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Modelling human endurance: Power laws vs critical power

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Outline

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Background
- Modelling human endurance
- Hyperbolic/Critical-power model
- Power-law model

Hyperbolic/Critical-power vs Power-law model
- Time to exhaustion at different powers
- Large data studies
- Summary

FTP

Summary

Modelling human endurance

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Why do we care?

Modelling human endurance

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Why do we care?

- **Predict** performance over a untested duration

Modelling human endurance

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- **Predict** performance over a untested duration
- **Assess** fitness

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- **Optimise** pacing/race strategies

Modelling human endurance

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Why do we care?

- **Predict** performance over a untested duration
- **Assess** fitness
- **Optimise** pacing/race strategies

What approaches are there?

Outline

Hyperbolic/Critical-power model

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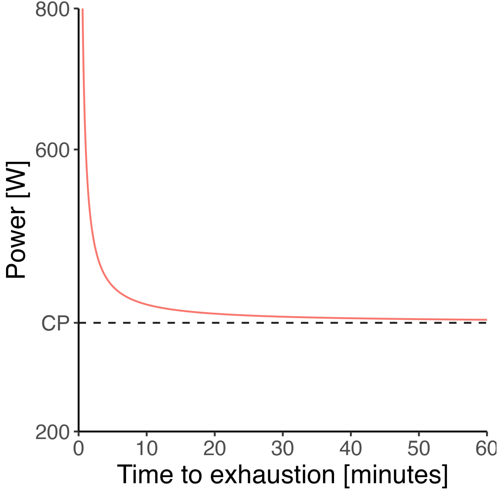
What do **CP** and **W'** imply?

Hyperbolic/Critical-power model



Parameters

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CP - Critical power

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CP - Critical power
W' - The finite amount of work that can be done above CP

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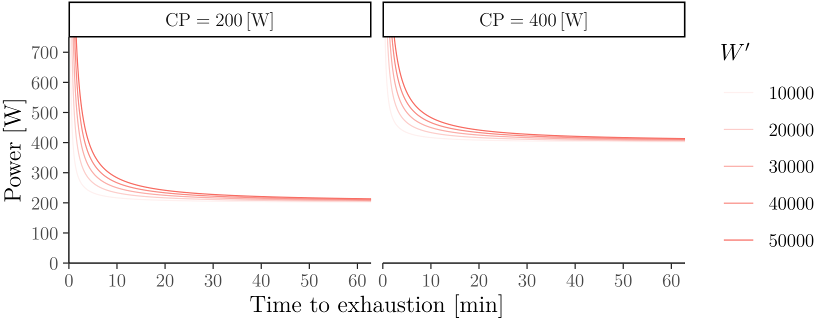

History

Hill (1925); Jones et al. (2019); Monod and Scherrer (1965)

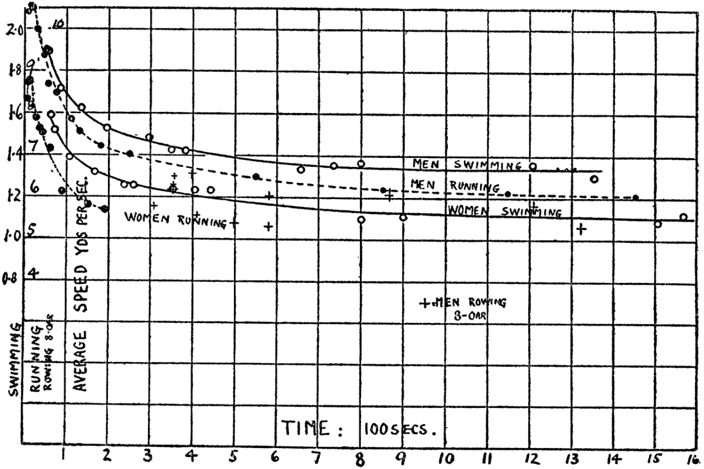

Figure: World records across different athletes (Hill, 1925)

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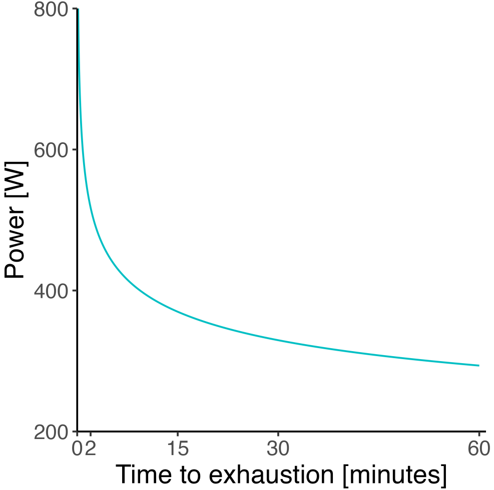
Power-law model



