Objectives

- Review basic considerations about modeling in science/biomechanics
- Define ‘optimisation’ in mathematical terms
- Basic considerations on sprinting biomechanics
- Learn about kinematic descriptors in sprinting
- Learn about kinetic descriptors in sprinting
- Overview over Cricket rules and biomechanics
- Learn about the use of simulation models in cricket bowling
- Research assisted design of Cricket boots

Contents

1. About models (as relevant to biomechanics)
2. Define ‘optimisation’ in mathematical terms
3. Apply the concept ‘optimisation’ to sports on various levels/examples
   - Sprinting
   - Execution of cricket bowling technique
   - Design of a cricket shoe
What is a model?
A theoretical construct that represents something (reality), with a set of variables and a set of logical and quantitative relationships between them.

Characteristics of model:
- Reduction / simplification
- Mapping / representation
- Subjectivation / individualisation
- Pragmatism

What is a model?
A model is not reality!
It is aimed at understanding fundamental principles, laws, processes.
It can only be validated by applying it to ‘practice’ (experiments):
- does it explain past observations?
- does it explain future observations?

What is a model?
Statistical (black box) - probabilities
Physical models - simple representations
Causal/conceptual models - relationships
Models in biomechanics

Mathematical models – deterministic
- inverse dynamics ('external')
- forward dynamics ('internal')
- quasi static
- mixed

Optimization

Mathematical definition:
Given: a function \( f : A \rightarrow \mathbb{R} \) from some set \( A \) to the real numbers
Sought: an element \( x_0 \) in \( A \) such that
\( f(x_0) \leq f(x) \) for all \( x \) in \( A \)

most simple example:
\[
\min_{x \in \mathbb{R}} x^2 + 1.
\]

What if: \( f = f(x, y, t, I, ...) \)??

Biomechanics of Sprint Running
(Data from: acceleration phase!)

Uwe Kersting & Joe Hunter
PhD, CSCS, SESNZ Accredited

Bruce Pulman Park
Papakura

Department of Sport and Exercise Science
Overview

Phases in a sprint race

Step length and step rate (kinematics)

External forces acting on a sprinter (kinetics)

Sprint Competitions WCA 1997

Six LAVEG® Sport Systems

Speed Measurement

Greene, final run

raw
Phases in a 100 m Race

- Start
- Acceleration
- Maximal Velocity
- Deceleration

Speed Measurement

Greene, final run
- raw
- filtered

Velocity (m/s)

Race section
0-10 m, 10-20 m, 20-30 m, 30-40 m, 40-50 m, 50-60 m
Step Length and Step Rate (kinematic descriptors)

Definition: Step Length

Step length (m)

Definition: Step Rate

Step Rate (Hz) = \( \frac{1}{\text{Step time}} \)
Phases in a 100 m Race

Start → Acceleration → Maximal Velocity → Deceleration

Importance of Step Length and Step Rate

Mann et al. (1985): “direct performance descriptors”

\[
\text{Sprint velocity (m/s) } = \text{ step length (m) } \times \text{ step rate (Hz)}
\]

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>11.0 m/s</td>
<td>2.50 m</td>
<td>4.5 Hz</td>
</tr>
<tr>
<td>11.3 m/s</td>
<td>2.50 m</td>
<td>4.5 Hz</td>
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A weakness might be in one or the other factor...

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<tbody>
<tr>
<td>11.0 m/s</td>
<td>2.75 m</td>
<td>4.0 Hz</td>
</tr>
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Step Length and Step Rate at Max. Velocity

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<tr>
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</thead>
<tbody>
<tr>
<td>Sprint Velocity (m/s)</td>
<td>Step Length (m)</td>
<td>Step Rate (Hz)</td>
<td>Race Section (m)</td>
</tr>
<tr>
<td>Elite NZ male</td>
<td>10.5</td>
<td>2.33</td>
<td>4.5</td>
</tr>
<tr>
<td>Ben Johnson*</td>
<td>11.8</td>
<td>2.44</td>
<td>4.8</td>
</tr>
<tr>
<td>Carl Lewis*</td>
<td>11.8</td>
<td>2.53</td>
<td>4.7</td>
</tr>
</tbody>
</table>

*1987 World Champ. 100 m Final.

Source: Moravec et al. (1988)
Which factor is more important?

