Myths and Science in Cycling

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Who am I

- PhD in Exercise Physiology under Dr. Jim Martin at the University of Utah.
- Lifelong endurance athlete
- 3 time All-American in cross country/track and field
- Pro triathlete and CAT II cyclist
- Spent 2 years working with the US speedskating team
Myth and Science in Cycling

- Pedaling Rate
- Crank length
- Pedaling Technique
- Non-round chainrings
Pedaling rate: cycling cultural beliefs

“... he increases his pedaling rate on climbs to improve his efficiency”

- What is the truth about pedaling rate?
  - Which is most efficient  ???
Pedaling Rate

After 10 and 20 minutes at 85% VO2max

Coast et al 1985 and 1986
Neuromuscular Fatigue??

- Subjects pedaled at 85% VO2 max for 20 minutes at 6 different pedaling rates.

Takaishi et al 1996
Reductions in EMG With Cycling Experience
Summary: Pedaling Rate

- For non-competitive cyclists ≈70 rpms is the most metabolically efficient.
- Cyclists pedal at higher rates to:
  - Minimize recruitment of fast twitch fibers
  - Reduce muscle fatigue
  - Improve blood flow in the legs
- Physiological adaptations with training allow elite cyclists to pedal at higher rates with less neuromuscular fatigue.
Myth and Science in Cycling

- Pedaling Rate
- Crank length
- Pedaling Technique
- Non-round chainrings
Crank Length

- Maximal power
- Metabolic Cost of Submaximal Cycling
- Biomechanics
Crank Length: Cycling Cultural Beliefs

1. There is an optimal crank length for each cyclist
2. The optimal crank length will substantially improve performance
3. Non optimal crank length will substantially compromise performance
Cycling Crank Length

- Google: optimal "crank length" = 1,670,000 hits
- Books, magazines, web sites etc.
- Scientific evidence?
  - Inbar et al., 1983 (Wingate test power)
  - Yoshihuku and Herzog 1996 (model)
  - McDaniel et al., 2002 (metabolic cost)
  - Thomas et al., 2009 (fatigue)
  - Barratt et al., 2011 (biomechanics)
Cycling Crank Length

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  - McDaniels et al., 2002 (metabolic cost)
  - Thomas et al., 2009 (fatigue)
  - Barratt et al., 2011 (biomechanics)
Crank Length, Pedaling Rate, and Power

Determinants of maximal cycling power: crank length, pedaling rate and pedal speed

J.C. Martin · W.W. Spirduso

DOI 10.1007/s004210100400

ORIGINAL ARTICLE
Purposes

- Determine the effects of crank length on
  - Maximum cycling power
  - Optimal pedaling rate

- Determine the optimal crank length for maximum power
Methods

- 16 trained cyclists performed maximal cycling with 120, 145, 170, 195, and 220mm cranks
- Seat height: maintain maximum leg extension
- TALL and short cyclists
  - Measured Thigh, Tibia, and Total leg length
- Two practice sessions on each length
- Maximal power-velocity relationships
Inertial Load Cycle Ergometry

Max Power vs. Crank Length

![Bar chart showing max power vs. crank length. The x-axis represents crank length (mm) with values 120, 145, 170, 195, and 220. The y-axis represents power (watts) ranging from 0 to 1400. There are error bars indicating variability in the data. Asterisks denote statistically significant differences.](chart.png)
Max Power vs. Crank Length

- Power (Watts)
  - 120: ~1150
  - 145: ~1200, ±3.9%
  - 170: ~1150, ±3.9%
  - 195: ~1150
  - 220: ~1150

- Crank Length (mm)
  - 120
  - 145
  - 170
  - 195
  - 220

* Asterisks indicate significance.
Max Power vs. Crank Length

**Diagram Description:**
- The diagram illustrates the relationship between Crank Length (mm) and Power (watts).
- The x-axis represents Crank Length ranging from 120 to 220 mm.
- The y-axis represents Power (watts) ranging from 1100 to 1300 watts.
- Bars indicate the measured power at different crank lengths:
  - 120 mm: Power approximately 1140 watts
  - 145 mm: Power approximately 1180 watts, marked with an asterisk
  - 170 mm: Power approximately 1180 watts
  - 195 mm: Power approximately 1180 watts
  - 220 mm: Power approximately 1140 watts, marked with an asterisk
- A note indicates a 1.6% change between two specific crank lengths.
What about Individual Differences?
Leg/Crank Length vs. Power

Relative Maximum Power

Crank Length to Leg Length Ratio

90% 92% 94% 96% 98% 100%
Leg/Crank Length vs. Power

Crank Length to Leg Length Ratio

Relative Maximum Power

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

0.1 0.15 0.2 0.25 0.3
One Size Fits All?

