Strength training applied for endurance sports

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Scientific evidence for strength training-induced benefits in endurance runners and cyclists

1. Effects of combining strength training with a large volume of endurance training on strength training adaptations
2. Effects of combining strength and endurance training on endurance performance

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3. Some few potential mechanisms
4. Maintenance of developed strength throughout the competition season
5. Practical applications

Effects of concurrent strength and endurance training on strength training adaptations

A relative large volume of endurance training seems to reduce strength training adaptations:

- Reduced increase in maximal strength
- Reduced muscle hypertrophy
- Reduced increase in rate of force development

(e.g. Hickson 1980, Dudley & Djamil 1985, Hunter et al. 1987, Hennessy & Watson 1994, Kraemer et al. 1995, Hakkinen et al. 2003, Putman et al. 2004, Izquierdo et al. 2005, Aagaard et al. 2011, Rønnestad et al. 2011, Wilson et al. 2011, Jones et al. 2013)

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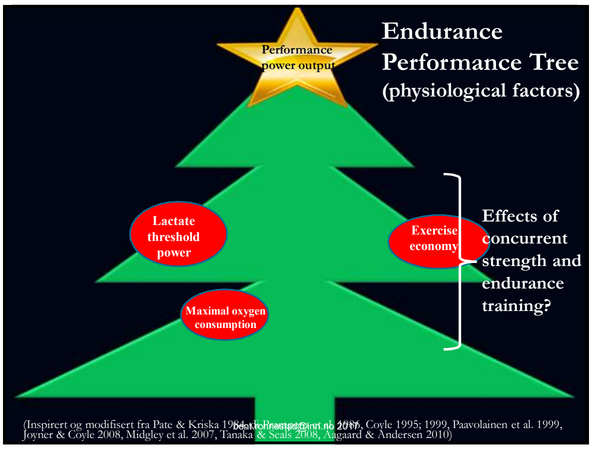
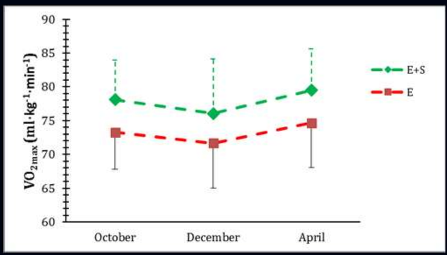
Endurance Performance Tree (physiological factors)



(Inspirert og modifisert fra Pate & Kriska 1984, di Prampero et al. 1986, Coyle 1995; 1999, Paavolainen et al. 1999, Joyner & Coyle 2008, Midgley et al. 2007, Tanaka & Seals 2008, Aagaard & Andersen 2010)

Concurrent training and maximal oxygen consumption

- Highly trained cyclists – mean values



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Concurrent training and maximal oxygen consumption

There seems to be neither a positive nor negative effect of concurrent strength and endurance training compared to endurance training alone regarding VO_{2max} adaptations in endurance trained athletes

(e.g. Hickson et al., 1988; Bishop et al., 1999; Bastiaans et al., 2001; Levin et al., 2009; Rønnestad et al., 2010a, b; Sunde et al., 2010; Aagaard et al., 2011), long-distance runners (Johnston et al., 1997; Paavolainen et al., 1999; Spurrs et al., 2003; Turner et al., 2003; Saunders et al., 2006; Mikkola et al., 2007a, 2011; Storen et al., 2008; Taipale et al., 2010), cross-country skiers (Hoff et al., 1999, 2002; Osteras et al., 2002; Mikkola et al., 2007b; Losnegard et al., 2011; Rønnestad et al., 2012), or triathletes Millet et al., 2002)

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   1. Maximal oxygen uptake
   2. Exercise economy
      1. Running

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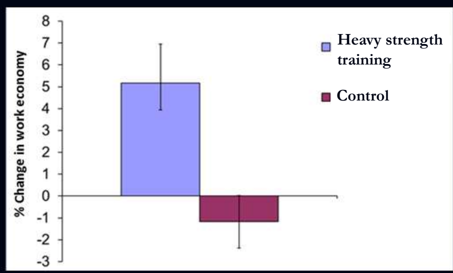
Effects of heavy strength training on running economy



8–14 weeks heavy strength training in endurance runners (Johnston et al. 1997, Hoff & Helgerud 2002, Millet et al. 2002, Støren et al. 2008).

