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Effects of saddle height on pedal force effectiveness

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Abstract

Bicycle saddle height configuration may affect pedal force application. Our aim was to compare pedal force effectiveness for different saddle height configurations. Eleven cyclists (38 ±12 years) and eleven triathletes (44 ±8 years) with competitive experience performed 2-min trials at four different saddle heights (preferred, high, low, theoretical optimal) each separated by one minute of rest. Workload was normalized by body weight and pedaling cadence was visually controlled by the athletes at 90 ±2 rpm for all trials. The preferred saddle height replicated the horizontal and vertical configuration of each athlete's bicycle. High and low saddle heights were selected to elicit ±10° knee flexion from knee flexion at preferred saddle height. Guidelines from Peveler (2008) were used to set the theoretical optimal saddle height based on 25° knee flexion when the pedal crank was at the 6 o'clock position. Knee joint angles were measured with a goniometer prior to each trial. Normal and shear forces were measured using an instrumented right pedal and pedal-to-crank angle was measured using an angular potentiometer. A reed switch attached to the bicycle frame detected the position of the crank in relation to the pedal revolution. Forces on the pedal surface were resolved into the tangential force on the crank to compute force effectiveness (ratio between tangential and resultant force applied on the pedal). Magnitudes of differences between the saddle heights were assessed by effect sizes (ES) for the average total (resultant) force and force effectiveness. To elicit ±10° knee flexion, changes of ±3% of the preferred saddle height were required. Changes in average resultant force with saddle height were trivial (1% for preferred versus optimal; ES = 0.2) to moderate (5% for high versus low; ES = 0.8). Changes in force effectiveness with saddle height were small (2% for preferred versus optimal; ES = 0.3) to moderate (6% for high versus low; ES = 1.0). Lower saddle heights produced higher resultant force but lower force effectiveness. Saddle height changes resulted in moderate effects for pedal resultant force and force effectiveness for most saddle height comparisons.

Keywords: pedaling technique, knee flexion angle, cycling

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1. Introduction

The position of the saddle is important for optimal performance because there seems to be a range of saddle heights that minimize oxygen consumption. When saddle height is equivalent to 100% of the height from the greater trochanter to the floor VO_2 can be minimized [1]. When knee flexion is between 25-30° as a result of saddle height VO_2 can also be minimized [2]. No studies have investigated effects on pedal forces as a result of saddle height changes based on the knee flexion angle. We would expect that force applied on the pedal would be minimized when saddle height was set to elicit 25-30° of knee flexion. Pedal force effectiveness has been used to express the percentage of the force applied on the pedal that creates propulsive torque on the crank. The greater the force effectiveness, the lower would be the waste of energy during cycling. The aim of the study was to compare pedal force effectiveness for different saddle height configurations (preferred, high, low, theoretical optimal).

Nomenclature

ES Effect sizes

2. Methods

2.1. Participants

Eleven cyclists and eleven triathletes with competitive experience were invited to participate in the study (mean ±SD: 41 ±11 years old, 74 ±14 kg, 8 ±4 week training hours, 31.5 ± 8 $km \cdot h^{-1}$ average speed at self-selected racing events) and signed an informed consent form in agreement with the research ethics committee of the institution where the study was conducted.

2.2. Protocol

At the start of the evaluation session body mass was measured (Secca scales) and self-reported age, week training hours and average speed at self-selected racing events were recorded. Participants' bicycle saddle height and horizontal position were measured to set up the stationary cycle ergometer (Velotron, Racemate, Inc) at the "preferred height" configuration. Knee joint flexion angle was measured using a goniometer while the participants held the pedal crank at the 6 o'clock position. Saddle height was recorded when the saddle was changed from the preferred position to high (-10° of knee flexion with respect to the preferred height), low (+10° of knee flexion with respect to the preferred height), and to the theoretical optimal (25° of knee flexion). Participants then performed 10 minutes of warm-up cycling at a self-selected cadence on the stationary Velotron cycle ergometer using their preferred saddle height. Workload was then increased to match 3.4 ±0.4 $W \cdot kg^{-1}$ (247 ±45 W) and pedalling cadence was visually controlled at 90 ±2 rpm for two minutes. Data were recorded during the first 20 s of the second minute for each saddle height trial. One minute of static rest was completed between trials with different saddle heights.

2.3. Data recording

Normal and anterior-posterior forces were measured using a strain gauge instrumented right pedal [3] and pedal-to-crank angle was measured using an angular potentiometer [4]. A reed switch attached to the bicycle frame detected the position of the crank in relation to the pedal revolution [5]. All data were acquired at 600 Hz by an analog to digital converter (PCI-MIO-16XE-50, National Instruments, USA) using a custom Matlab (Mathworks Inc, MA) data acquisition script.