Parameters

Speed, $\boldsymbol{S} > 0$, in cycling the theoretical 1 second power output

Parameters

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Speed, $\boldsymbol{S} > 0$, in cycling the theoretical 1 second power output

Endurance, $0 < \boldsymbol{E} < 1$, governs how quickly the power–duration curve decays

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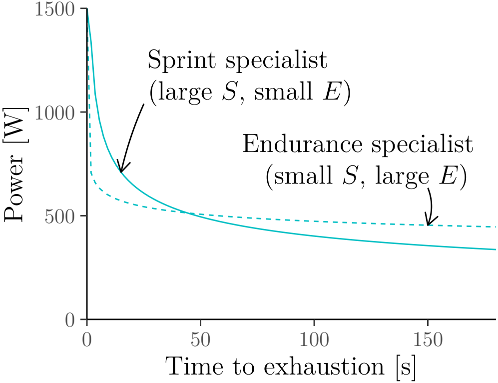

History

Kennelly (1906); Riegel (1981)

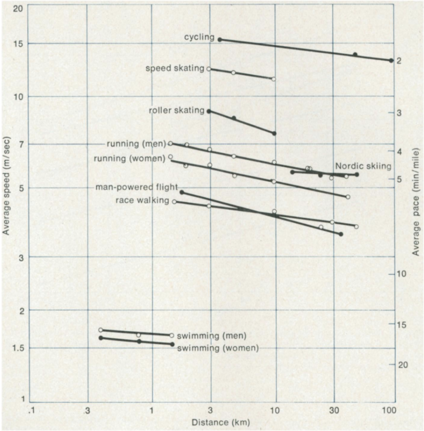

Figure: World records across different athletes from multiple sports (Riegel, 1981)

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Power–duration data

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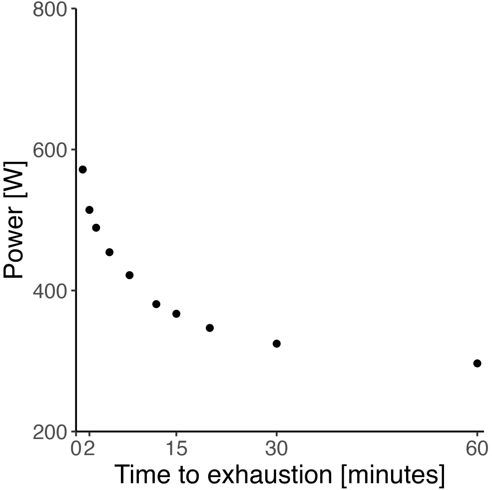

Hyperbolic/Critical-power model

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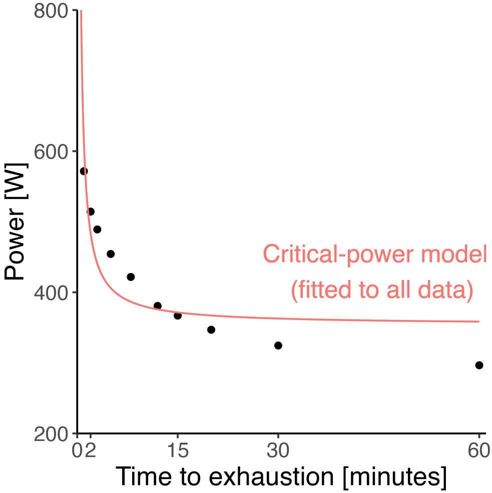

Figure: Fits poorly when applied to all data

Hyperbolic/Critical-power model

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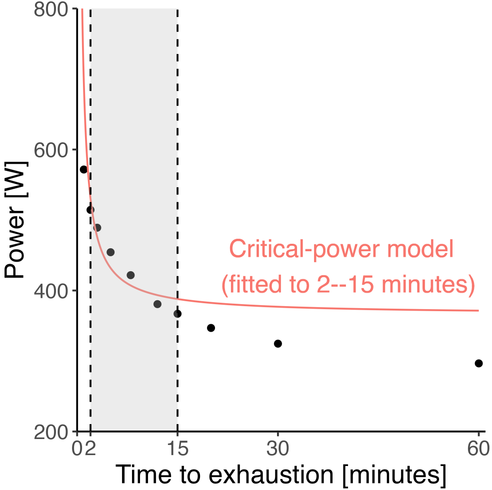