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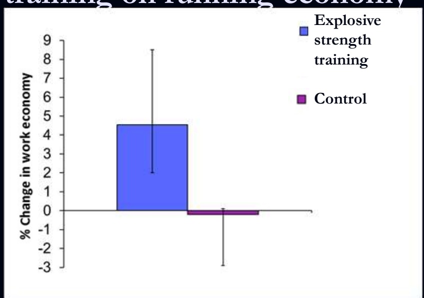
Effects of plyometric/explosive strength training on running economy



6–9 weeks explosive strength training oin distance runners (Paavolainen et al. 1999, Spurrs et al. 2003, Turner et al. 2003, Saunders et al. 2006, Mikkola et al. 2007).

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Running economy

Numerous studies have reported improved running economy after 6–14 weeks of concurrent heavy strength/explosive strength and endurance training, while no substantial changes were observed in the control groups

(e.g. Johnston et al., 1997; Hoff & Helgerud, 2002; Millet et al., 2002; Storen et al., 2008; Guglielmo et al., 2009; Taipale et al., 2010, Paavolainen et al., 1999; Spurrs et al., 2003; Turner et al., 2003; Saunders et al., 2006; Taipale et al., 2010; Barnes et al. 2013).

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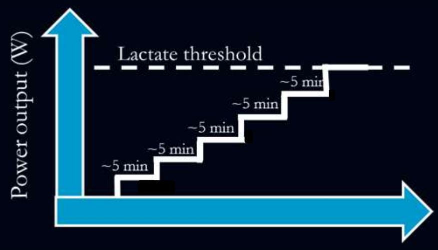
Effect of strength training on exercise economy



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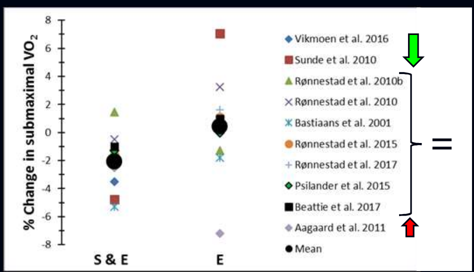
Effect of strength training on cycling economy$_1$



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Effect of strength training on cycling economy$_2$

Unclear findings during traditional 3-5 min submaximal workloads. Different findings during prolonged submaximal exercise?

Cycling is, amongst others, characterized by several hours submaximal cycling

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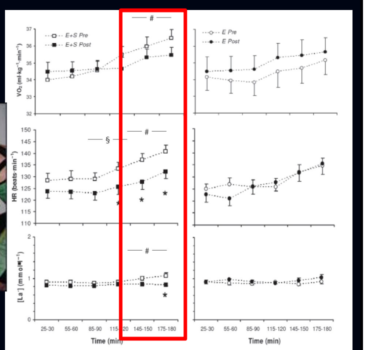
Effect of strength training on cycling economy$_3$

Prolonged submaximal cycling



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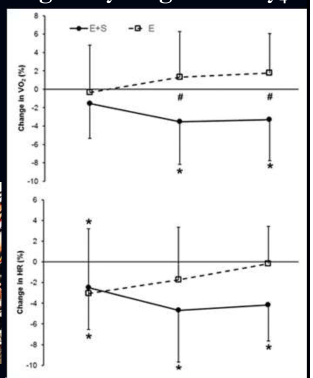
(Rønnestad et al. 2011)

Effect of strength training on cycling economy$_4$

Prolonged submaximal cycling, female cyclists



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(Vikmoen et al. 2017, Physiol Rep.5; e13149)

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   2. Exercise economy
   3. Power/velocity at lactate threshold
      1. Running

Effects of strength training on running velocity@lactate threshold

Little change in the lactate threshold of runners (% VO_{2max}) (Paavolainen et al., 1999; Hoff & Helgerud, 2002; Mikkola et al., 2011; Støren et al., 2008)

Substantial improvements in velocity at the lactate threshold (Mikkola et al., 2007a, 2011; Guglielmo et al., 2009; Taipale et al., 2013).