- 170 mm cranks would compromise the power of the shortest and tallest riders by no more than 0.5%
  
  – For example 6 watts out of 1200
Basic Science: Power vs. Pedaling Rate
What about joint power?

- Could crank length shift contribution of joint powers?
- Less power from knee and more from hip?
**Effect of Crank Length on Joint-Specific Power during Maximal Cycling**

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\(^2\)Department of Performance Analysis and Biomechanics, English Institute of Sport, Manchester, UNITED KINGDOM; and 
\(^3\)Department of Exercise and Sport Science, University of Utah, Salt Lake City, UT

- Fifteen trained cyclists
- Maximal isokinetic cycling trials
- 150, 165, 170, 175 and 190 mm cranks
- Pedaling rates of 120 and optimal pedaling rate for each length
Cycling Biomechanics

- **Kinematics**
  - Iliac crest, crank, pedal
  - Calculated geometrically

- **Kinetics**
  - Force measuring pedal

- **Joint-specific powers**
Effects of Crank Length on Joint Specific Power during Maximal Cycling
Barratt, Korff, Elmer, Martin
Summary for Crank Length and Maximum Power

- Small effect
- Significant only at extreme lengths
- 170mm cranks compromise power of the tallest and shortest riders by no more 0.5%
- No change in joint power contributions
Cyclists can ride the crank length they prefer without concern of decreasing maximal power.
Bad News:
Crank Length, Pedaling Rate, and Metabolic cost

Determinants of metabolic cost during submaximal cycling

J. McDANIEL, J. L. DURSTINE, G. A. HAND, AND J. C. MARTIN
Department of Exercise Science, University of South Carolina, Columbia, South Carolina 29208
Background

- Metabolic cost increases with pedaling rate
- Higher metabolic cost means lower efficiency
- Pedaling Rate proportional to Pedal Speed for any specific length
Determinants of metabolic cost during submaximal cycling

J. McDaniel, J. L. Durstine, G. A. Hand, and J. C. Martin
Department of Exercise Science, University of South Carolina, Columbia, South Carolina 29208

How is metabolic cost influenced by:

- Pedaling rate
- Pedal speed
- Crank length
Methods

- 9 trained cyclists performed submaximal cycling
  - 145, 170, and 195mm cranks
  - 30, 60, 90% of lactate threshold
  - 40, 60, 80, and 100 rpm
  - Combination of 3 lengths and 4 rates = 12 pedal speeds

- Metabolic cost by measuring $\dot{V}O_2$ and $\dot{V}CO_2$

- Power and pedaling rate recorded with SRM
Metabolic Cost vs. Mechanical Power

$R^2 = 0.95$

Metabolic Cost (watts)

Mechanical Power Output (watts)

3 lengths
4 pedaling rates
12 pedal speeds
Metabolic Cost vs. Mechanical Power

\[ R^2 = 0.95 \]

Only 5% of variability not due to power output

5% remaining (residual)
Analysis of Model Residuals

$R^2 = 0.55$

55% of the remaining 5% is accounted by pedal speed.

2.7% of the total variation
Analysis of Model Residuals

$R^2 = 0.41$

Pedaling Rate (rpm) vs. Model Residuals (watts)

R^2 = 0.41
Analysis of Model Residuals

R² = 0.06

Model Residuals (watts)

Crank Length (m)
Improved Model: Power and Pedal Speed

Power and pedal speed accounted for 98% of the variability in metabolic cost for all subjects.

