Physiology of Interval Exercise Training: Mechanistic Basis for Adaptation

8ο Συνέδριο Βιοχημείας & Φυσιολογίας της Άσκησης

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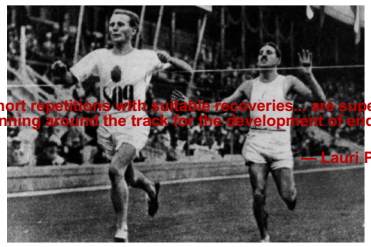
Overall Message

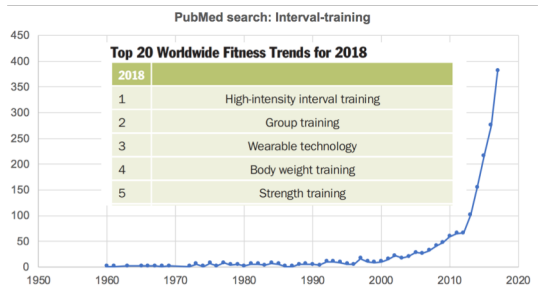
Interval training is an infinitely variable form of exercise that elicits physiological adaptations linked to improved health and performance in a time-efficient manner.



"Fast and short repetitions with suitable recoveries ... are superior to even speed running around the track for the development of endurance."

— Lauri Pihkala, 1916

https://upload.wikimedia.org/wikipedia/commons/9/99/J_O_Stockholm_1912_Bouin_et_Koleheimen.jpg



Top 20 Worldwide Fitness Trends for 2018

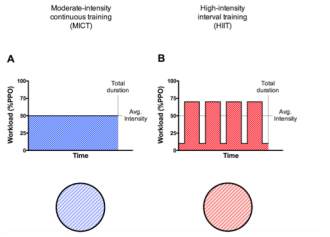
2018	
1	High-intensity interval training
2	Group training
3	Wearable technology
4	Body weight training
5	Strength training

Interval Training Terminology

Alternating periods of more intense effort and recovery in a single session

Aerobic Interval Training (e.g., "cardio"-style exercise)	Resistance Interval Training (e.g., bodyweight exercise)
Sprint interval training (SIT) 'near max' / 'all out' / 'supra-max'	Maximal efforts to failure
High-intensity interval training (HIIT) ≥80% of HRmax	Vigorous but not all out
Light-moderate intermittent exercise e.g., interval walking	Light-moderate effort

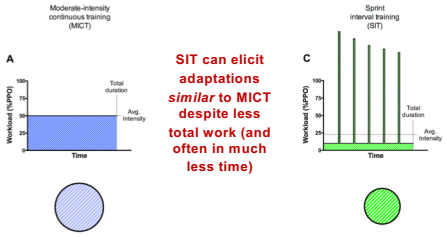
Interval vs Traditional Endurance Training



HIIT can elicit adaptations *superior* to MICT when total work is matched (and time commitment is similar).

MacInnis & Gibala, J Physiol 595: 2915-2930, 2017.

Interval vs Traditional Endurance Training



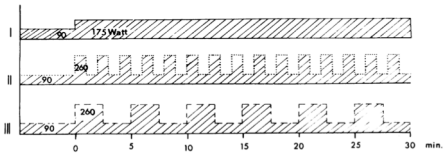
SIT can elicit adaptations *similar* to MICT despite less total work (and often in much less time)

MacInnis & Gibala, J Physiol 595: 2915-2930, 2017.

Optimum Patterns of Exercise for Healthy Adults

H. ROSKAMM, M.D., *Freiburg, Germany*

Soldiers assigned to 1 of 3 of exercise groups or control (n=20 each)



Canad. Med. Ass. J. Mar. 25, 1967, vol. 96

Optimum Patterns of Exercise for Healthy Adults

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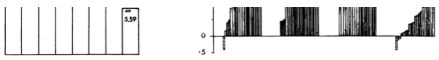
"Interval training is equally effective or even more effective in improving the maximum working performance."