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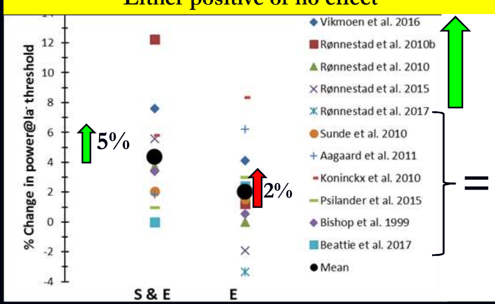
      2. Cycling

Effects of strength training on power output@lactate threshold in cyclists

Either positive or no effect



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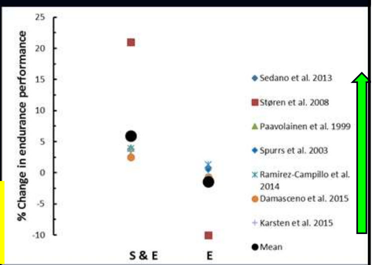
      1. Running

Effect of strength training on running performance

Both heavy and explosive strength training seems to improve running performance

Supported by studies investigating Vmax



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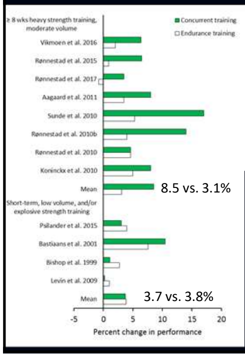
      1. Running
      2. Cycling

Effect of concurrent training on cycling performance



Characteristics of successful strength training:

Heavy loaded strength training with multiple leg exercises during a period of minimum 8 weeks

Characteristics of strength training with no additional effect:

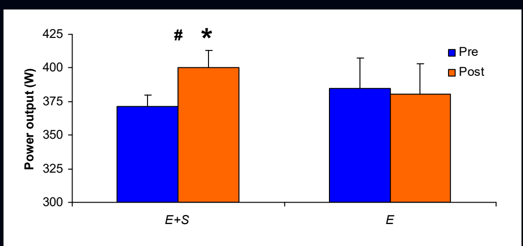
Short-term strength training period, low volume of strength training or explosive strength training is performed

Alternative approach to measure cycling performance

In the Grand Tours, around 70% of the race duration is spent at exercise intensities characterized as "light intensity"

(Lucia et al. 1999; 2003)

Mean power output during the 5-min all-out trial performed following 185 min of cycling

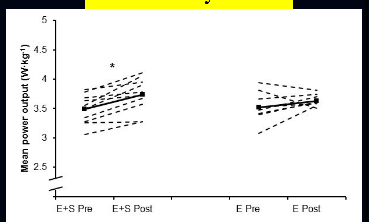


*Different from Pre (P<0.01). #Difference between groups in relative change from pre-test to post-test (P < 0.01).

(Rønnestad et al. 2011)

Mean power output during the 5-min all-out trial performed following 180 min of cycling

Female cyclists



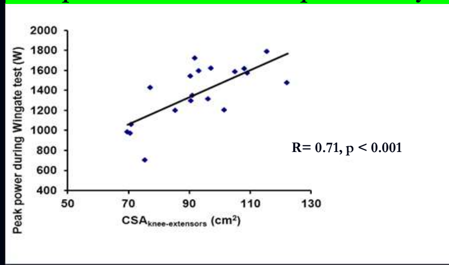
(Vikmoen et al. 2017)

Sprint performance

Sprint performance

- Sprint abilities – male cyclists

Importance of CSA for sprint ability

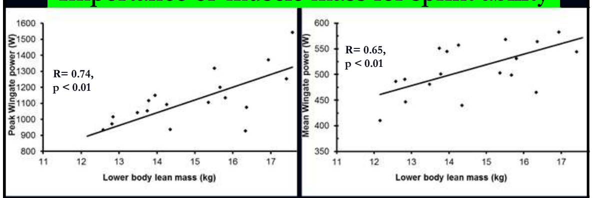


(Unpublished data, Rønnestad et al.)