Individual predictions were even better: 99%.
Conclusion

- Crank length and pedaling rate influence metabolic cost and efficiency only by influencing pedal speed
- No direct effect of crank length
- Joint Powers?
Effects of Crank Length on Joint Specific Power during Submaximal Cycling
Barratt, Korff, Elmer, Martin   In review

- Fifteen trained cyclists
- Maximal isokinetic cycling trials
- 150, 165, 170, 175 and 190 mm cranks
- Pedaling rates of 90 and matched for pedal speed
Effects of Crank Length on Joint Specific Power during Submaximal Cycling
Barratt, Korff, Elmer, Martin   In review
Summary: Crank Length During Submaximal Cycling

- Power Output and Pedal Speed account for 98% of the variability in metabolic cost in this group of 9 cyclists.

- Of the remaining 2% variability, crank length accounted for 0.02% of total cost.

- No significant changes in joint power distribution.
Crank Length Summary

- Very small effect on maximum power
  - Significant only at extreme lengths
- No effect on metabolic cost (efficiency)
  - 145-195mm cranks
Good News

- Cyclists can ride the cranks they prefer without concern of decreasing efficiency
- Crank lengths can be chosen to meet other criteria:
  - Aerodynamic position (shorter)
  - Ground clearance (shorter)
  - Rehabilitation (shorter or longer)
  - Flexibility (longer)
Myth and Science in Cycling

- Pedaling Rate
- Crank length
- Pedaling Technique
- Non-round chainrings
Topic II: Pedaling Technique

- Efficiency
- Power
- Individual variability
Pedaling Technique: Premises

1. Elite cyclists have highly developed pedaling technique that makes them more efficient
2. Efficient pedaling requires pedaling "circles" or producing even torque throughout the cycle
3. Pedaling technique is highly individual
Pedaling Technique

- Google ”Pedaling Technique” 314,000 hits
  - Pedal circles, pull up, pull across the bottom, etc...

- Scientific evidence?
  - Coyle et al., 1991 Physiological and biomechanical factors associated with elite cycling performance
  - Korff et al., 2007 Pedaling technique and efficiency
  - Burnes et al., 2014 Cardiovascular Responses to Counter-weighted Single-Leg Cycling
Coyle et al., 1991

- Regional level cyclists and Elite cyclists (7-11 team and US National team)
- Elite cyclists pushed down harder and pulled up less
- Elite were significantly more efficient and had greater % slow twitch fiber

![Graph showing torque comparison between Elite and Regional cyclists]
The Coyle results were complicated by muscle fiber type.

What if the same cyclist used different techniques?

**Methods**

- Eight cyclists were instructed to pedal with four techniques:
  - Preferred
  - Circling
  - Pulling Up
  - Pushing

- Pedal Forces and metabolic cost were measured:
  - Index of effectiveness and evenness of torque distribution
  - Metabolic Efficiency
Crank Torque

- Cyclists followed the directions and significantly changed their pedaling technique
Index of Effectiveness

- Ratio of the force perpendicular to the crank to the total force
- Averaged over the entire cycle
Index of Effectiveness

- More force was perpendicular to the crank with pulling
- Pulling was more mechanically “effective”
Evenness of Torque Distribution

- Torque was distributed more evenly throughout the cycle with “pulling”
Efficiency

Pulling up was significantly LESS efficient!

7.4% LESS power for same VO$_2$
Single leg cycling

- 10 cyclists
- 40, 80 and 120 watts
  - Double leg
  - Single leg without counterweight
  - Single leg with counterweight

- Measured VO2, HR, MAP and blood flow to the legs
Both VO2 and HR are much greater when forced to pull up and pedal in circles.
Summary: Pedaling Technique and Efficiency

- Pulling up is significantly less efficient than pushing down.
- Data suggest that muscles that flex the leg are intrinsically less efficient.
- Pedaling is a leg extension / leg flexion task.
  - Spinal cord level programming.
Premise 3: Pedaling Technique is Individual
Premise 3: Pedaling Technique is Individual
Ankle Power

Pedal Power

Ankle Angle
Hip Power

Crank Angle

Hip Power

0 90 180 270 360
Take Home Message:
Pedaling Technique IS Highly Individual

- Similar Patterns at Pedal
- Different Patterns at Knee and Hip
- Implications for Fitters?
  - No One Fit for all?
  - Biomechanics for Fitting?
  - Stay open minded!
Summary: Pedaling Technique

- Elite cyclists DO NOT pull up more than regional level cyclists
- Pulling up is LESS efficient than preferred pedaling technique
- Pedaling is a basic leg extension / leg flexion action likely hard wired in the spinal cord
Myth and Science in Cycling

- Pedaling Rate
- Crank length
- Pedaling Technique
- Non-round chainrings
Non Round Chainrings

Fig. 462.

