patterns were significantly more developed in highly trained cyclists in relation to recreational cyclists. This improved recruitment pattern is believed to occur because of neuromuscular adaptations associated with training (5). With specificity to training position and improved recruitment patterns during the pedal cycle, well-trained cyclists may react differently to alterations in saddle height. The purpose of the current study was to examine the effect of saddle height on economy and anaerobic power in well-trained cyclists. Based on previous work, it was hypothesized that a 25° knee angle would lead to optimal performance (15,19).

## Methods

### Experimental Approach to the Problem

*Economy.* Cycling is an endurance sport in which economy may influence energy reserves and consequently performance outcomes. To determine economy, subjects in this study were required to pedal 15 minutes at a fixed resistance and a fixed cadence at a saddle height using each model discussed. $\dot{V}O_2$ recorded throughout the 15-minute trials was accepted as a measure of economy. Because resistance and cadence were fixed, any change in $\dot{V}O_2$ would reflect alterations in economy because of modification of saddle height. A lower $\dot{V}O_2$ would reflect improved economy, whereas a higher $\dot{V}O_2$ would reflect poorer economy and consequently greater energy expenditure. This methodology has been successful in detecting alterations in economy during previous studies (15,17). Although less reliable, heart rate (HR) shares a linear relationship with $\dot{V}O_2$ at submaximal intensities and can also be used as a measure of economy (12). Rating of perceived exertion (RPE) is widely accepted as reflection of effort during exercise (1,6). If saddle height adjustment improves economy, it is plausible that RPEs may systematically be reduced.

*Anaerobic Power.* Anaerobic power accurately predicts cycling performance (2,3,8,21). The 30-second Wingate test is a widely accepted measure of anaerobic power production (4). This protocol has been used successfully in previous studies to detect alterations in power production because of modifications in cycling position (18,19).

### Subjects

Subjects consisted of 11 well-trained male cyclists (mean $\dot{V}O_2max$ = 61.55 ± 4.72 $ml \cdot kg^{-1} \cdot min^{-1}$; range = 55.20–68.60 $ml \cdot kg^{-1} \cdot min^{-1}$). Testing occurred during the cyclists' off-season. Other descriptive statistics were as follows: mass = 71.98 ± 7.79 kg; body fat percentage = 7.80 ± 2.87%; height = 176.87 ± 8.51 cm; and age = 28.09 ± 4.99 years. The study commenced with 21 subjects. However, because of exclusion criteria (a required $\dot{V}O_2max$ of ≥55 $ml \cdot kg^{-1} \cdot min^{-1}$), 10 subjects were eliminated without further testing. One subject was injured in training after completion of the economy trials and was unable to complete the anaerobic power trials. Consequently, analyses for economy trials included 11 subjects, whereas dependent measures for anaerobic power included 10 subjects. No comparisons were made between the economy and anaerobic power trials during this study.

Approval for this study was obtained through the local institutional review board and all 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).

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

### Procedures

*Economy Trials.* Subjects completed a graded exercise protocol on a Monark 828E cycle ergometer (Monark Exercise AB, Vansbro, Sweden). Resistance began at 1 kilopond (kp) and increased by 0.5 kp every 2 minutes until volitional exhaustion. Subjects were required to maintain 90 rpm or higher throughout the graded exercise protocol (11). Achievement of $\dot{V}O_2max$ was determined by an HR equal to or greater than age-predicted maximum, a respiratory exchange ratio equal to or greater than 1.15, or a $\dot{V}O_2$ plateau with increasing workload was attained (12). The graded exercise protocol was employed to determine $\dot{V}O_2max$ for descriptive statistics, for exclusion criteria (a required $\dot{V}O_2max$ of ≥55 $ml \cdot kg^{-1} \cdot min^{-1}$), for identifying resistance needed for economy trials (70% of $\dot{V}O_2$max), and to anchor RPE.