Sprint performance

- Sprint abilities- female cyclists

Importance of muscle mass for sprint ability



(Data from Vikmoen et al. 2016)

Effect of strength training on cycling performance

Heavy strength training seems to positively affect cycling performance

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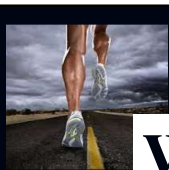
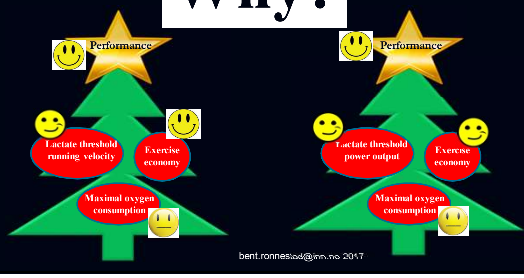
Summarizing the findings…..



Why?



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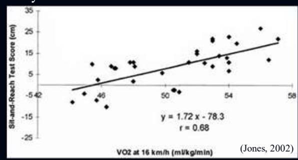
3. Some few potential mechanisms

Potential mechanisms behind improved performance

- Strength training induces more optimal muscle-tendon stiffness? (e.g. Spurrs et al. 2003, Barnes et al. 2013, Millet et al. 2002)

↳ Improved utilization of elastic energy in the muscle-tendon system?



Potential mechanisms behind improved performance

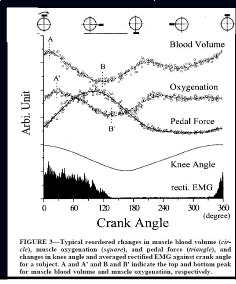
- Strength training induces more optimal muscle-tendon stiffness? (e.g. Spurrs et al. 2003, Barnes et al. 2013, Millet et al. 2002)

↳ Improved utilization of elastic energy in the muscle-tendon system?

➡ Improved exercise economy ➡ ⬆ Performance?

Potential mechanisms behind improved performance

- Reduced blood flow during the power phase in the pedal stroke (i.e. downstroke) (Takaishi et al. 2002)

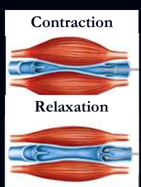


(Takaishi et al. 2002)

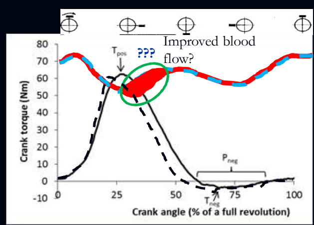
Potential mechanisms behind improved performance

⬆ RFD ➡ earlier peak torque in the pedal stroke?

↳ ⬆ relaxation ➡ ⬆ blood flow? ➡ ⬆ performance?

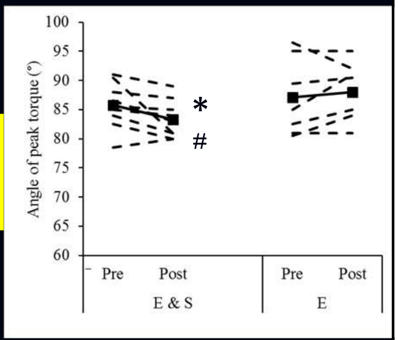


Torque during the pedal stroke



Crank torque curve with selected characteristics. This data example from one of the cyclists represents a single random crank arm (right) revolution during one of the 5-min all-out trials. The following selected characteristics are indicated on the curve: T_{pos}, peak positive crank torque; T_{neg}, peak negative crank torque; P_{neg}, phase with negative crank torque.