1895
Circular vs Non-Circular Chainring

Circular Chainring

Non-circular Chainring
Benefits

The OSYMERIC ring is not an oval nor an ellipse – it is a twin cam shaped to win. This patented design reduces the gear and the effort needed to get through what is commonly called the “dead spot” in everyone’s pedal stroke. Then it increases the usable gear during the power portion of the pedal stroke between the 1 and 5 o’clock positions of the crank so your body can take full advantage of its natural strength. This powerful tool can reduce lactic acid by 10% and increases power by 10% for anyone that uses them. With OSYMERIC chainrings installed properly on a bicycle, one can expect a gain of 7-10% watts. Interestingly the rings are most beneficial the closer you are to your personal anaerobic threshold. This can be easily confirmed with testing on an SRM, POWERTAP or Quarq power meters.
Why Q-Rings?

Q-Rings boost your performance by varying drivetrain resistance during pedaling in line with your legs natural strengths and weakness. They make better use of the strongest muscle groups (increasing positive work) and compensate for the weaker zones in the pedaling stroke (reducing negative work).

- Faster time-trials (TT), with an average improvement of 2%.
- Average increase of 6% in power.
- Reduce $O_2$ consumption and HR.
The Influence of Elliptical Chainrings on 10 km Cycling Time Trial Performance

Jeremiah Peiffer  
*Edith Cowan University*

Christopher Abbiss  
*Edith Cowan University*

### Table 1  Cycling economy, heart rate, and ratings of perceived exertion (RPE) measured during submaximal exercise at 150 W and 200 W using circular, elliptical\textsubscript{1} (offset 110\textdegree), and elliptical\textsubscript{2} (offset 100\textdegree) chainrings

<table>
<thead>
<tr>
<th></th>
<th>Circular</th>
<th></th>
<th>Elliptical\textsubscript{1}</th>
<th></th>
<th>Elliptical\textsubscript{2}</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>150 W</td>
<td>200 W</td>
<td>150 W</td>
<td>200 W</td>
<td>150 W</td>
<td>200 W</td>
</tr>
<tr>
<td>Economy (W·L\textsuperscript{-1}·O\textsubscript{2})</td>
<td>67.8 ± 3.2</td>
<td>73.0 ± 3.5</td>
<td>67.0 ± 2.5</td>
<td>72.5 ± 2.4</td>
<td>67.0 ± 2.4</td>
<td>73.0 ± 2.7</td>
</tr>
<tr>
<td>Heart Rate (bpm)</td>
<td>117 ± 12</td>
<td>132 ± 12</td>
<td>119 ± 12</td>
<td>134 ± 14</td>
<td>117 ± 12</td>
<td>132 ± 14</td>
</tr>
<tr>
<td>RPE</td>
<td>7.7 ± 1.7</td>
<td>8.8 ± 2.1</td>
<td>7.4 ± 1.7</td>
<td>9.1 ± 2.4</td>
<td>7.8 ± 1.8</td>
<td>9.0 ± 2.0</td>
</tr>
</tbody>
</table>

### Table 2  Sustainable power output and completion time measured during a 10 km cycling time trial using circular, elliptical\textsubscript{1} (offset 110\textdegree), and elliptical\textsubscript{2} (offset 100\textdegree) chainrings

<table>
<thead>
<tr>
<th></th>
<th>Circular</th>
<th>Elliptical\textsubscript{1}</th>
<th>Elliptical\textsubscript{2}</th>
<th>%Δ C-E1</th>
<th>%Δ C-E2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Output (W)</td>
<td>340 ± 30</td>
<td>342 ± 29</td>
<td>341 ± 31</td>
<td>0.67 ± 0.01</td>
<td>0.40 ± 0.02</td>
</tr>
</tbody>
</table>

*Note.* %Δ = Percent change; C-E1 = Circular vs. Elliptical\textsubscript{1}; C-E2 = Circular vs. Elliptical\textsubscript{2}.
Although the design of the Harmonic chainring was based on optimization analysis, comparison of the physiological response in this study did not translate into an advantage of the Harmonic over circular chainring during submaximal and maximal pedaling in trained cyclists.

