

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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2. Effects of combining strength and endurance training on endurance performance
3. Some few potential mechanisms
4. Maintenance of developed strength throughout the competition season
5. Practical applications

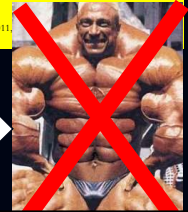
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Effects of concurrent strength and endurance training on strength training adaptations

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, Knierim et al. 1995, Hakkinen et al. 2003, Putman et al. 2004, Lopez de la Puente et al. 2005, Aagaard et al. 2011, Rønnestad et al. 2013, Wilson et al. 2013, Jones et al. 2015)

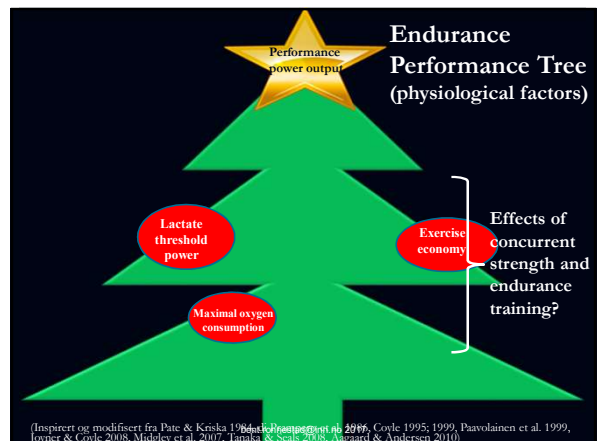


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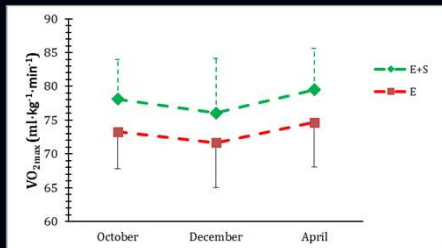
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Concurrent training and maximal oxygen consumption

- 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

(eg. Hickson et al., 1988; Bishop et al., 1999; Bastians et al., 2001; Levin et al., 2009; Ronnestad et al., 2010a, by Sunds et al., 2010; Asgaard et al., 2011), long-distance runners (Johnston et al., 1997; Paavolainen et al., 1999; Spurr 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; Ronnestad et al., 2012), or triathletes (Miller et al., 2002)

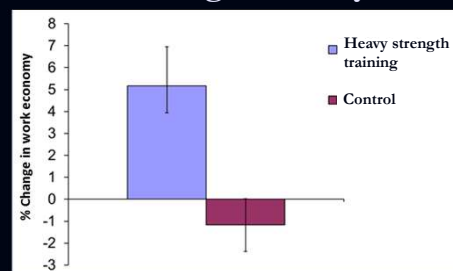
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Scientific evidence for strength training-induced benefits in endurance runners and cyclists

- Effects of combining strength training with a large volume of endurance training on strength training adaptations
- Effects of combining strength and endurance training on endurance performance
 - Maximal oxygen uptake
 - Exercise economy
 - Running

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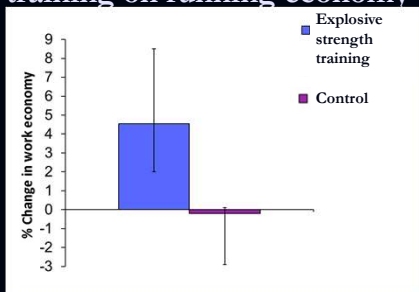
Effects of heavy strength training on running economy



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

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Effects of plyometric/explosive strength training on running economy



6–9 weeks explosive strength training in distance runners (Paavolainen et al. 1999, Spurr 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

(eg. 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; Spurr et al., 2003; Turner et al., 2003; Saunders et al., 2006; Taipale et al., 2010; Barnes et al. 2013).