2.4. Data analysis

Forces on the pedal surface were resolved into the tangential force on the crank to compute force effectiveness (ratio between tangential resultant pedal forces) [6]. Tangential (effective) force and resultant pedal force were averaged over ten complete pedal revolutions. Data analysis was conducted offline using a custom Matlab (Mathworks Inc, MA) analysis package.

2.5. Statistical analysis

Magnitudes of differences between the saddle heights were assessed by effect sizes (ES) for the average resultant pedal force and force effectiveness [7, 8]. Effect sizes were rated as trivial (<0.25), small (0.25-0.49), moderate (0.5-1.0), and large (>1.0) [9].

3. Results

In Table 1, means and standard deviations for knee flexion angle, saddle height, resultant force and force effectiveness of the 22 athletes for four saddle heights (preferred, high, low and optimal) are presented. Average preferred saddle height among cyclists and triathletes was 86.5 ±5.1 cm. To elicit -10° of knee flexion (high saddle height), changes of +3 ±1% of the preferred saddle height were conducted, while to achieve +10° of knee flexion (low saddle height) changes of -2 ±1% of the preferred height were conducted. For the optimal saddle height (25° of knee flexion) changes of +3 ±2% of the preferred height were conducted.

Table 1. Means and standard deviations for knee flexion angle (°), saddle height (% of preferred height), resultant force (N) and force effectiveness (%) of the 22 athletes for four saddle heights (preferred, high, low and optimal).

Variables	Preferred saddle height	High saddle height	Low saddle height	Optimal saddle height
Knee flexion angle at 6 o'clock pedal crank position (°)	37 ±3.6	26 ±3.6	46 ±3.5	25
Saddle height (%)	100	103 ±1.4	98 ±0.8	103 ±1.5
Resultant force (N)	160 ±33	156 ±35	163 ±36	159 ±36
Force effectiveness (%)	54 ±5	57 ±6	54 ±6	56 ±7

Changes in average resultant force with saddle height were trivial (1% for preferred versus optimal; ES = 0.2) to moderate (5% for high versus low; ES = 0.8). Changes in force effectiveness with saddle height were small (2% for preferred versus optimal; ES = 0.3) to moderate (6% for high versus low; ES = 1.0).

The low saddle height condition produced higher resultant force but similar force effectiveness compared to the preferred height (see Table 2).

Table 2. Percentage differences and effect sizes for knee flexion angle, saddle height, resultant force and force effectiveness of the 22 athletes for four saddle heights (preferred, high, low and optimal).

Saddle height/ Variables	Preferred vs. High	Preferred vs. Low	Preferred vs. Optimal	High vs. Low	High vs. Optimal	Low vs. Optimal
Knee flexion angle at 6 o'clock pedal crank position (% change; ES)	38%; 2.4, large	22%; 2.4, large	45%; 2.7, large	43%; 4.8, large	5%; 0.3, small	85%; 5.2, large
Saddle height (% change; ES)	3%; 2.1, large	2%; 2.8, large	4%; 2.1, large	6%; 4.8, large	1%; 0.4, small	6%; 4.6, large
Resultant force (% change; ES)	3%; 0.4, small	2%; 0.4 small	1%; 0.2, trivial	5%; 0.8, moderate	2%; 0.2, trivial	3%; 0.5, moderate
Force effectiveness (% change; ES)	4%; 0.6, moderate	2%; 0.4, small	2%; 0.3, small	6%; 1.0, moderate	2%; 0.3, small	4%; 0.6, moderate

4. Discussion

Previous research suggested that optimal efficiency in cycling may be achieved when the saddle height is set to elicit a knee flexion angle of 25° when the pedal crank is at the 6 o'clock position [2]. We expected that pedal force application would also be optimized using this configuration for the saddle height. However, we found that preferred saddle height used by competitive cyclists and triathletes resulted in greater knee flexion (~37°) then that recommended to optimize efficiency. Only trivial changes in resultant force (-1%) and small improvements in force effectiveness (+2%) were found when the optimal saddle height was compared to the preferred saddle height.

Lowering the saddle height by approximately 2% of the current preferred saddle height elicited only small increases (2%) in resultant force applied on the pedal for cyclists and triathletes, which may not be expected to improve cycling efficiency. Hip and ankle joints would be expected to compensate for changes in saddle height to achieve similar power production of the knee joint muscles. Given the varied results for comparisons between the various saddle heights, further work is required to determine how best to set saddle height to improve both force effectiveness and resultant force.

5. Conclusion

Saddle height changes resulted in small to large effects for pedal resultant force and force effectiveness for most saddle height comparisons.

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