HSTR *can* change angle of peak torque



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(Rønnestad et al. 2015)

Potential mechanisms behind improved performance

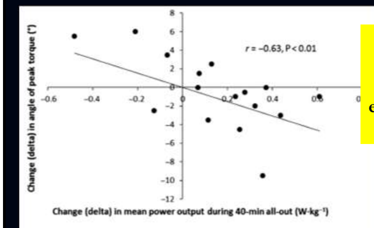

Fig. 3. Correlation between changes (delta) in mean power output during 40-min all-out trial and changes in angle of peak torque during the pedal stroke.

Improvement in 40-min power correlates largely with changes towards earlier peak torque during the pedal stroke

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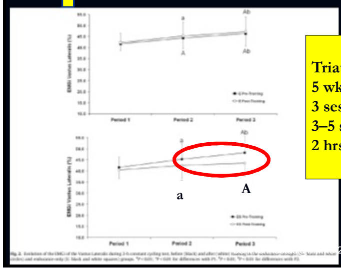
(Rønnestad et al. 2015)

Potential mechanisms to improved performance

- The more economical type I fibres becomes stronger → ↑contribution to power output → ↑long-term performance?



Triathletes, VO_{2max} ~68 ml/kg/min
5 wks strength training
3 sessions/wk
3–5 sets and 3–5 RM
2 hrs submaximal cycling

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(Hausswirth et al. 2010)

Potential mechanisms to improved performance

- Changed fibertype composition? IIx → IIa (Aagaard et al. 2011)

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Potential mechanisms to improved performance

- Changed fibertype composition? IIx → IIa

12 wks heavy strength training in female duathletes

- **Hybrid fibers (IIAX MyHC) was reduced from 9 ± 7% to 0%**
- **Increase in fibers positive for type 2A only (from 39 ± 13% to 51 ± 10%)**
- **Mean power during 40-min all-out trial increased by 6.4 ± 7.9%**

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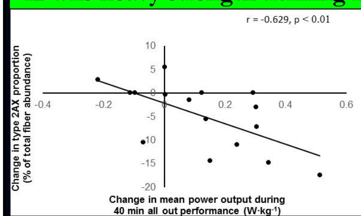
(Vikmoen et al. 2016)

Potential mechanisms to improved performance

- Changed fibertype composition? IIx → IIa

12 wks heavy strength training in female duathletes



Improvement in 40-min power correlates largely with reduction in type IIAX fibres

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(Vikmoen et al. 2016)

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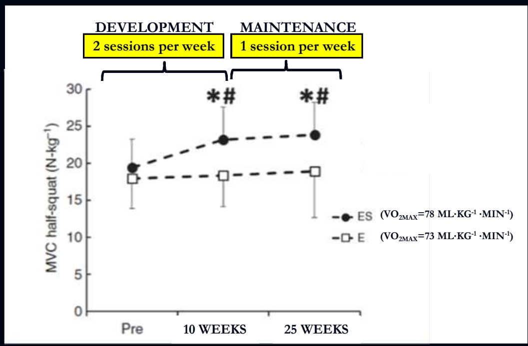
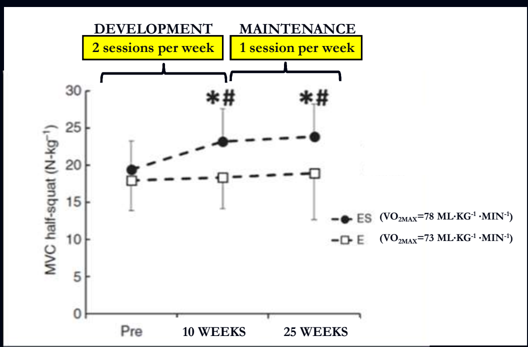
Maintenance of strength