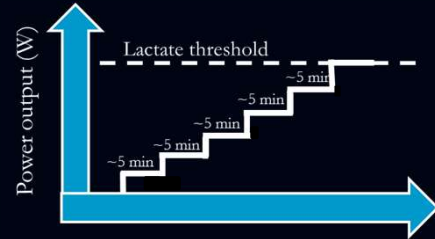
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 1. Maximal oxygen uptake
 2. Exercise economy
 1. Running
 2. Cycling

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Effect of strength training on exercise economy



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Effect of strength training on cycling economy₁



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Effect of strength training on cycling economy₂

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

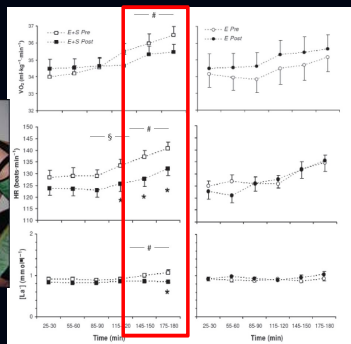
Cycling is, amongst others, characterized by several hours submaximal cycling



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Effect of strength training on cycling economy₃

Prolonged submaximal cycling

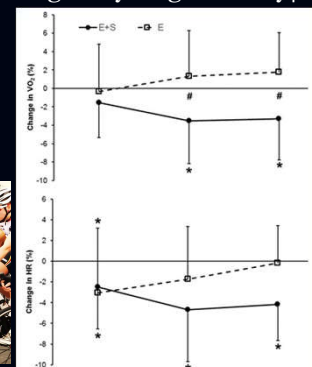


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(Rønnestad et al. 2011)

Effect of strength training on cycling economy₄

Prolonged submaximal cycling, female cyclists



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

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 3. Power/velocity at lactate threshold
 1. Running

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Effects of strength training on running velocity@lactate threshold

Little change in the lactate threshold of runners (% $\text{VO}_{2\text{max}}$) (Paavolainen et al., 1999; Hoff & Helgerud, 2002; Mikkola et al., 2011; Storen 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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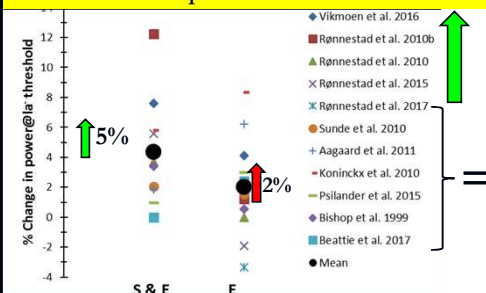
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Effects of strength training on power output@lactate threshold in cyclists

Either positive or no effect



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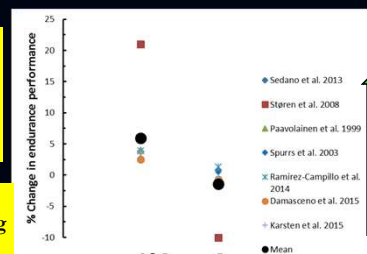
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Effect of strength training on running performance

Both heavy and explosive strength training seems to improve running performance

Supported by studies investigating V_{max}



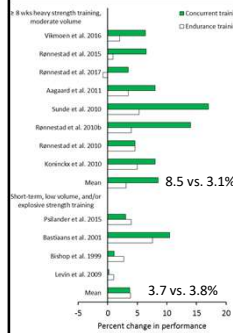
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Effect of concurrent training on cycling performance



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

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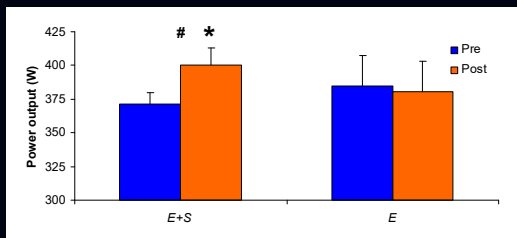
In the Grand Tours, around 70% of the race duration is spent at exercise intensities characterized as “light intensity”

(Lucia et al. 1999; 2003)



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



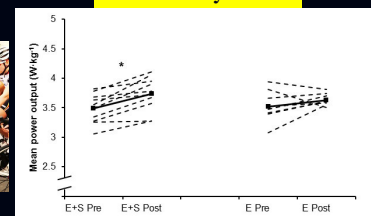
*Different from Pre ($P < 0.01$). #Difference between groups in relative change from pre-test to post-test ($P < 0.01$).

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(Rønnestad et al. 2011)

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

Female cyclists



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(Vikmoen et al. 2017)

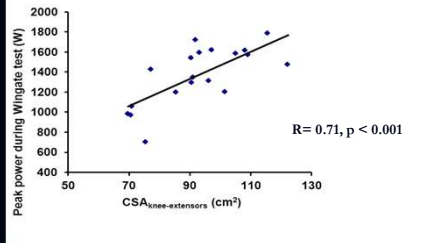
Sprint performance

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Sprint performance

- Sprint abilities – male cyclists

Importance of CSA for sprint ability



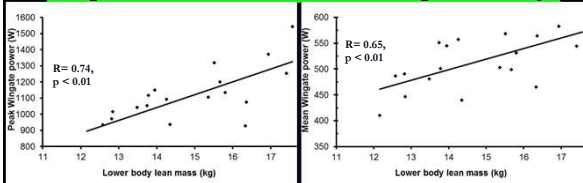
bent.ronnestad@inn.no 2017 (Unpublished data, Ronnestad et al.)

