Cycling Biomechanics: Science to take your performance from zero to hero

W. Lee Childers PhD

The purpose of this lecture is to introduce myself to you
Let you know what is happening at ASU
Get the students of ASU and AUM together to start collaborating on research
Highlight research to help improve cycling performance

Purpose
• Introduction

My background is mechanical engineering.
My former career was an engineer on top fuel dragsters. It was fun but they explode a lot.
The human machine is far more interesting to me.

Purpose
• Introduction

My cycling experience begins designing land speed bicycles during engineering school, (not shown)
I’ve ridden around Europe, New Zealand, The US, and the Continental Divide
Raced for Georgia Tech in Cross Country mountain biking and Track
• At Georgia Tech, I built a lab to study cycling biomechanics.
• Our research was focused on how to improve the lives of people living with amputation.
• However, since my advisor and I both love performance, we did a lot of side projects to understand cycling performance.

• I am new faculty here at ASU’s new Prosthetics and Orthotics program
• We’re building a new lab here to study human movement, especially those with amputation.
• Students from ASU and AUM are here

• Research cannot be done without community support.
• If you are interested in volunteering as research subjects, email me
  lchilders@alasu.edu
Introduction

- Cycling Biomechanics
- The Pedal Stroke
- Effects of Position
- Project 96
- Modeling Performance

I’m going to tell the story of the 1996 Olympic Superbike program as an example of integrating science into bicycle design.

- The “Superbikes” developed for the ‘96 Olympic games were so advanced they were banned from competition.
- Lessons learned and technology developed from Project ‘96 are still applied today.
- Project ‘96 incorporated the same equipment we have here at ASU.
- Dr. Jeff Broker was the biomechanist for Project ‘96, he was a former student of my advisor, Dr. Robert Gregor, and invented the force pedals in our lab.

Bicycle/Rider System

- I think of the whole bicycle and rider as a system.
- The human machine has all these different muscles
- The position of the rider on the bicycle will define the operating lengths of those muscles

- This lab will study how and why people move.
- We will focus our research on how people use prosthetic and orthotic devices to move.
- Additional research will be conducted to study sport performance and mechanisms of injury.
- It is being renovated and updated with a new Vicon motion capture system. This is a special camera system used to track how people move and can be used for movie special effects.
• The heart of any cycling lab is a pedal system
• There are only seven of these systems in the world
  – one of those is here at ASU
• This system can measure forces about 3-axes and moments about 2 axes.

• The pedal information is combined with a camera system to track motion and EMG to measure when muscles are active
• This information is combined to give us a picture of how the person uses their muscles to energize the bicycle
• These techniques may also be used for walking, running, any other motion.

• Some light reading about cycling
A common misconception about cycling is you should concentrate on the pedal stroke and always direct forces perpendicular to the crank arm.

This is a view I had as an engineer but it is NOT correct.

The human machine has to account for all of the muscles, what they can do and how they can do it.

This means work done at the crank is NOT constant.

This is work done by both legs at the crank.

It is NOT constant.

The blue and magenta lines are power output for the right and left limbs throughout one pedaling cycle.

Note the large power impulse during the downstroke and the negative power produced by each limb during the upstroke.

This negative power production during the upstroke is the focus of a lot of training programs yet being negative isn't necessarily bad.
The Pedal Stroke

- "Pulling Up" during recovery not an efficient strategy
- Increase joint flexor EMG 1.1 – 3.4 times baseline - Morieux et al., 2008

• "Pulling Up" during recovery not an efficient strategy
• Increase joint flexor EMG 1.1 – 3.4 times baseline - Morieux et al., 2008

• Each leg weighs about 40 lbs and there is a lot of inertia associated with the legs spinning at 90 rpm.
• In order to “pull up” on the pedal, you have to overcome inertial/gravitational forces AND pull the pedal up faster than the opposite leg is pushing down.
• The muscles used in pulling up the pedal are smaller and not well designed for this.
• If you actively try to pull up, you will drastically increase energetic demand and fatigue these muscles very fast.

Pedaling Technique

- Over time, training in a specific discipline (like mountain biking) will change pedaling technique a little.
- What is more important is to look at pedaling as a motor skill.
- A motor skill is the ability to invariably maintain task performance in a variable environment. In other words, being able to quickly react and adapt to changes during a race.
- The more you train for a specific task, the better you become. In other words, ride your bicycle.