The workload for the 3 economy trials was set by determining the resistance, in kp, at which the subject achieved approximately 70% of $\dot{V}O_2$max during the graded exercise protocol. The 3 economy trials were conducted on the Monark 828E. Subjects were required to maintain a constant 90 rpm throughout the 3 economy trials. During one trial, the saddle height was determined using a 25° knee angle, in another using a 35° knee angle, and in the third using 109% of inseam (procedure described in the following). The 3 economy trials were counterbalanced to protect against an ordering effect. Heart rate, RPE, and $\dot{V}O_2$ were recorded every minute during the 15-minute trials and later compared to determine economy between trials.

During the 3 economy trials, a manual goniometer (LeMond Fitness, Inc., Woodinville, WA, USA) was used to set saddle height at a 25 and 35° knee angle. Subjects pedaled until they obtained a comfortable riding position and then stopped at the bottom of the pedal stroke. The clipless pedal systems used by the cyclists allow for very minimum foot movement during the measuring process. 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 of the hip. All measurements were taken by the primary investigator and repeated multiple times to ensure accuracy.

Setting saddle height using 109% of inseam required the subject's inseam be measured from the ischium to the floor. This was accomplished by requiring the subjects to stand with their back against the wall and their feet approximately 5 cm apart. A straight edge was placed between the subject's legs at a 90° angle from the wall and the distance from the straight edge to the floor measured in centimeters. This measurement was then multiplied by 1.09 and the resultant number used to measure from the center of the pedal axle to the top of the saddle. The pedal was placed at the bottom of the pedal stroke during this measurement. Once saddle height was established using this method, a manual goniometer was used to measure knee angle to determine if saddle height produced the recommended knee angle range of 25–35°. All measurements were taken multiple times to ensure accuracy.

*Anaerobic Power Trials.* The anaerobic power trials consisted of four 30-second Wingate tests with at least 1 day of rest between trials. Trials were conducted on a Monark 894E sprint cycle ergometer (Monark). Before commencement, subjects were informed to remain seated and to give maximal effort throughout the entire trial. Resistance was attained by determining 7.5% of the subject's body weight in kilograms. After a 5-minute warm-up, subjects were given a rolling start to break the initial inertia of the flywheel. The Monark Wingate system is fully automated and resistance was initiated and timer started when the subject's pedaling cadence reached 120 rpm. Peak power (PP) and mean power (MP) were recorded for the trial. After the completion of the 30-second sprint, resistance was removed and the subjects participated in an active cool down. The first trial was employed as a familiarization trial and was conducted after the completion of the 15-minute economy trials. Saddle height during the last 3 anaerobic power trials was set at a 25° knee angle, a 35° knee angle, and 109% of inseam. The last 3 trials were counterbalanced to protect against an ordering effect. Saddle height was determined using the same methodology as in the economy trials.

### Statistical Analyses

Dependent measures for economy ($\dot{V}O_2$, HR, and RPE) and anaerobic power (PP and MP) were compared among trials, individually, using repeated measures analysis of variance. Significance was set a priori with an alpha of 0.05 (2 tailed). An interclass correlation coefficient was used to determine reliability for each dependant measure and all were found to be high ($\dot{V}O_2 = 0.94$; HR = 0.93; RPE = 0.92; PP = 0.97; and MP = 0.99). Observed power for the dependent measures

**TABLE 1.** Dependent variables for economy and anaerobic power trials*

| | 25° | 35° | 109% |
|---|---|---|---|
| $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$) | 44.77 ± 6.40†‡ | 45.22 ± 6.79§ | 45.97 ± 5.33 |
| Heart rate (beats per min) | 163.48 ± 13.07‡ | 163.49 ± 14.23§ | 165.70 ± 13.14 |
| RPE | 12.86 ± 3.02†‡ | 13.31 ± 3.41 | 13.56 ± 2.58 |
| Peak power (W) | 1,041.55 ± 168.72‡ | 1,003.93 ± 143.60 | 1,002.05 ± 147.65 |
| Mean power (W) | 672.37 ± 90.21† | 654.71 ± 80.67§ | 662.86 ± 79.72 |