Sprint performance

- Sprint abilities- female cyclists



Importance of muscle mass for sprint ability



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Effect of strength training on cycling performance

Heavy strength training seems to positively affect cycling performance

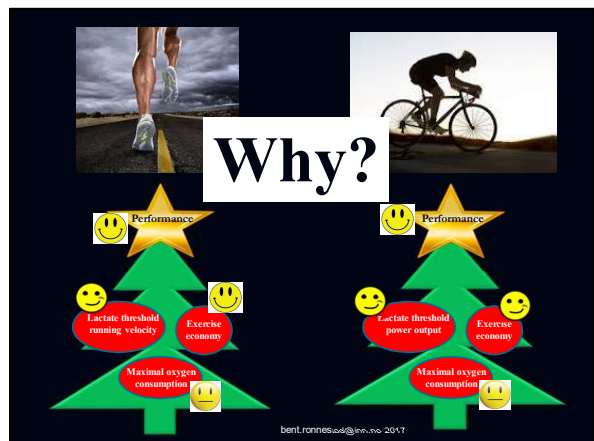
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Summarizing the findings.....

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3. Some few potential mechanisms

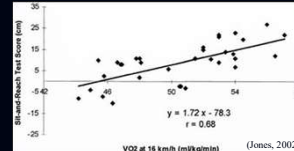
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Potential mechanisms behind improved performance

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



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



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Potential mechanisms behind improved performance

- Strength training induces more optimal muscle-tendon stiffness? (e.g. Spurr 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?

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Potential mechanisms behind improved performance

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

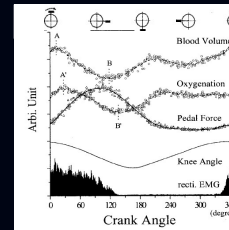
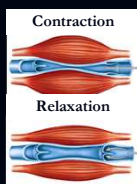


FIGURE 3—Typical recorded changes in muscle blood volume (circles), muscle oxygenation (squares), and pedal force (triangles) against crank angle for a subject. A and B indicate the top and bottom peaks for muscle blood volume and muscle oxygenation, respectively.

(Takaishi et al. 2002)

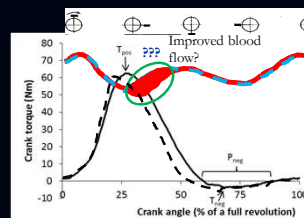
Potential mechanisms behind improved performance

- ↑ RFD → earlier peak torque in the pedal stroke?
- ↓ relaxation → ↑ blood flow? → ↑ performance?



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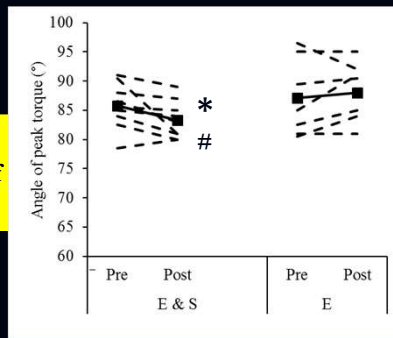
Torque during the pedal stroke



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.

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HSTR can change angle of peak torque



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(Rønnestad et al. 2015)

Potential mechanisms behind improved performance

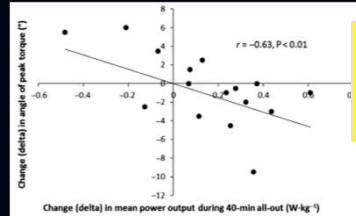


Fig. 3. Correlation between changes (delta) in mean power output during 40-min all-out trial and changes in angle of peak torque during the pedal stroke.