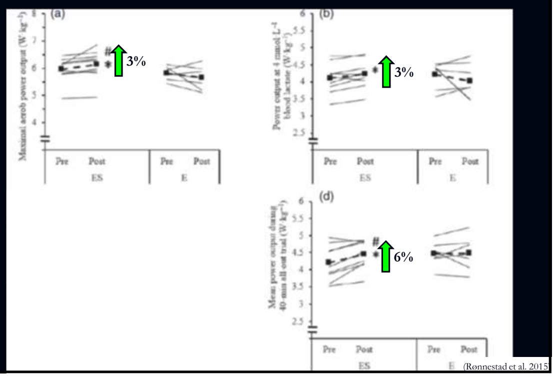
(Rønnestad et al. 2015)

Maintenance of strength – training effects?



(Rønnestad et al. 2015)

Maintenance of strength – training effects?



(Rønnestad et al. 2015)

Maintenance of strength

Cyclists have a relatively tight race schedule, making it challenging to prioritize strength training during the competition season.

Maintenance of strength

Many cyclists who perform strength training during the preparatory period stop the strength training during the competition season.

Purpose

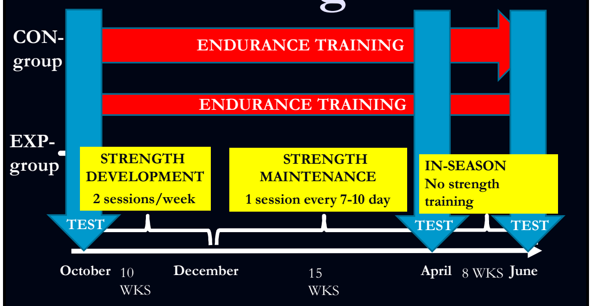
- To investigate the effects of 8 weeks strength training cessation after 25 weeks of strength training on indices of
  - Strength training adaptations — Maximal isometric half squat force; Lean lower body mass; Squat jump
  - Sprint performance — Power during 30-sec Wingate sprint
  - Endurance performance — Maximal oxygen uptake (VO_{2max}); Maximal aerobic power (W_{max}); Power output at 4 [$mmol \cdot L^{-1}$]

Physical characteristics of the cyclists

Variables	EXP (n=7)	CON(n=7)
Age (years)	19±1	20±1
Body mass (kg)	67.8±7.8	74.3±7.5
Body height (cm)	179±8	183±9
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	77±6	73±5
Maximal aerobic power ($W \cdot kg^{-1}$)	5.9±0.5	5.8±0.2
Maximal isometric half-squat (N)	1400±378	1340±364
Squat jump (cm)	27±5	30±5
30-sec Wingate sprint ($W \cdot kg^{-1}$)	10.7±0.9	10.7±0.7
Power@4mmol ($W \cdot kg^{-1}$)	4.1±0.5	4.2±0.4

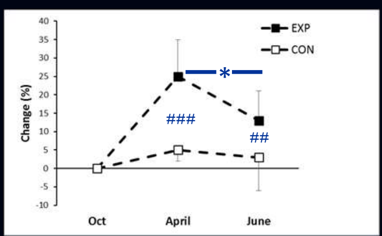
Values are mean ± SD

Design



Results

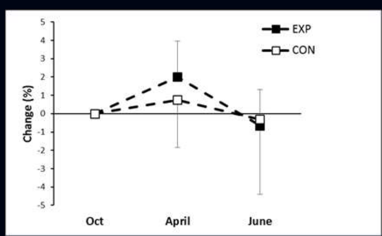
Maximal isometric half squat strength



##Very likely between-group differences from pre
###Most likely between-group differences from pre,
*Likely between-group differences from 25 weeks

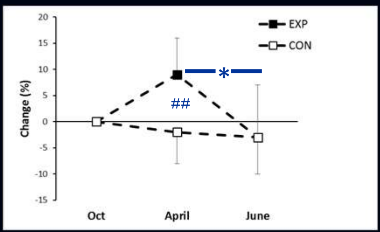
(Rønnestad et al. 2016)