*$n = 11$ for $\dot{V}O_2$, heart rate, and RPE (rating of perceived exertion); $n = 10$ for peak power and mean power.
†Significant difference between 25 and 35°.
‡Significant difference between 25° and 109%.
§Significant difference between 35° and 109%.

was as follows: $\dot{V}O_2 = 0.99$; HR = 0.95; RPE = 0.99; PP = 0.41; and MP = 0.85. All statistics were calculated using SPSS 17.0 statistical analysis software (SPSS, Inc, Chicago, IL, USA).

## Results

### Economy Trials

Results for dependent variables can be located in Table 1. Economy ($\dot{V}O_2$) measures were significantly lower at 25° knee angle vs. a 35° knee angle ($p = 0.039$) and 109% of inseam ($p < 0.001$). $\dot{V}O_2$ at a 35° knee angle was significantly lower in comparison to 109% of inseam ($p = 0.018$). Heart rate was significantly lower at a 25° knee angle vs. 109% of inseam ($p < 0.001$). Heart rate was significantly lower at a 35° knee angle vs. 109% of inseam ($p = 0.006$). There was no significant difference in HR between a 25 and 35° knee angle. Rating of perceived exertion was significantly lower at a 25° knee angle vs. a 35° knee angle ($p < 0.001$) and 109% of inseam ($p < 0.001$). There were no significant differences in RPE between a 35° knee angle and 109% of inseam during this study.

### Anaerobic Power Trials

Peak power at a 25° knee angle was significantly higher vs. 109% of inseam ($p = 0.033$). There were no significant differences detected between a 25 and 35° knee angle or between a 35° knee angle and 109% of inseam. Mean power at a 25° knee angle was significantly higher in relation to a 35° knee angle ($p = 0.007$). Mean power was significantly higher at 109% of inseam in relation to a 35° knee angle ($p = 0.017$). There were no significant differences found between a 25° knee angle and 109% of inseam. Intraclass correlation coefficients were found to be high in the dependant variables measured (PP = 0.98 and MP = 0.99).

## Discussion

There is considerable debate regarding the most appropriate method for establishing saddle height for cyclists. Saddle height may influence performance and also contribute to injury incidence (7,10,13–16,19,20). This study examined the effects of 3 approaches to the establishment of saddle height on economy and anaerobic power in well-trained cyclists ($\dot{V}O_2max \geq 55$ ml·kg$^{-1}$·min$^{-1}$). Similar to previous studies, the use of 109% of inseam led to a saddle height resulting in the cyclists' knee angle falling outside the recommended 25–35° range 73% (8 of 11 subjects) of the time. In previous studies, use of 109% of inseam fell outside the recommended 25–35° knee angle 63, 45, and 74% of the time (15,16,19). Whereas the mean knee angle created by the use of 109% of inseam was 34.64 ± 8.33°, the range was 19–44°, indicating a large amount of variability. This is more than likely because of the between-subjects variability in anthropometric measures, which cannot be accounted for by measuring inseam alone.