Pedaling Technique

- This shows the difference in muscle activation of highly trained triathletes, cyclists and novice riders. Note the cyclists have very little variability where as the triathletes and novices have a lot of variability.
- Triathletes train for multiple events and become a "Jack of all trades, master of none"
- Summary is variability is a key for performance may be something to focus on.
Bicycle Positioning

- Project ‘96 had to find the best positions for the cyclists to make power yet minimize wind resistance for the 4km Pursuit
- A key component of this is seat tube angle (STA)

Seat Tube Angle

- Effects muscle coordination
  - Childers et al., 2007
  - Silder et al., 2011
- The Rectus Femoris muscle has to increase activity in steep STA because it is shorter and short muscles have to work harder.
When you work harder, variability increases.

Project ‘96 was the first to identify this and use it to develop the Superbikes.

They varied position and looked at variability in pedaling forces at the top of the pedal stroke (when the rectus femoris is active).

This is the US team and Dr. Jeff Broker at the General Motors wind tunnel.

They went back and forth between the wind tunnel and the Olympic Training Center in Colorado Springs, CO to fine tune the design.

Then, each bicycle was made for each specific rider.

The results, the US team managed a Silver medal and although lacking in the 4km individual and team Pursuits, it was enough to scare the IOC so...

If you can’t beat it, ban it.

The bicycles are illegal to this day and now hang in museums.

One of the many technologies developed via Project ‘96 was advancements in computer modeling of cycling.
We developed our own computer model of cycling (based off the original work of Project ‘96) to investigate how to best spend our (college student budget) money to go faster.

Turns out it is just like Drag Racing, cost goes up with speed.

A lot of the baseline conditions for this model are presented in the article;


Aerodynamic drag is the major resistance to cycling.

At 30 mph (typical Pursuit speeds) this is 92% of the resistance on a wood velodrome.

On a rough, outdoor concrete velodrome, the rolling resistance of the tires is much larger so aerodynamics plays a smaller but significant role.

We built a model based of this equation.

The model is being reviewed now for publication in Medicine and Science in Sports and Exercise.

More details about the model may be found here;

– http://www.dicklanevelodrome.com/node/1037
The model does an incredible job of predicting speed based on power. The model output is in blue and the magenta is what actually happened at the track.

The model is calibrated to a standard error of +/- 0.14 m/s and can predict 4km Pursuit performance within +/- 3.7 seconds

You can use this model to predict performance based on doing different things.

The cost of going faster

- **Internal factors**
  - Interval training
  - Altitude training
    - “Sleep high, race low”
  - Caffeine
  - Doping
    - EPO or blood doping

The cost of going faster

- **External factors**
  - Shoe Covers
  - Aero helmet
  - Aero wheels
  - Aero frameset
  - Aerobars
  - Wind tunnel
  - Gruber Motor
    - “Mechanical Doping”

One way to go faster is through “internal factors” that would increase the cyclist’s ability to produce more power.

- Interval training (Jeukendrup & Martin, 2001)
  - Power increase of 5%
  - Cost assumed to be one month of coaching at $200/month
- Altitude training (Jeukendrup & Martin, 2001)
  - Power increase of 2%
  - Cost for an altitude tent = $2400
- Caffeine (Jeukendrup & Martin, 2001)
  - Power increase of 5% with 400 mg an hour before competition
  - Cost = $4.50 at Starbucks
- Doping (Eichner, 2007)
  - EPO
  - Power increase of 6% for one month regimen
  - Cost of EPO treatment for renal failure = $5000 per year
  - Assumed cost = $5000/12 or $417