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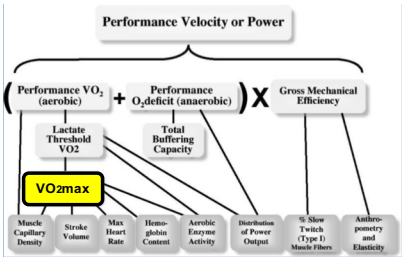
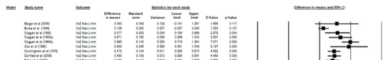
Physiological Determinants of Performance

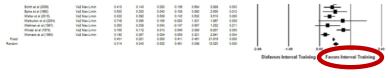


Joyner & Coyle. J Physiol 586: 35-44, 2008.

VO_2max Trainability and High Intensity Interval Training in Humans: A Meta-Analysis



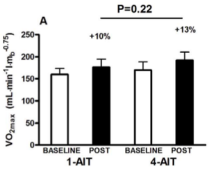
"Interval training produces improvements in VO_{2max} slightly greater (than) continuous training even though many of the studies were of short duration with limited sessions per week."



Bacon et al., PLoS One 8: e73182, 2013.

Low- and High-Volume of Intensive Endurance Training Significantly Improves Maximal Oxygen Uptake after 10-Weeks of Training in Healthy Men

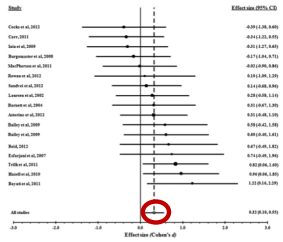
Inactive men performed 1x4-min or 4x4-min bouts of cycling at 90% HRmax



"a single bout of AIT performed three times per week may be a time-efficient strategy to improve VO2max (and reduce blood pressure and fasting glucose) in inactive but otherwise healthy middle-aged individuals."

Bacon et al., PLoS One 8: e73182, 2013.

Sprint Interval Training Effects on Aerobic Capacity: A Systematic Review and Meta-Analysis



318 participants from 16 RCTs who were assigned to 30-s "maximal" or "all out" interval exercise training or control

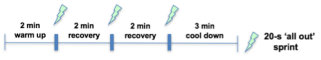
"SIT improves aerobic capacity in healthy young people. Relative to continuous endurance training of moderate intensity, SIT presents an equally effective alternative with a reduced volume of activity."

Gist et al. Sports Med. 44:269-279, 2014.

Twelve Weeks of Sprint Interval Training Improves Indices of Cardiometabolic Health Similar to Traditional Endurance Training despite a Five-Fold Lower Exercise Volume and Time Commitment

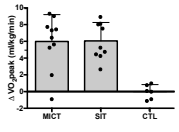
PLOS ONE | 309,824 View | 3,692 Share

Jenna B. Gillen, Brian J. Martin, Martin J. MacInnis, Lauren E. Skelly, Mark A. Tarnopolsky, Martin J. Gibala



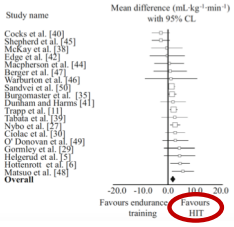
	SIT	MICT
Protocol (3x/wk)	3 x 20-s sprints within 10 min	50 min continuous
Workload	~ 500 W (50 W)	~ 110 W
RPE	16 (hard)	13 (somewhat hard)
Mean HR	~83%	~73%
Work/session	~60 kJ	~300 kJ

CRF ↑ 19% (~ 2 METs)



PLoS One 11: e0154075, 2016.

Effectiveness of High-Intensity Interval Training (HIT) and Continuous Endurance Training for VO_{2max} Improvements: A Systematic Review and Meta-Analysis of Controlled Trials

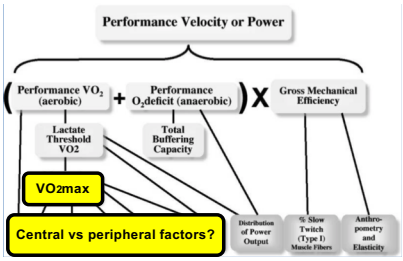


723 untrained or recreationally active subjects aged 18-45 y who performed 3-24 wk of interval or continuous training

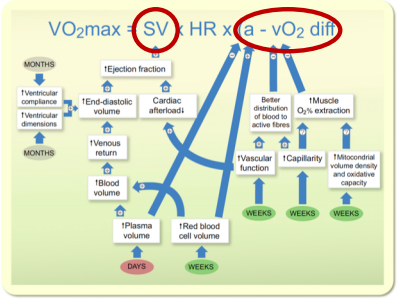
"In healthy, young to middle-aged adults, high intensity interval training improves maximal oxygen uptake to a greater extent than traditional endurance training."