Figure: Fits reasonably when applied to 2–15 minutes

Hyperbolic/Critical-power vs Power-law model

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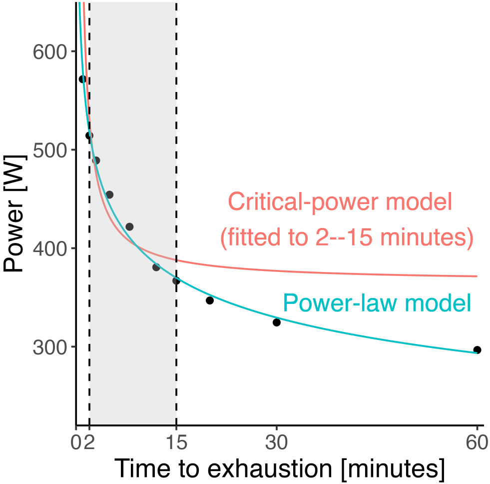

Figure: Power-law model fits better

Medium durations

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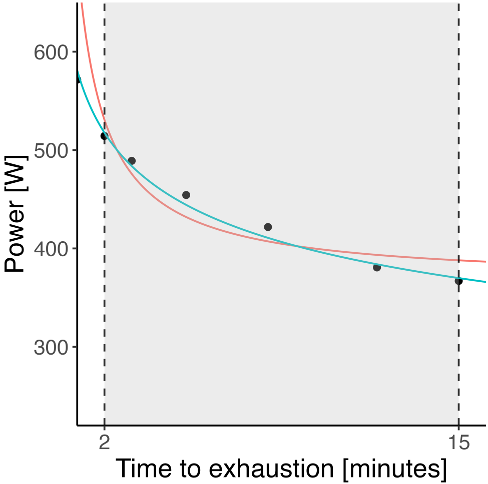

Medium durations

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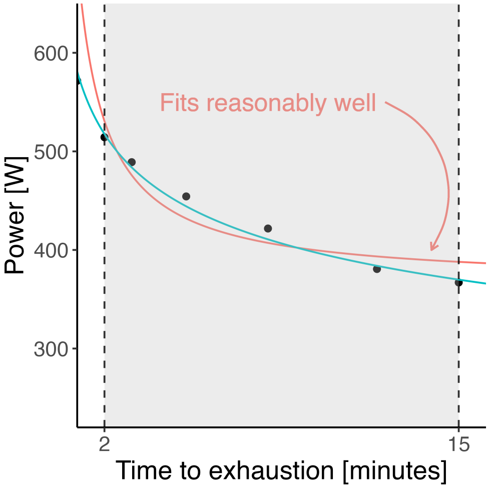

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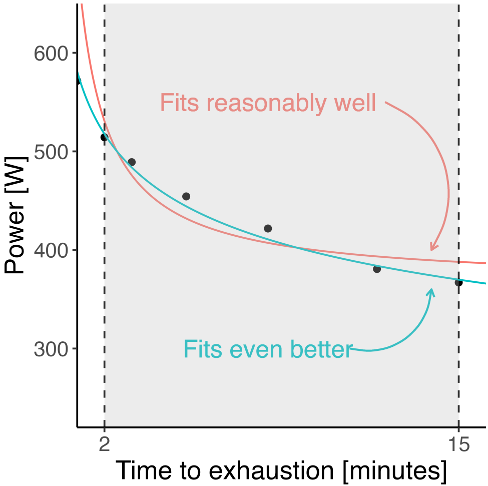