### Table 2

Maximal values of physiological data measured during cycling with noncircular “Harmonic” and circular chainrings. Values are expressed as means (SD). No significant difference was observed between the two chainrings.

<table>
<thead>
<tr>
<th>Physiological data</th>
<th>Chainring</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Harmonic</td>
</tr>
<tr>
<td>$V_{E_{max}}$ (l min$^{-1}$)</td>
<td>168.1 (13.5)</td>
</tr>
<tr>
<td>$V_{O_{2max}}$ (ml min$^{-1}$ kg$^{-1}$)</td>
<td>59.5 (8.4)</td>
</tr>
<tr>
<td>$V_{CO_{2max}}$ (l min$^{-1}$)</td>
<td>4.80 (0.44)</td>
</tr>
<tr>
<td>$R_{max}$</td>
<td>1.16 (0.04)</td>
</tr>
<tr>
<td>$HR_{max}$ (beats min$^{-1}$)</td>
<td>190.5 (9.7)</td>
</tr>
<tr>
<td>$[La]<em>{i</em>{max}}$ (mmol 1$^{-1}$)</td>
<td>11.8 (1.7)</td>
</tr>
</tbody>
</table>
Chee Hoi Leong

C (Ecc = 1.0)  R (Ecc = 1.13)  O (Ecc = 1.24)
Non Round Chainrings

- **Study 1: Maximal Power – Pedaling Rate**
  - Inertial load 3s sprints

- **Study 2: Maximal Power and Biomechanics**
  - Isokinetic 3s sprints 60, 90, and 120 rpm

- **Study 3: Submaximal Cycling Biomechanics and Metabolic Cost**

- **Blind to the chain ring**
  - Cir 30%
  - Rotor 30%
  - Osymetric 90%
Crank Arm Orientation

- Chainrings were oriented such that the smallest chainring radii (minor axes) are encountered at the beginning phase of whole leg extension.

Martin and Brown 2009
Study 1: Maximal Cycling Power (N=7)

Pedaling Rate (rpm)

Power (watts)

- Round
- Osym: Close to sig.
- Rotor
Why Don’t They Improve Power?

- Assumption: Altering crank angular velocity will alter joint mechanics
- Cyclists use ankling action to alter joint mechanics
- The ankle joint path is highly non-circular already
Joint angle velocities during maximal cycling

![Crank Angular Velocity at 90 rpm](#)

![Knee Angular Velocity at 90 rpm](#)

![Ankle Angular Velocity at 90 rpm](#)

![Hip Angular Velocity at 90 rpm](#)
Joint angle velocities during submaximal cycling
Pilot Data (N=1)
Good News: They don’t seem to hurt
Bad News: They don’t seem to help
Just What Does Matter????

- Maximizing the power you can produce
- Minimizing the power you must produce
- Training and Skill

\[ R^2 = 0.98 \]
Maximizing the power you can produce

- Hard training to improve VO$_2$ max and Lactate Threshold for endurance
- Following a well-designed program built around sound training principles
- Increasing muscle mass and choosing the right pedaling rate / gear for sprint power
- **Proper bike fit = Comfort = Power**
  - **Confidence in position!**
- Proper nutrition and recovery
Minimizing the power you must produce

- Reducing aerodynamic drag
  - Body position and equipment
- Drafting
  - Cornering: Don’t leave gaps
  - Climbing: Important even on steep climbs
  - Cross winds: Find whatever draft is available
- Reducing braking
  - Energy lost during braking from 50 to 40 kph requires 93 watts for 30 s to regain
- Maintaining equipment to minimize friction
Questions?

Neuromuscular Function Lab