Milanovic et al. Sports Med 45: 1469-1481, 2015.

Physiological Determinants of Performance



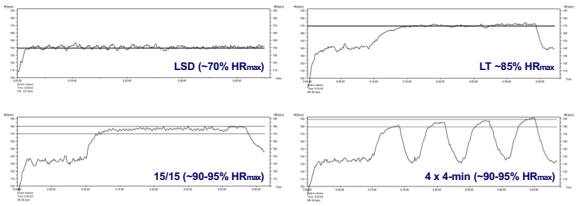
Joyner & Coyle. J Physiol 586: 35-44, 2008.



Lundby et al. Acta Physiol 2017, 220, 218-228.

Aerobic High-Intensity Intervals Improve $\dot{V}O_{2max}$ More Than Moderate Training

40 trained men assigned to 1 of 4 groups matched for total work (3x/wk for 8 wk)



Helgerud et al., Med Sci Sports Exerc. 39: 665-671, 2007.

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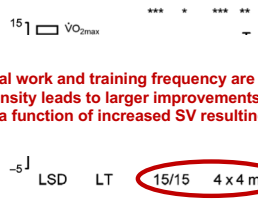


"When total work and training frequency are matched, higher aerobic intensity leads to larger improvements in VO_{2max} (which) seem to be a function of increased SV resulting in increased Q."

Helgerud et al., Med Sci Sports Exerc. 39: 665-671, 2007.

Improvements in exercise performance with high-intensity interval training coincide with an increase in skeletal muscle mitochondrial content and function

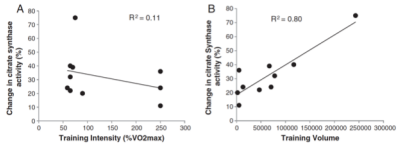
8-12 x 60-s intervals at ~100% PPO with 75-s recovery (6 sessions over 2 wk)

"The improvements in exercise performance occurred independent from any alterations in maximal cardiac capacity or blood characteristics (and) suggest that increases in mitochondrial content may facilitate improvements in respiratory capacity and oxygen extraction."

Jacobs et al. J Appl Physiol 115: 785-793, 2013.

Can we optimise the exercise training prescription to maximise improvements in mitochondria function and content?☆

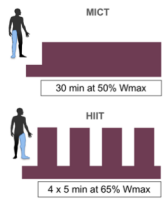
David J. Bishop *, Cesare Granata, Nir Eynon
Institute of Sport, Exercise and Active Living (ISEAL), Victoria University, Australia



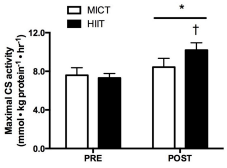
"Further research, directly comparing different training intensities and volumes within the same study is required."

Biochim Biophys Acta 1840: 1266-1275, 2014.

Superior mitochondrial adaptations in human skeletal muscle after interval compared to continuous single-leg cycling matched for total work



6 sessions per leg over 2 wk



Greater mitochondrial adaptations after interval vs continuous cycling despite same total work

Exercise intensity and/or contraction pattern is important

MacInnis et al., J Physiol 595: 2955-2968, 2017.

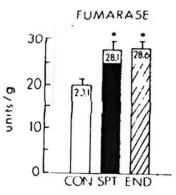
Skeletal muscle enzyme alterations after sprint and endurance training

SPT = 48 x 10 sec sprints (99 m/min) with 40 sec recov

8 min total work (800 m)

END = 50 min continuous running (36 m/min)

50 min total work (1800 m)

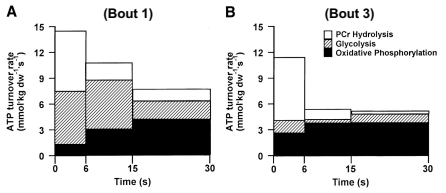


"We did not expect to find an increase in muscles of sprint-trained animals because **aerobic metabolism contributes very little of the energy**."

Hickson RC et al. J Appl Physiol. 40: 868-872, 1976.

Sprinting is Highly Dependent on Aerobic Metabolism!