Short durations

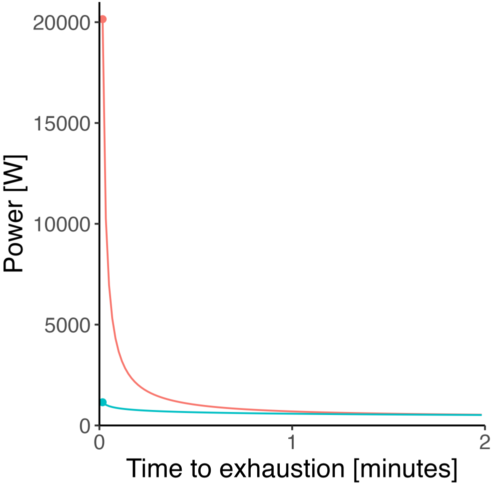

Figure: Power sustainable over 1 second

Short durations

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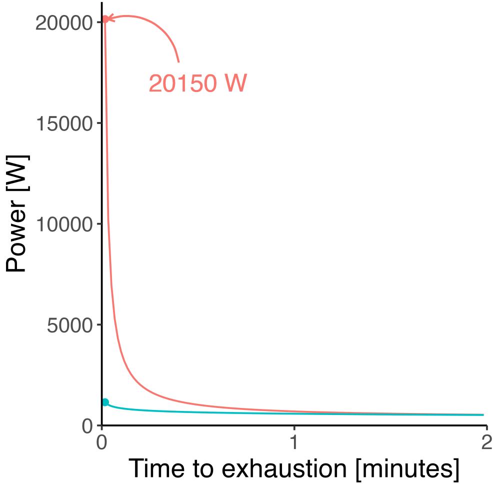

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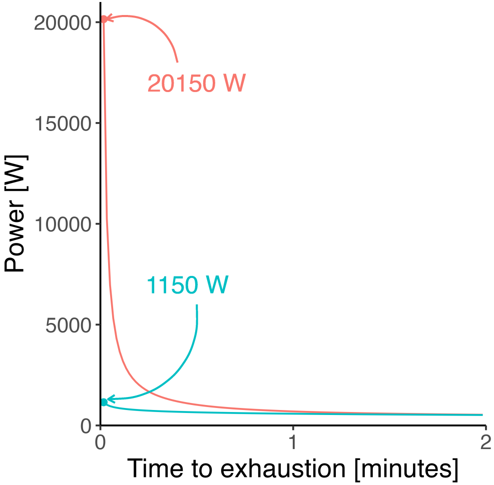

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Long durations

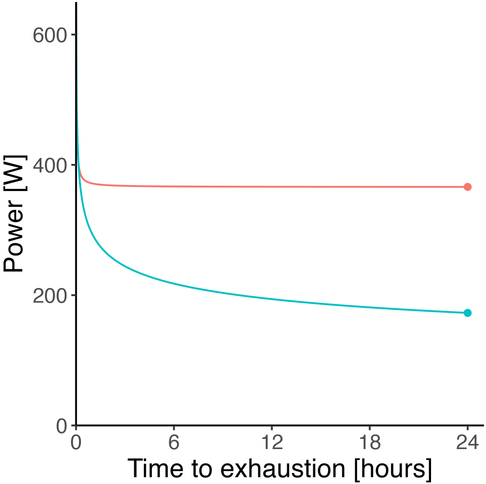

Figure: Power sustainable over 24 hours

Long durations

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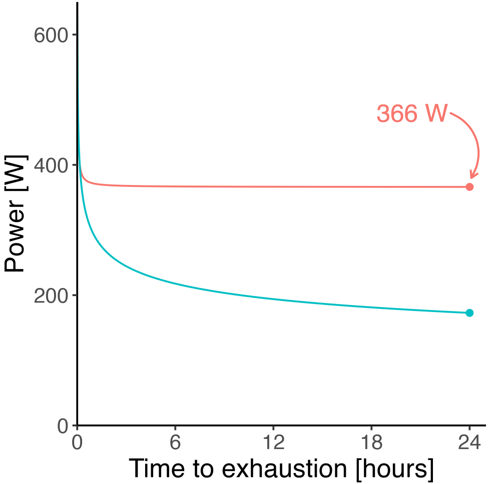

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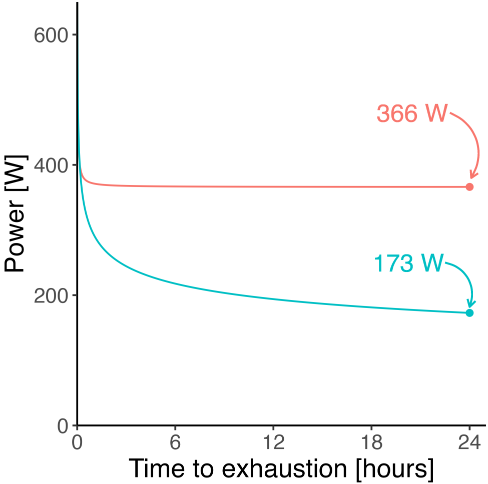

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What do we think happens?

