Double amputee sprinting
– biomechanical challenge, mechanical advantage or just a different kind of locomotion

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Sprinting and jumping with prostheses - 2008

Sprint (100m): < 11 s

Long jump: > 6.00 m (6.50 m)
World record 100m TT44  Transtibial male

Year

sec

13.5
13
12.5
12
11.5
11
10.5
10

1990

Carbon sprint foot

Sprint Flex Modular IV: Cheetah
• SACH (1950)

• Seattle (1970-1980)

• Flex-Foot (1984)
Energy return

SACH FOOT

31%

SEATTLE FOOT

52%

FLEX FOOT

84%

Ankle joint in WALKING: 240 %
Energy return: running

Roy et al. 2006
At a running speed of 7,5 ms\(^{-1}\) (knee disarticulation sprinter)

Energy loss: 19.3%
Run-up speed: 7.04 m/s
Oscar Pistorius, * November 22nd, 1986

without fibulae, calcanei and lateral foot rays amputated at 11 months

walking on prostheses
various sports activities in adolescence

since 2004 sprinting on blades

**Olympic Finals** *(2004 Summer Paralympics)*:
- 100 m, Bronze
- 200 m, Gold

**World Finals** *(2006 Paralympic World Cup)*:
- 200 m, Gold
- 400 m, Gold

**Olympic Finals** *(2008 Summer Paralympics)*:
- 100 m, Gold
- 200 m, Gold
- 400 m, Gold
Competing with able bodied athletes

Rome 2007: 2nd in Golden League Meeting Race

Plan to start in Beijing Olympics 2008

IAAF rule 144.2:
“...any technical device that incorporates springs, wheels or any other element that provides a user with an advantage over another athlete not using such a device"
Comparison of sprinting biomechanics of Pistorius and able bodied athletes (same level)

... in the phase of maximal constant running speed
Methods - Subjects

<table>
<thead>
<tr>
<th>Oscar Pistorius</th>
<th>5 able bodied sprinters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.85 m</td>
<td>1.88 m</td>
</tr>
<tr>
<td>83.3 kg</td>
<td>78.6 kg</td>
</tr>
<tr>
<td>400 m: 46.56 sec</td>
<td>400 m: 46.5 – 49.26 sec</td>
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<tr>
<td>Cheetah (Össur)</td>
<td>spikes</td>
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</tbody>
</table>
Model

- Marker placement on the artificial limb according to anatomical positions
- Blade modelled as a torsion spring
Mass

Stump, socket, blade: 3,0 kg
Shank, foot, shoe: 5,8 kg

Moment of inertia (resp. knee)

Stump, socket, blade: 0,24 kgm²
Shank, foot, shoe: 0,51 kgm²
The lower moment of inertia of the swing leg of OP,

• the smaller amount of mechanical (muscular) work in the swing,

• the less energy for the swing.
Linear stiffness: 39 kNm\(^{-1}\)

Hysteresis: < 10\%
Ground reaction forces (speed > 9 ms\(^{-1}\))

- less CM lift, less neg. mechanical work (23.4 vs 52 joules)
- less (horizontal) braking and acceleration (CM)

![Graph showing ground reaction forces](image)
Joint reaction moments

RIGHT ANKLE

Net joint moment [Nm/kg]

very high reaction moments in the prosthetics (bending moment)
Joint reaction moments

LEFT KNEE JOINT

Net joint moment [Nm/kg]

Time stance phase [%]

Extension

Flexion

-8
-6
-4
-2
0
2
4
6
8

0 20 40 60 80 100

OP
Mean contr.
SD contr.
Joint reaction moments

LEFT HIP JOINT

Relatively low reaction moments at knee and hip joints for OP

Time stance phase [%]

Joint moment [Nm/kg]
Mechanical power, ankle joint

RIGHT ANKLE JOINT

Power [Watt/kg]

OP
Mean contr.
SD contr.

Time stance phase [%]

0  20  40  60  80  100

-40
-30
-20
-10
0
10
20
30
Mechanical work, ankle joint

**RIGHT ANKLE JOINT**

Work [Joule/kg]

Time stance phase [%]

- Absorption
- Generation

- OP
- Mean contr.
~ 100% more work done in the prosthesis than in healthy lower leg

Energy dissipation (loss)
O. Pistorius: 8%
Healthy controls: 40%
Mechanical power, knee joint

LEFT KNEE JOINT

Power [Watt/kg]

Time stance phase [%]
Summary

• Lower GRFs when sprinting with Cheetah prostheses.

• Much higher load (moment) in the blade compared to ankle joint.

• Hip and knee are much less loaded when sprinting with Cheetah prostheses.
Summary

• Majority of work done in blade (without muscular work).

• Blade returns elastic energy up to 92% (< 10% dissipated).

• … ankle joint about 60% (~ 40% dissipated).

• Different kind of locomotion.

  (with less muscular work and lower metabolic costs (?))
Metabolic capacity

• submaximal 400m race, VO2 consumption
400m race simulation - VO2 uptake

O. Pistorius: 51.3s
Controls: 52.18s (50.5 – 55.4s)

lower oxygen uptake, about the same speed
• Running of a double transtibial amputee using dedicated prostheses is biomechanically different from sprinting of able bodied athletes.

• Majority of work done in blade (without muscular work and fatigue) driven by the total body kinetic energy.

• Blade returns elastic energy up to 92%.  
  … sound ankle joint about 60% (in sprinting).

• Less muscular work is required at knee and hip joint.

• Different kind of locomotion at lower metabolic cost.
Double amputee sprinting

- is a biomechanical challenge
“People have always thought the human body is the ideal. It's not.”

Hugh Herr, MIT Boston double transtibial amputee expert witness for Pistorius
“I would like to challenge the biomechanics community to develop prostheses that will produce world records in many track and field disciplines. It should not be too difficult.”

Benno M. Nigg
University of Calgary
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