Lean lower body mass



(Rønnestad et al. 2016)

Squat jump



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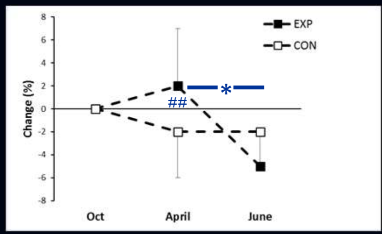
(Rønnestad et al. 2016)

30-s Wingate Sprint



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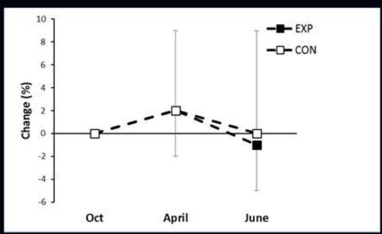
(Rønnestad et al. 2016)

Maximal oxygen uptake



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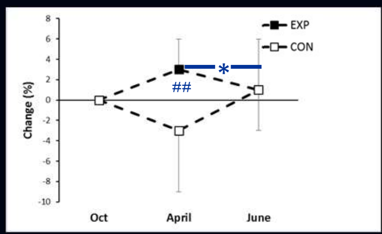
(Rønnestad et al. 2016)

Maximal aerobic power output



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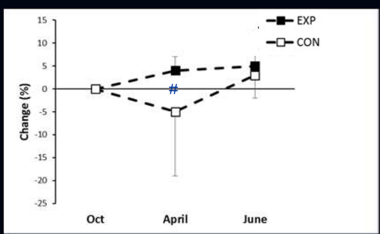
(Rønnestad et al. 2016)

Power output@4mmol·L^{-1} [blood lactate]



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(Rønnestad et al. 2016)

Summary: Effects of EXP vs. CON

	October→April	April→June	October→June
Lean lower-body mass			
MVC			
SJ			
30-sec Wingate			
W_{max}			
Power@4mmol/L			
VO_{2max}			

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(Rønnestad et al. 2016)

Maintenance of strength

Strength maintenance training seems to be very important in a long-term perspective

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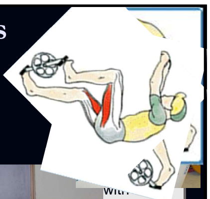
Stop!!!!!
You don`t have to perform strength training to be a world champion!!

You have to find the right way for each individual athlete

Practical application - strength training

- Specificity
  - Movement and muscle groups
  - Contraction (muscle action)

Potential strength exercises for cycling

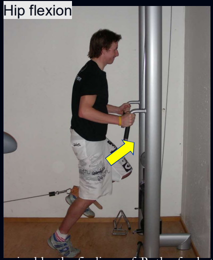


Half squat

Inspired by Rutherford et al. 1986, Coyle et al. 1991, Schantz et al. 1989, Cresswell & Ovendal 2002, Hickson et al. 1988, Behm & Sale 1993, Morrissey et al. 1995.

Potential strength exercises for cycling

Hip flexion



Toe raise

Inspired by the findings of Rutherford et al. 1986, Coyle et al. 1991, Schantz et al. 1989, Cresswell & Ovendal 2002, Hickson et al. 1988, Behm [illegible] et al. 1995.

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Practical application

- Specificity
  - Movement and muscle groups
  - Contraction
- Maximal mobilization during the concentric phase
- Heavy loading (4-12RM), must not always be to failure! Plyometrics is also ok for runners
- Multiple exercises for the target muscle groups
- 2 (to 3) strength training sessions per week to increase strength
- 1 strength training session per week to maintain strength
- If you have a long competition season, perform some weeks with 2 strength training sessions per week
- Remember the total training stress

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Practical application

Example of a strength training program that have improved cycling performance

Table 1 Strength training program for the cyclists who performed heavy strength training