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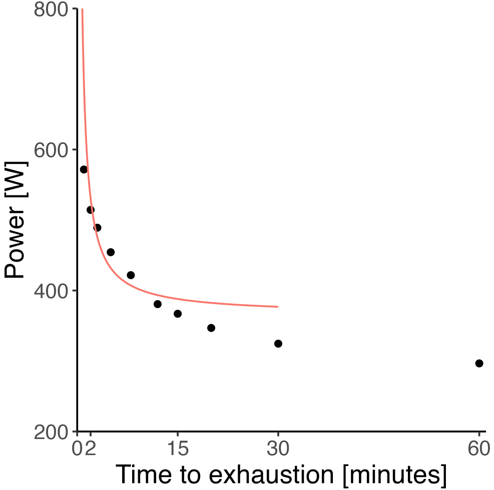

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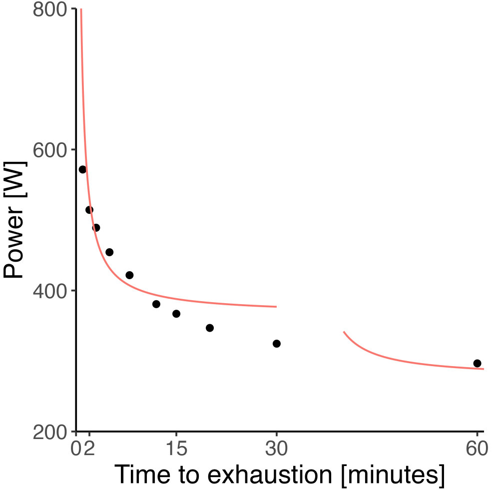

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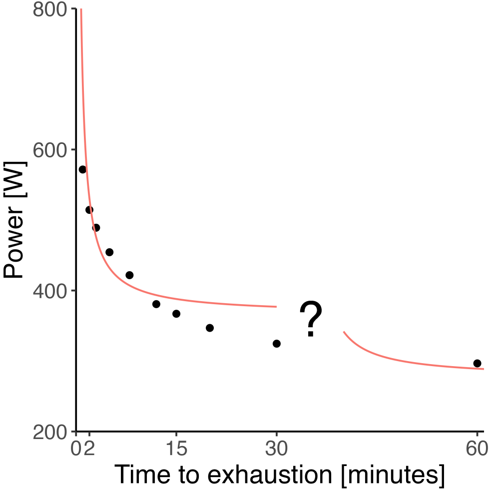

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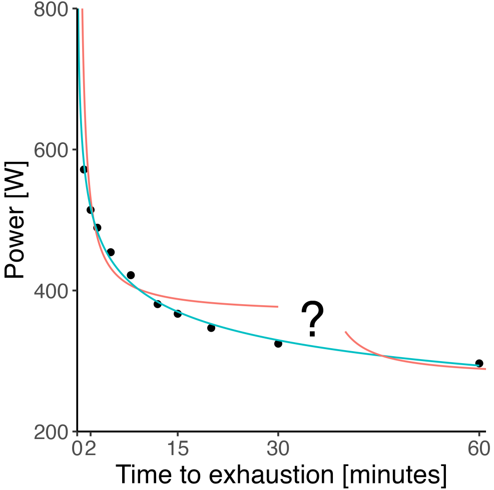

Outline

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Cycling

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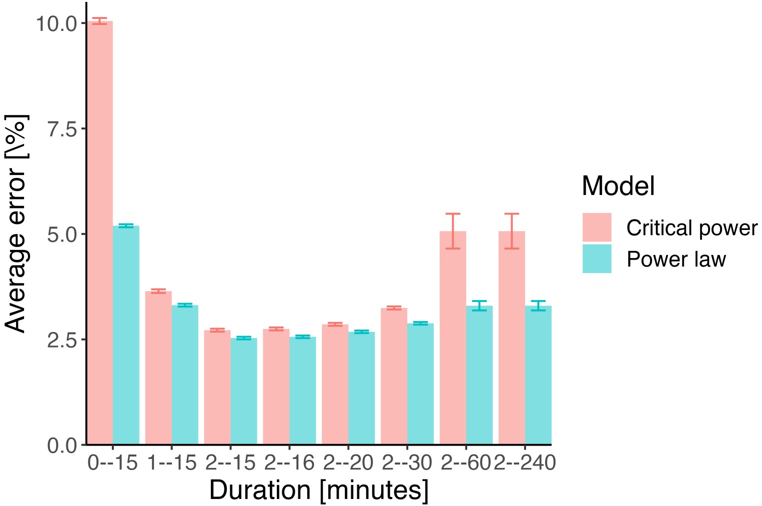
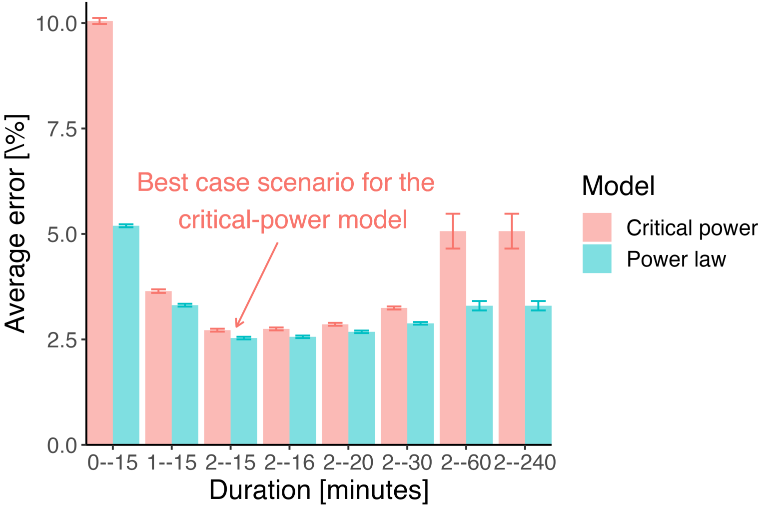