Use of a 25° knee angle was found to be more economical in relation to a 35° knee angle and 109% of inseam. This would translate into a lower metabolic cost at a fixed submaximal work rate with the use of a 25° knee angle. On average, cyclists were more economical by 1.20 ml·kg$^{-1}$·min$^{-1}$ at a 25° knee angle in comparison to 109% inseam and by 0.45 ml·kg$^{-1}$·min$^{-1}$ in relation to a 35° knee angle. A 35° knee angle was found to be more economical in relation to 109% of inseam (average difference equal to 0.75 ml·kg$^{-1}$·min$^{-1}$). Although the differences may not appear large, hypothetically they could make a substantial difference during an actual race. The economy trials consisted of 15 minutes of cycling only, and the duration of most cycling races will be in excess of 3 hours. However, this extrapolation is only a hypothesis and was not directly measured during this study. These findings are very similar to the investigations in a previous study where cyclists were more economical by 1.55 ml·kg$^{-1}$·min$^{-1}$ at a 25° knee angle in comparison to 109% inseam and by 1.25 ml·kg$^{-1}$·min$^{-1}$ in relation to a 35° knee angle (15). Although not significantly different, a saddle height set using a 35° knee angle was more economical than 109% of inseam by 0.30 ml·kg$^{-1}$·min$^{-1}$, during the previous study (15).

Rating of perceived exertion and HR were also assessed as dependent measures. A saddle height set using a 25° knee angle resulted in a significantly lower RPE in relation to a 35° knee angle and 109% of inseam (Table 1). Cyclists reported lower feelings of exertion at a 25° knee angle when cycling at a fixed resistance. Although not directly measured in this study, this could translate into increased power output at any given submaximal RPE while cycling at a saddle height set using a 25° knee angle. The use of 109% of inseam resulted in a greater HR in relation to a 25 and 35° knee angle. This is not surprising because of the linear relationship between HR and $\dot{V}O_2$ at submaximal intensities. In the author's previous study, there were no significant differences detected for RPE or HR (15).

When examining the results of the economy trials as a whole, it would appear to support the recommendation of a 25° knee angle for optimal performance. Additionally, a 25° knee angle is also recommended for injury prevention (10). Use of 109% of inseam not only falls outside the recommended range for injury prevention but also leads to a decrease in economy.

Compared to economy trials, results for anaerobic power are less clear. Although a 25° knee angle produced a significantly higher PP compared to 109% of inseam, there was no significant difference for MP between the 2 conditions. In a previous study, subjects experienced a decrease in performance at 109% of inseam compared to a 25° knee angle when they fell outside the recommended 25–35° range (19). Although there was no significant difference in PP between a 35° knee angle and 109% of inseam, MP was significantly lower at a 35° knee angle compared to 109% of inseam. Among studies from our laboratory, this is the first time a decrease in performance has been observed when using a 35° knee angle compared to 109% of inseam. This is contradictory to previous studies and the results for the economy trials during this study (15,19).

Previous research has established anaerobic power as predictor of cycling performance (2,3,8,21). However, it may not be as sensitive a predictor of endurance performance as economy. Overall, the sport of cycling requires aerobic power and economy of motion. A short 30-second anaerobic test may not be a sensitive measure of performance in comparison to a longer economy test. Similarly, our previous study examining the effect of saddle height on economy produced much stronger result in relation to our previous anaerobic power study (15,19). The variation between the economy and anaerobic trials could also be contributed to the results being intensity and time dependent. During the economy trials, subjects worked at 70% of $\dot{V}O_2$max over a 15-minute period of time at a submaximal effort. The anaerobic trials required 100% effort for a 30-second period of time. This maximal effort over a short period of time may not be sensitive enough to accurately measure changes in performance that occur because of alterations in saddle height.

## Practical Applications

There are 2 key points to be taken from this study. The first is that measures of economy may provide a more sensitive measure of alteration to performance because of seat height. From this, it can be suggested that practitioners concentrate more on measures of economy when adjusting riding position with cyclists. Second, results from this study, in combination with results from previous studies comparing the Hamley and Holmes methods, support the use of a 25° knee angle for optimal performance (15,19). However, it is important to note that alterations may be needed because of individual variations in anthropometrics and history of injury. Also, it is important that the practitioner uses correct methodology when adjusting saddle height using a goniometer. It is vital that the appropriate landmarks be located and that the cyclist is in the correct position for measurement. Saddle height is an important component of correct bike setup with respect to avoiding injury and optimizing performance. Results extend the understanding of establishing correct saddle height.

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