	Preparatory period						Competition period
	Week 1–3		Week 4–6		Week 7–12		Week 13–25
	1. Bout	2. Bout	1. Bout	2. Bout	1. Bout	2. Bout	1. Bout
Half squat	3 × 10RM	3 × 6RM	3 × 8RM	3 × 5RM	3 × 6RM	3 × 4RM	2 × 5 reps@80–85% of 1RM
One-legged leg press	3 × 10RM	3 × 6RM	3 × 8RM	3 × 5RM	3 × 6RM	3 × 4RM	2 × 5 reps@80–85% of 1RM
One-legged hip flexion	3 × 10RM	3 × 6RM	3 × 8RM	3 × 5RM	3 × 6RM	3 × 4RM	1 × 6RM
Ankle plantar flexion	3 × 10RM	3 × 6RM	3 × 8RM	3 × 5RM	3 × 6RM	3 × 4RM	1 × 6RM

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PRACTICAL APPLICATION

13 months with block periodization

But only a singel case……….

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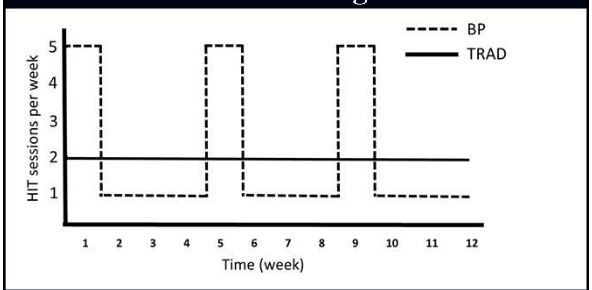
Block periodization has been observed to be superior more evenly distribution of the training



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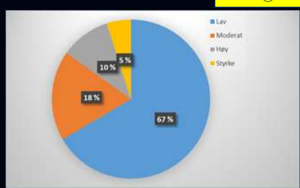
13 months with block periodization

Best previous test result:
VO_{2max}=76.5
W_{max}=6.43 W/kg
Power@3mmol/L=3.9 W/kg



LIT	451.64 h
MIT	124.03 h
HIT	69.02 h
HSTR	33.60 h
TOTALT	678.29 h

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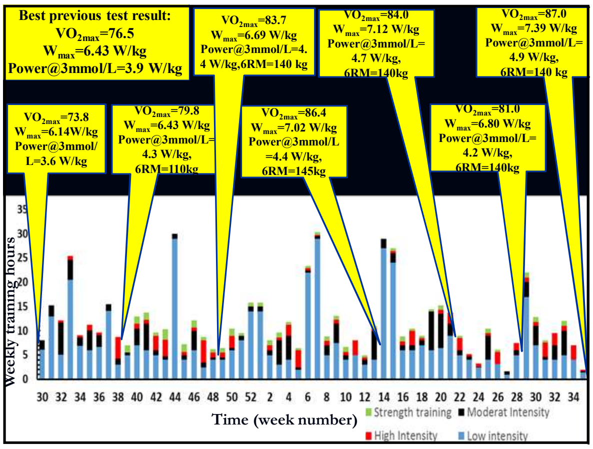

Block periodization seems to induce more favorable training adaptations than more traditional organization despite the total volume and intensity of the training are similar.

(Rønnestad et al. 2014, SJMSS, 24:327-35; Rønnestad et al. 2014, SJMSS, 24: 34-42; Rønnestad et al. 2016, SJMSS, 26:140-6)

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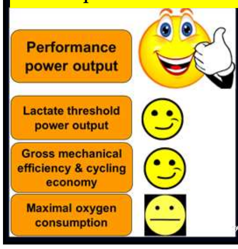
Conclusion

Heavy strength training *can* improve endurance performance



Remember the total training stress – do as little strength training as necessary

Strength training adaptations needs to be maintained

Don`t forget monitoring individual responses to the training and talk ***with*** your athlete…..It doesn't matter if an athlete can squat 250 kg, but is overtrained.

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Thank you!

Acknowledgement:

Amongst others, friendly colleagues from Lillehammer