Figure: Large data study of 5805 cyclists

Cycling



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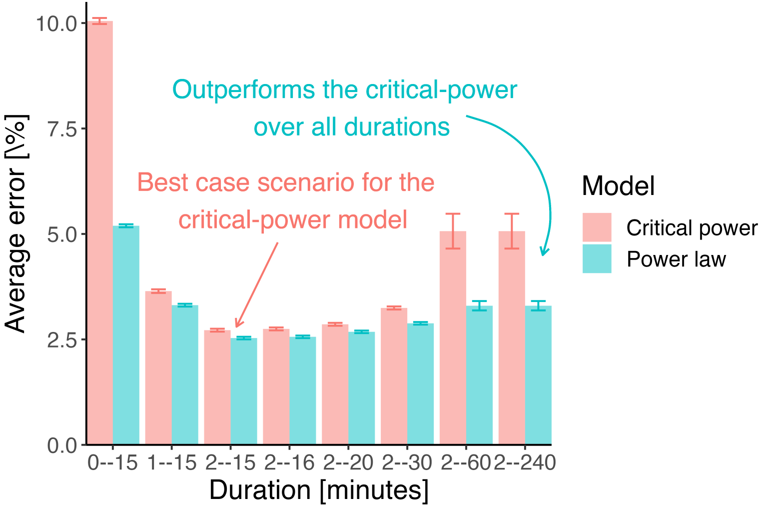