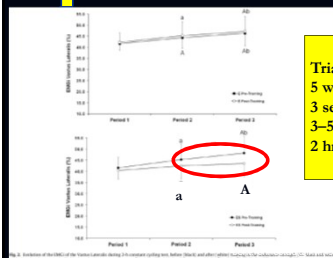
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(Rønnestad et al. 2015)

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

Potential mechanisms to improved performance

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



Triathletes, $VO_{2max} \sim 68$ 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 $9 \pm 7\%$ to 0%
- Increase in fibers positive for type 2A only (from $39 \pm 13\%$ to $51 \pm 10\%$)
- Mean power during 40-min all-out trial increased by $6.4 \pm 7.9\%$



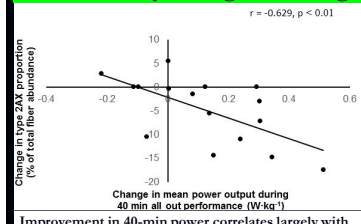
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(Vikmoen et al. 2016)

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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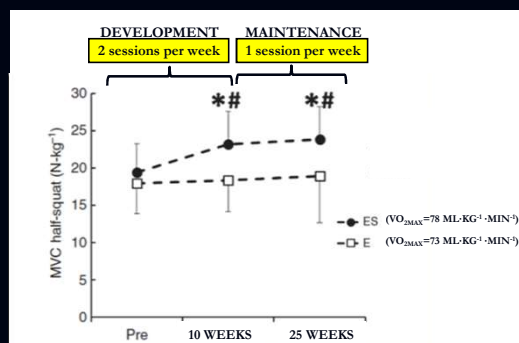
(Vikmoen et al. 2016)

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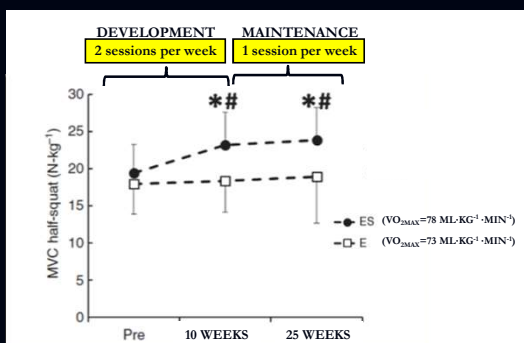
Maintenance of strength



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(Rønnestad et al. 2015)

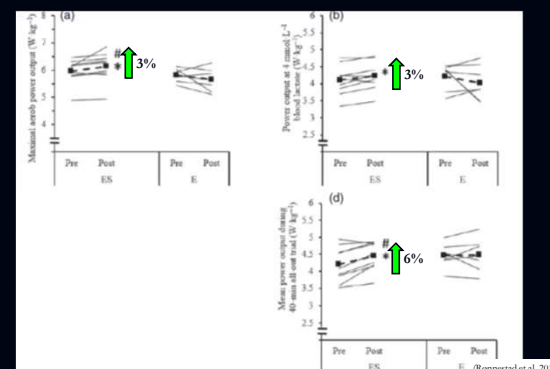
Maintenance of strength – training effects?



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(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.

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Maintenance of strength

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

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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 [$mmol \cdot L^{-1}$]

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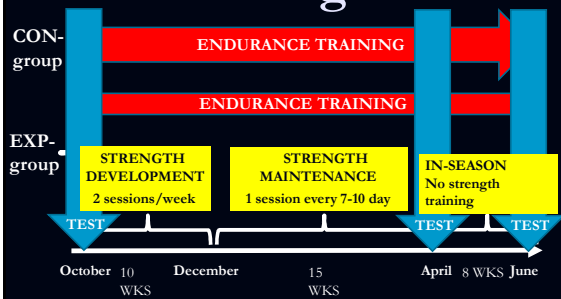
Physical characteristics of the cyclists

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

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Design

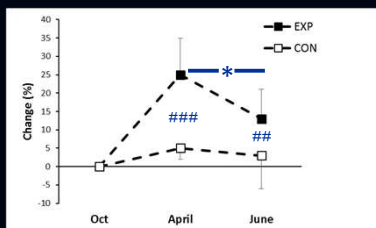


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Results

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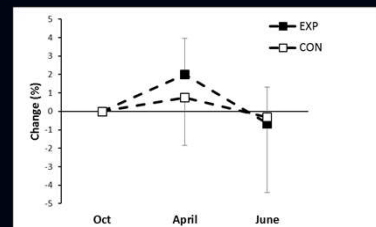
Maximal isometric half squat strength



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

(Rønnestad et al. 2016)

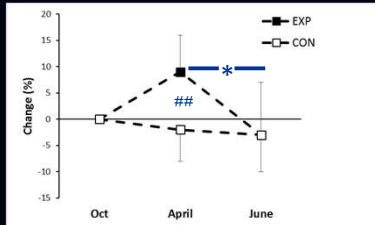
Lean lower body mass



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(Rønnestad et al. 2016)