Mero et al. (1981): “...[step] rate has a more decisive role than [step] length.”

Weyand et al. (2000): downplayed the importance of rapid repositioning the limbs


Above average step length – 2.25 m  Good step rate – 4.8 Hz

Relationship among Step Length, Step Rate, and Sprint Velocity (Joe’s data)

Results

<table>
<thead>
<tr>
<th>Name</th>
<th>Country</th>
<th>Time</th>
<th>RT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greene</td>
<td>(USA)</td>
<td>9.86</td>
<td>0.134</td>
</tr>
<tr>
<td>Bailey</td>
<td>(CAN)</td>
<td>9.91</td>
<td>0.145</td>
</tr>
<tr>
<td>Montgomery</td>
<td>(USA)</td>
<td>9.94</td>
<td>0.134</td>
</tr>
<tr>
<td>Fredericks</td>
<td>(NAM)</td>
<td>9.95</td>
<td>0.129</td>
</tr>
<tr>
<td>Boldon</td>
<td>(TRI)</td>
<td>10.02</td>
<td>0.123</td>
</tr>
<tr>
<td>Ezinwa</td>
<td>(NGR)</td>
<td>10.10</td>
<td>0.135</td>
</tr>
</tbody>
</table>
• Two different patterns of step frequency development were identified.

• Step length does not show such clear grouping.

• Both parameters do not show a relationship with the resulting time.
Other factors:
Body mass of sprinters

Sprinters are the heaviest of all track athletes

<table>
<thead>
<tr>
<th></th>
<th>1967 Olympic Games</th>
<th>1996 Aussie Institute of Sport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>72 kg</td>
<td>76 kg</td>
</tr>
<tr>
<td>Females</td>
<td>56 kg</td>
<td>58 kg</td>
</tr>
</tbody>
</table>

Sprinters are muscular, lean, but not excessively heavy

We may conclude

Maybe it is simplistic to think that one factor is more 'important'

We also need to consider:
- phase of a race
- stature (leg length, mass, inertia)
- strength and power abilities
- influence of past training
- negative interaction between step length and step rate

An athlete-specific optimal combination of step length and step rate might be best

External Forces
Acting on a Sprinter

(kinetic descriptors)
External forces acting on a sprinter

- Gravity: 4 % Body weight
- Wind Resistance: 4 % Body weight
- Ground Reaction Force: 400 % Body weight

Wind resistance: significance

- Tailwind of 2 m/s: 0.1 s advantage for 100 m, ~1 m advantage for 100 m
- Altitude (Mexico City 2,250 m): 0.07 s advantage for 100 m, ~0.7 m advantage for 100 m

Minimising wind resistance

- Shaving the head
- Wearing tight, smooth clothes
- "Smoothing" the laces
- Suits developed based on WCA1997 data

Possible result: 2 % decrease in drag force
- 0.01 s advantage for 100 m
- 0.1 m advantage for 100 m
Methods

28 male athletes
sprints, 25 m in length
GRF and kinematic data collected at the 16 m mark
Calculated variables
  Relative impulses (mean of three trials)
  Sprint velocity (mean of three trials)

Bivariate regressions

Relative braking impulse \rightarrow Sprint velocity
Relative propulsive impulse \rightarrow Sprint velocity
Relative vertical impulse \rightarrow Sprint velocity
Results: relative braking impulse

![Graph showing relative braking impulse vs sprint velocity.](image1)

$r = 0.19$

Results: relative propulsive impulse

![Graph showing relative propulsive impulse vs sprint velocity.](image2)

$r = 0.75^{***}$

Results: relative vertical impulse

![Graph showing relative vertical impulse vs sprint velocity.](image3)

$r = 0.49^*$
Conclusions
Faster sprinters produced:
- high magnitudes of relative propulsive impulse
- moderate magnitudes of relative vertical impulse

Multiple Regression Approach
Relative braking impulse
Relative propulsive impulse
Relative vertical impulse
Sprint velocity

Results: multiple regression
Relative propulsive impulse,
$R^2 = 0.56, P < 0.001$
Relative braking impulse,
$R^2 = 0.64, P < 0.05$
Relative vertical impulse was not significant
Conclusions revisited

Faster sprinters produced:
- higher magnitudes of relative propulsive impulse
- moderate magnitudes of relative vertical impulse
- lower magnitudes of relative braking impulse

Simulation models

forward dynamics approach to optimize running strategy for individual athletes ???