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Running

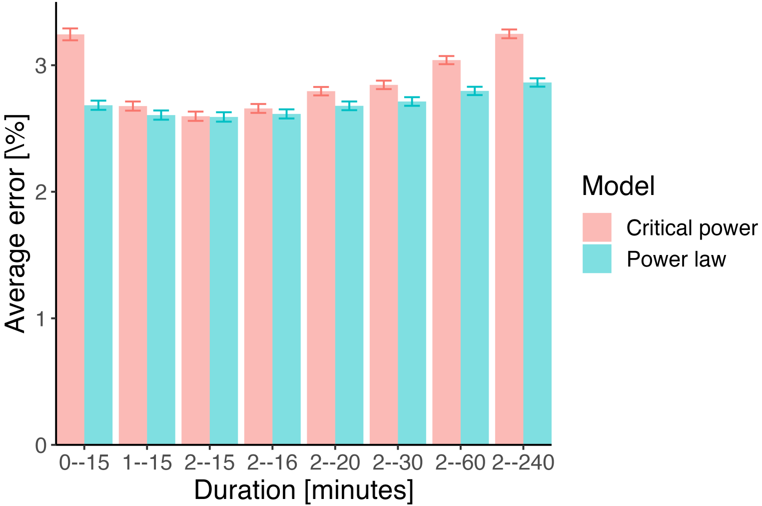

Figure: Large data study of 2571 runners

Rowing

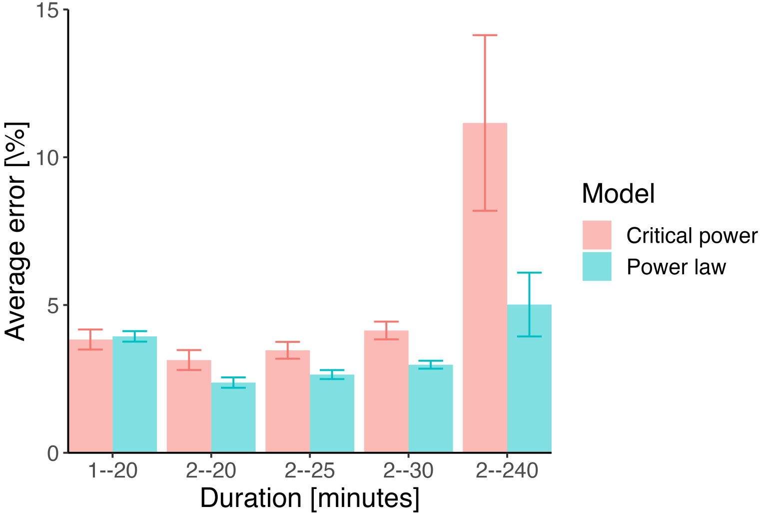

Figure: Large data study of 3244 rowers

Outline

Takeaways

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The power-law model...

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- more accurately predicts performance than CP/W' over **a wide range of durations**,

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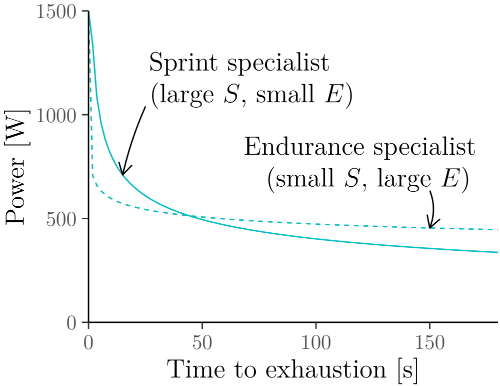

Riegel (1981)

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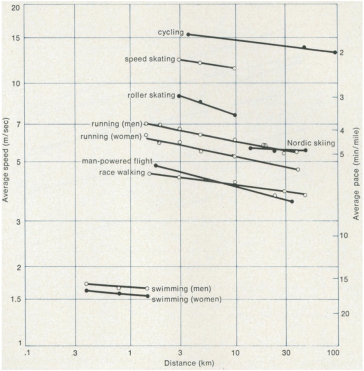

Figure: World records **across different athletes** from multiple sports (Riegel, 1981)

Estimated the endurance parameter to be $E \approx 0.953889$

Connecting FTP

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FTP - Originally defined as 1 hour power (Allen and Coggan, 2012)

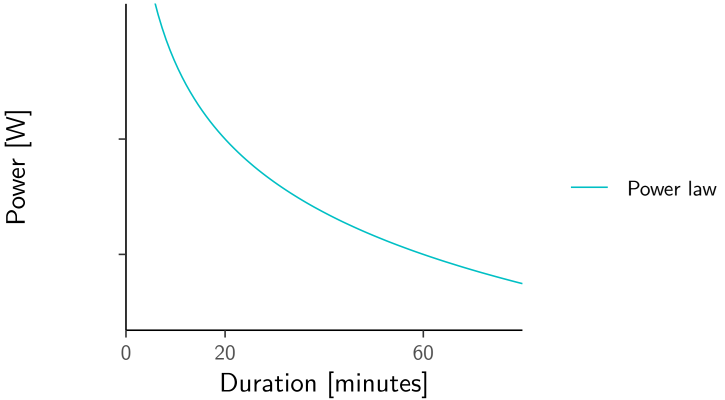

Figure: Power–duration curve from Riegel (1981)

Connecting FTP

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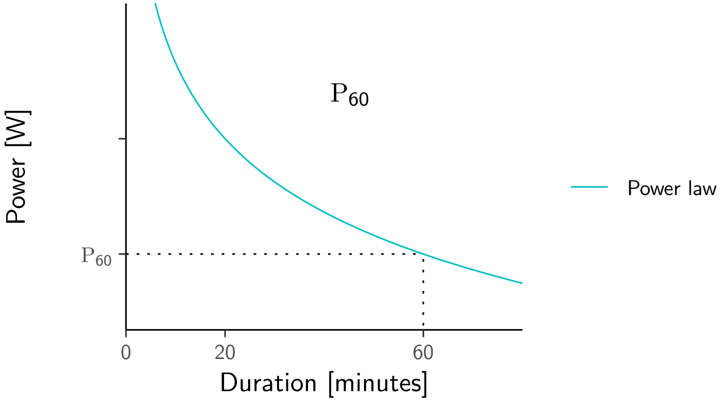