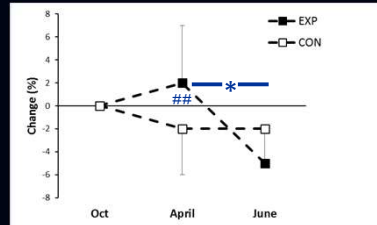
Squat jump



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

(Rønnestad et al. 2016)

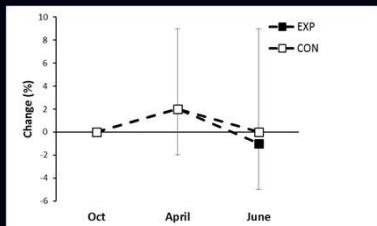
30-s Wingate Sprint



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

(Rønnestad et al. 2016)

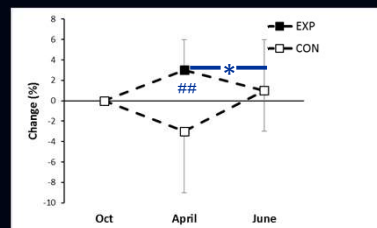
Maximal oxygen uptake



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(Rønnestad et al. 2016)

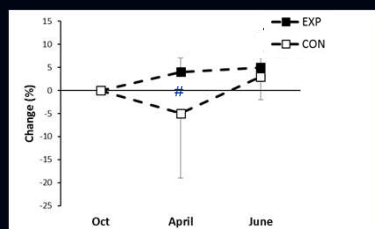
Maximal aerobic power output



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

(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!!



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You have to find the right way for each individual athlete



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Practical application - strength training

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

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Potential strength exercises for cycling

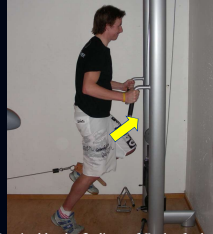
Half squat



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. 1992, bent.romnestad@inn.no 2017

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 & Overdal 2002, Hickson et al. 1988, Behm et al. 1993, Attwells et al. 2007 et al. 1995.

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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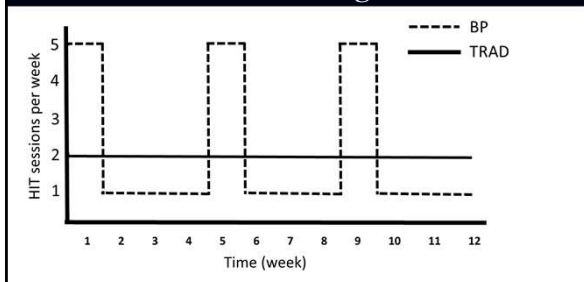
PRACTICAL APPLICATION

13 months with block periodization

But only a single case.....

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

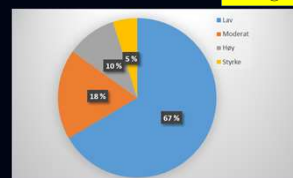


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(Ronnestad et al. 2014a;2014b; 2016)

13 months with block periodization

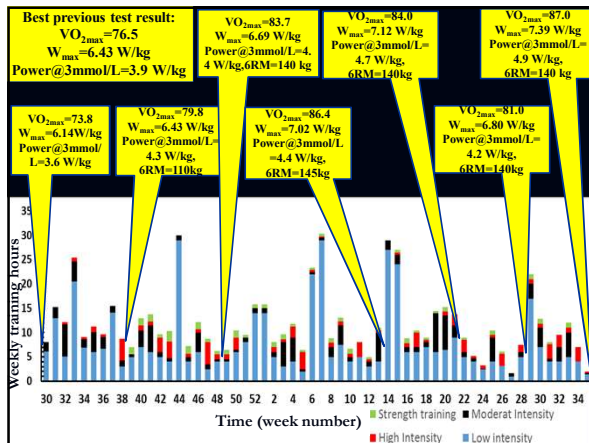
Best previous test result:
 $VO_{2max} = 76.5$
 $W_{max} = 6.43 \text{ W/kg}$
 $Power@3mmol/L = 3.9 \text{ W/kg}$



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

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(Ronnestad & Hansen 2017)



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

Performance power output



Lactate threshold power output



Gross mechanical efficiency & cycling economy



Maximal oxygen consumption



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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.

Thank you!

Acknowledgement:

Amongst others, friendly colleagues from Lillehammer