Such a model is not available
but we applied one to cricket bowling

Cricket
(As Explained to a Foreign Visitor)

You have two sides, one out in the field and one in.

Each man that’s in the side that’s in goes out and when he’s out he comes in and the next man goes in until he’s out.

When they are all out the side that’s out comes in and the side that’s been in goes out and tries to get those coming in out.

Sometimes you get men still in and not out.

When both sides have been in and out including the not outs,

That's the end of the game.
**Cricket vs Baseball**

- Played in middle of Oval
- Played on Diamond
- Ball can be hit in any direction
- Ball must be hit between 1st and 3rd Base

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**Fast Bowlers**

- Many Techniques, Different Strengths
- Tall, Lean, Flexible

- Sites of Injury
  - Knees
  - Toes
  - Heel
  - Back
  - Ankle
  - Shoulder

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**The back injury toll of cricket**

- Bowling mechanics and back injuries

  Spondylolysis, disk abnormalities and muscle injuries (65%)  
  
  (Elliot, 2000)

- Kinematic predisposing factors:
  - Separation angle
  - Counterrotation
  - Shoulder alignment at BFC

  (Burnett et al., 1995)

  (Elliott, 2000)

  (Portus et al., 2000)
Alignments Definition

Data analysis

Background

Twisting and bending of the spine under high compressive loads at FFC!

Comprehensive biomechanical testing:
- Kinematics
- Ground reaction forces
- Three dimensional analysis, full body model ...

Question: Do 'common' kinematic measures reflect what is happening at the spine?
Why models?

Motivation: The back problem in Cricket

Approach: 15 segment three dimensional rigid body model in Mathematica (Wolfram Research Inc., V. 3.0)

Bowling continuum

Statistical relationships of injury and CR

<table>
<thead>
<tr>
<th>Study</th>
<th>Shoulder Counter Rotation</th>
<th>Correlation Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foster et al. (1989)</td>
<td>Less than 10°</td>
<td>No reported case of lower lumbar injury in sample.</td>
</tr>
<tr>
<td>Elliott et al. (1992)</td>
<td>Greater than 20°</td>
<td>Progression of disc degeneration and pain.</td>
</tr>
<tr>
<td>Burnett et al. (1996)</td>
<td>Greater than 30°</td>
<td>Increased risk of sustaining disc abnormality.</td>
</tr>
<tr>
<td>Foster et al. (1989)</td>
<td>Greater than 40°</td>
<td>Increased risk of abnormal radiological features of lower lumbar vertebrae.</td>
</tr>
<tr>
<td>Elliott et al. (1992)</td>
<td></td>
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</tr>
</tbody>
</table>

Forward solutions model

4 athletes analysed so far:
- ad hoc modifications (actions [=torques] around individual joints)
- no GRF included so far Take-off to BFC (pre-delivery leap)

Results:
Animations
FRONT Bowler 1
TOP Bowler 1
Results:
Reduction of separation angle at BFC from
30 - 40 deg down to 0 - 3 deg
Main modifications: front arm action + front leg
trunk side flexion
‘Out of plane’ movements
Qualitative comparison with ‘odd’ solutions of premiere
bowlers (who didn’t get injured) matches up

Example:
Bob Willis at BFC
Head well inside front arm
Front arm abducted and flexed
Front leg adducted
Rear foot straight
Hips elevated
Shoulders could be more elevated
Orthodox type of action for very
open shoulder alignment to
minimise CR
No straight line alignment

Ground Reaction Forces
Have been described but no substantial data
base existent (LCS)
Ground Reaction Forces

Forces LCS

Fzmax Fymin

Force component

Fz [BW]

RF striker

FF striker

Forces SCS

-Fzmin FSxmax

Force component

Fz [BW]

RF striker

FF striker

Bowling footwear

Players Modifications

Toe slamming into end of shoe
- Cut holes in toes
- Relieve Pressure
- Prevent or at least delay losing toe-nail

Important to reduce anterior shift within shoe
Players' Modifications

Needed: an optimized shoe → Result

Acknowledgements

New Zealand Cricket
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The Biomechanics Lab Team