Another way to go faster is to reduce aerodynamic drag

- Shoe Covers (adjusted from data in Kyle, 2003)
  - Reduction of ~150 grams in drag savings
  - Converts to a CDA reduction of 0.0073 m²
  - Cost = $30.00
- Aero helmet (adapted from Sidelko, 2007)
  - Reduces power requirement by 3.8%
  - Cost = $140.00
- Aero wheels compared to std. rim, 36 round spokes (Kyle, 2003)
  - HED jet 9 used for aero front wheel (data from HED website)
    - CDA reduction of 0.0056 m²
    - Cost = $900
  - Carbon flat disc used for rear wheel
    - CDA reduction of 0.0068 m²
    - However, the rear wheel is blocked by the frame and is adjusted by 0.5 to compensate (Jeukendrup & Martin, 2001)
    - Cost = $1100
• Aero frameset compared to round, steel tube bike
  • Assumed to be Felt and similar drag reduction to a Cervelo or Lotus (Jeukendrup & Martin, 2001)
  • CDA reduced 0.020 m²
  • Cost = $4440
• Aerobars
  • The modeled rider was already in an “aero” position so CDA was increased to 0.307 m² (Jeukendrup & Martin, 2001)
  • Cost = $180
• Wind tunnel
  • “Optimizing” position in a wind tunnel should reduce CDA by 0.029 m² (Jeukendrup & Martin, 2001)
  • Cost = $1000 for 2 hours in the A2 tunnel plus travel to NC
• Gruber Motor
  • This is the Motor assist system Cancellara was accused of using.
  • Claims increase in 130 watts, I used 130 watts in the model but my feeling is the actual benefit may be less.
  • Cost = $2400

<table>
<thead>
<tr>
<th>Item</th>
<th>Seconds saved in 3k pursuit</th>
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<tbody>
<tr>
<td>Everything</td>
<td>30.8</td>
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<tr>
<td>Aerobars</td>
<td>24.1</td>
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<tr>
<td>Wind Tunnel</td>
<td>18.2</td>
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<tr>
<td>Caffeine and Training</td>
<td>11</td>
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<tr>
<td>EPO</td>
<td>6.1</td>
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<tr>
<td>Interval Training</td>
<td>6.2</td>
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<tr>
<td>AEP</td>
<td>5.5</td>
</tr>
<tr>
<td>Altitude Tent</td>
<td>5.0</td>
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<tr>
<td>Shoe Covers</td>
<td>4.9</td>
</tr>
<tr>
<td>Aero Frame</td>
<td>4.5</td>
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<tr>
<td>Aero/Disc Wheelset</td>
<td>3.8</td>
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<td>Altitude Tent</td>
<td>2.8</td>
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<tr>
<td>Aero/Disc Wheelset</td>
<td>2.3</td>
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<tr>
<td>EPO</td>
<td>2.3</td>
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<tr>
<td>Shoe Covers</td>
<td>2.2</td>
</tr>
<tr>
<td>EPO</td>
<td>2.1</td>
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The cost of going faster

Note – if simply summed, everything would be a 53 second time savings

• You can’t simply add the seconds saved because things interact.
• The item “everything” represents what would happen if you combined everything in the red box.
• If you simply added everything, you’d “save” 53 seconds. Yet when you adjust for everything in the model, it calculates a time savings of 30.8 seconds. This is due to how all the variables interact within the model.
The cost of going faster

<table>
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<td>Shoe Covers</td>
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<td>Aerosols</td>
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<td>Skinuit</td>
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<td>Everything</td>
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<tr>
<td>Disc Rear Wheel</td>
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</table>

Note – The cost of Everything is ~$11,000.

- Just because the wind tunnel may shave 18.2 seconds, it does cost $1000 for the service. For those of us on a budget, it may be a good idea to look at things from a cost/benefit perspective or $ spent per second saved. Low number = good

Modeling Cycling with and without amputation

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- A person with a transtibial amputation cannot make as much power as someone with intact limbs
- BUT, the prosthesis is more aerodynamic
- Could the aerodynamics of the prosthesis actually provide Parathletes an advantage during the Pursuit?

We modeled a world record Pursuit and then reran the model as if Bobridge had an amputation.

- We used lots of experimental data from my prior research to adjust the power output of Bobridge.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Abbreviation</th>
<th>Type</th>
<th>Frontal Area (m²)</th>
<th>CDA</th>
<th>Angle</th>
<th>Power Factor</th>
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<tbody>
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<td>TTAX</td>
<td>GP</td>
<td>FR</td>
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<td>0.086</td>
<td>0.015</td>
<td>21.45</td>
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<td>GP</td>
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<td>FR</td>
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<td>FR</td>
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<td>FR</td>
<td>0.424</td>
<td>0.080</td>
<td>0.010</td>
<td>7.06</td>
</tr>
</tbody>
</table>
Using a prosthesis will NOT provide you an advantage.

Brian Hicks is just that much faster than you.

Questions?

Thank You
- Cindy Laporte
- Hank Williford
- Arletha Willis
- Regina Adams
- Jesse Adams
- Brenda Dawson
- Dan Guide
- Chad Duncan
- Dean Chesbro
- Lindsey, the Vicon Commander