BIOMECHANICS OF CYCLING FOR BIKE-GEEKS
Going from Zero to Hero with the turn of a Hex Key

W. Lee Childers
PhD candidate

Robert Gregor PhD

Introduction
• General Overview
• Human System
• Performance
• How to study Biomechanics
• The Pedal Stroke
• Effects of Position
• Project 96
• Team Pursuit

Team Pursuit is the Olympic Event
We will Concentrate on because it was optimized as part of project '96 Pursuit is a 4-man team
The lead rider will pull the team later the lead rider will rotate to the back.
Cycling represents integration of man and machine.

The human physiological system must work with the mechanical (Bicycle) system in order to perform.

The saddle, handlebar and pedals create the contact points for the body.

That in turn determines the skeletal alignment and joint range of motion for the rider.
Muscles are attached to the skeleton so position will affect the length of these muscles as they cross their respective joints.

Muscles produce different forces at different length and contraction velocities.

The brain and spinal cord needs to take the properties and training state of each muscle in order to figure out how to coordinate these muscles to turn the cranks.
In this case, the nervous system decides to activate a large thigh muscle to generate mechanical energy that will eventually turn the crank.

The nervous system will then have to coordinate additional muscle activation to transfer that energy into the crank.

This resolves as a force (orange arrow) at the pedal that will turn the crank.
Another important thing to remember is the muscles and joints will send information back to the nervous system to help shape the next set of motor commands and allow the person to adjust to change in their environment whether you're riding a bike or running, walking, etc.

Resistance to Overcome

- Aerodynamic Drag
- Gravity
- Energy to Accelerate
- Rolling Resistance
- Drivetrain Resistance

The bicycle rider system must overcome resistance in order to move

In our case of team pursuit, aerodynamic drag will be the largest force to overcome
To reduce drag, these riders adopt different positions. However, these positions will affect muscle lengths for muscles around the hip joint, compromising the person’s ability to produce power. Project '96 tried to find the best balance between power output and aerodynamic drag.

Biomechanics study the last three variables trying to provide a detailed picture of how this person is performing a task.
We use a special set of camera that track markers on someone's joints, providing the researcher with data on how the person is moving.

We use a special set of pedals that measure force designed by Jeff Broker (project '96 and former student of Dr. Gregor)
We combine these data with Newtonian physics to solve the inverse dynamics problem and provides the researcher with information about the forces and moments (torques) at each joint.

Example of a knee moment x-axis is from 0–360 degrees of crank rotation.

We also measure muscle activation that tells us when a muscle is "on" or "off". Combining all these data provides insight into how the nervous, muscular, and skeletal systems are working together to turn the bicycle cranks.
What happens during the pedal stroke

Childers et al., 2009. Pros Orthot Int. 33:256-271.

While riding one day, another rider told me this... This idea of a perfectly circular pedal stroke does not have any scientific evidence supporting it.

This graph shows what some people believe would be an ideal pedal stroke.
The Pedal Stroke

This is total crank power showing how people really pedal a bicycle.

This shows the power output for each leg. Note the portions of negative power production.

The following slides will break the pedal stroke up into quadrants.
The Pedal Stroke

This shows the top of the pedal stroke. Lines in red indicate muscles that are active.

The power phase constitutes about 90-95% of the total power output.
The recovery phase does not have much muscle activity. Also the ascending limb cannot lift faster than the pedal being pushed up into it by the opposite descending limb.

Recent research explored "pulling up" type pedal technique and showed this may not be an effective strategy for sub-maximal, steady-state cycling.

There are slightly different pedal techniques for each cycling discipline. Mountain bikers have the smoothest, possibly due to the loose environment they must perform in.
Another important aspect of learning how to pedal is that it takes training. Variability in muscle activation is less in trained cyclists.
Seat Tube Angle

Power vs. Crank Position

Crank Position (deg)

Crank Angle (deg)

100 200 300 400 500

Power (watts)

-200 -100 0 100 200 300 400 500

Project 96; The US Olympic Superbike Program

Project 96

- Began in 1992
- Key Figures
  - Chester Kyle PhD
  - Jeff Broker PhD
  - Edmund Burke PhD
- Combine Science with Cycling to create a Bike/Rider Combination for the ’96 Olympics

Pictures are of the Obree and Superman positions that showed the importance of aerodynamics for time trial performance
Both positions were banned for competition and the subsequent rules provided additional challenge for the project '96 scientists.

A radical new and aerodynamic "superbike" was developed for the US cycling team.

Dr. Broker used force pedals to analyze the cyclist's pedaling technique in different positions to determine the best compromise between aerodynamic/legal positions and the cyclist's ability to produce power about the crank center.
This was combined with wind tunnel testing

A saving of 2.3 seconds could mean the difference between medal or no medal
They developed equations to predict power requirements for individual pursuit

\[ P = K(0.00953 M V + 0.0077V^2 + K_t(A_f)0.007551V^3) \]
\[ A_f = 0.0293 H^{0.725} M^{0.425} + 0.0604 \]

- \( P \) = Power (Watts)
- \( K \) = Track Condition Constant (Basset et al. 1999)
- \( M_t \) = Total Mass (kg)
- \( V \) = Velocity (kph)
- \( K_t \) = Aero Factor (Basset et al. 1999)
- \( A_f \) = Calculated Frontal Area
- \( H \) = Height (m)
- \( M \) = Mass (kg)

But team pursuit was different and would require additional testing

So they stuck the whole team in the wind tunnel.
Then out to the track for field testing. With all of this data they were able to optimize rider order for the team pursuit.

After 4 years of work, they accomplished a lot and much of their work still influences bicycle design and performance evaluation.

But how did they actually do in the Olympics?
We were beaten by the French.

Project 96

Gold: France (4:05.930)
Silver: Russia (4:07.730)
Bronze: Australia (4:07.570)
USA 6th (4:12.510)

Why? Bikes so aerodynamics, the riders behind the lead couldn't get a good draft.

Project 96

• The bikes were too Aerodynamic
• Athletes not adjusted to bikes
• Athletes were over-trained

And then the Superbikes were banned from future competitions
Position alone won't take you from zero to hero, it is a combination of several factors. Better performance also requires lots of training. If you want to get better, riding your bike!... Ride your bike!

Thank you

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Cycling Biomechanics Laboratory