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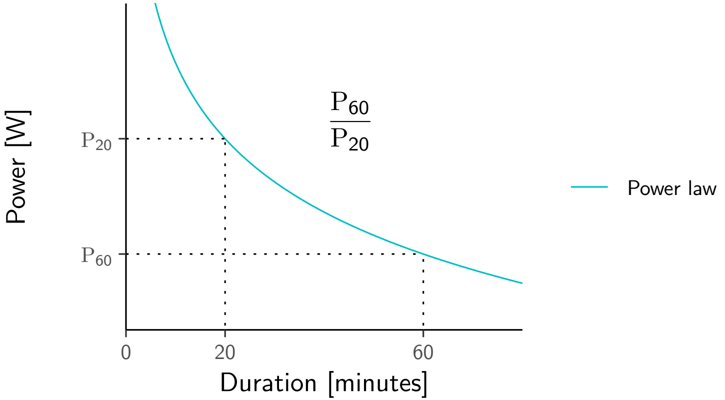

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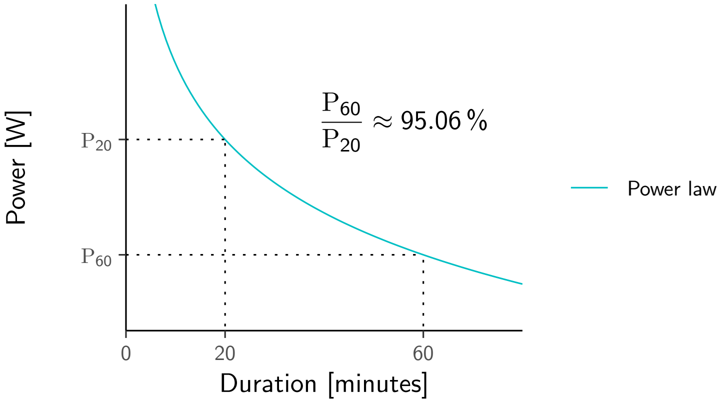

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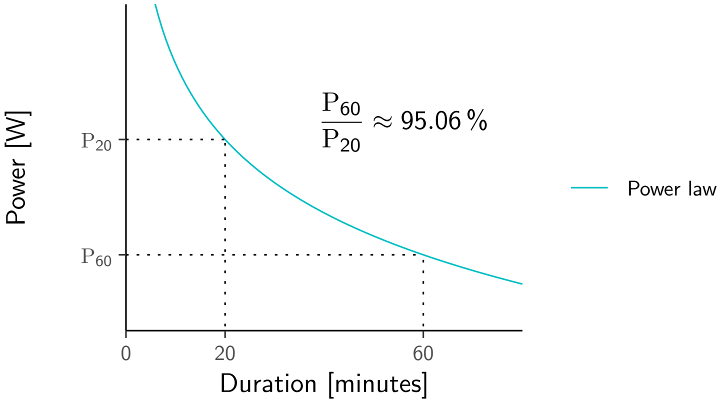

Exactly the rule used to estimate FTP

Takeaways

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The power-law model...

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Takeaways

Loughborough University

The power-law model...

- more accurately predicts performance than CP/W' over **a wide range of durations**,
- is just as **easy to use**,
- can use the **same testing protocols** as CP/W'
- explains why the 95 % rule for **FTP is typically an overestimate**

Limitations

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The power-law model **can not** explain...

Limitations

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The power-law model **can not** explain...

- **recovery**

Limitations

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The power-law model **can not** explain...

- **recovery**
- **slowdown**

References I

Hunter Allen and Andrew Coggan. *Training and racing with a power meter*. VeloPress, 2nd edition, 2012.

Archibald Vivian Hill. The physiological basis of athletic records. *The Scientific Monthly*, 21(4):409–428, 1925.

Andrew M Jones, Mark Burnley, Matthew I Black, David C Poole, and Anni Vanhatalo. The maximal metabolic steady state: redefining the 'gold standard'. *Physiological Reports*, 7(10):e14098, 2019.

Arthur Edwin Kennelly. An approximate law of fatigue in the speeds of racing animals. *Proceedings of the American Academy of Arts and Sciences*, 42(15):275–331, 1906.

H Monod and J Scherrer. The work capacity of a synergic muscular group. *Ergonomics*, 8(3):329–338, 1965.

Peter S Riegel. Athletic records and human endurance. *American Scientist*, 69(3):285–290, 1981.