3 x 30-s 'all out' sprints with 4 min recovery periods



Parolin et al. Am J Physiol 277: E890-E900, 1999.

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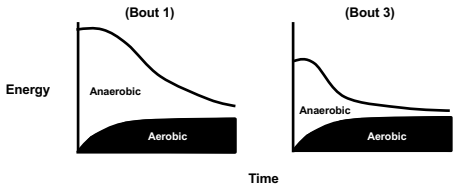


Parolin et al. Am J Physiol 277: E890-E900, 1999.

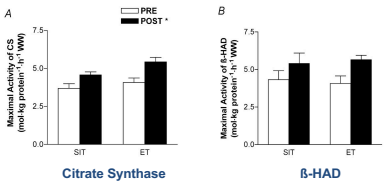
Similar metabolic adaptations during exercise after low volume sprint interval and traditional endurance training in humans

Group (n = 10 each)	Sprint	Endurance
Training Intensity	"All out" effort (~500 W)	65% VO_2 peak (~150 W)
Exercise Protocol (6 wk)	30 sec x 4-6, 4 min recov 3x / wk	40-60 min 5x / wk
Weekly Exercise Time	~10 min	~4.5 h
Weekly Training Time (including recovery)	~1.5 h	~4.5 h
Weekly Training Volume	**90% lower in Sprint group**	

Burgomaster et al. J Physiol. 151-160, 2008.

Similar metabolic adaptations during exercise after low volume sprint interval and traditional endurance training in humans

Similar increases in mitochondrial enzymes



Citrate Synthase ß-HAD

Burgomaster et al. J Physiol. 151-160, 2008.

Similar metabolic adaptations during exercise after low volume sprint interval and traditional endurance training in humans

Similar changes in fuel utilization (1 h at 65% VO2peak)

PRE
POST *

PRE
POST *

"Low-volume SIT is a time-efficient strategy to induce changes in selected markers of whole-body and skeletal muscle metabolism during exercise that are comparable to changes induced by traditional high-volume (endurance training)".

Rest 60 min

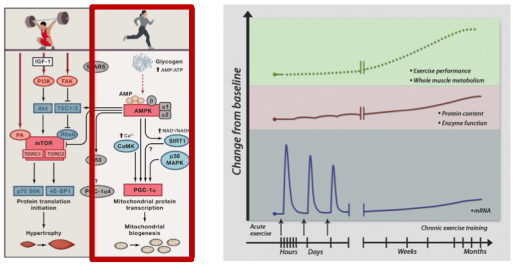
Endurance Group

Rest 60 min

Sprint Group

Burgomaster et al. J Physiol. 151-160, 2008.

How Do Sprints Elicit Endurance Adaptations?



Hawley et al. Cell 159: 738-749, 2014 (left); Egan & Zierath, Cell Metab 17: 162-184, 2013 (right).

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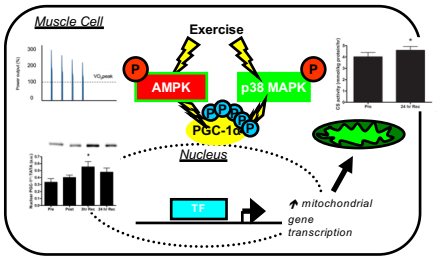
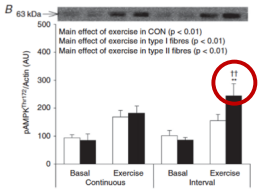


Little et al. Am J Physiol 300: R1303-1310, 2011.

Human muscle fibre type-specific regulation of AMPK and downstream targets by exercise

30 min continuous at ~70% or 6 x 1.5 min intervals at ~95% VO_{2peak}

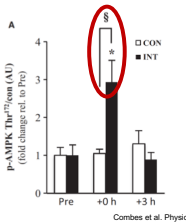


"increased activation of AMPK in interval vs. continuous exercise could be important for exercise type-specific adaptations"

Kristensen et al. J Physiol 590: 2053-2069, 2015.

Exercise-induced metabolic fluctuations influence AMPK, p38-MAPK and CaMKII phosphorylation in human skeletal muscle

30 min continuous or 30 x 1-min intervals (1-min recovery) at ~70% VO_{2peak}



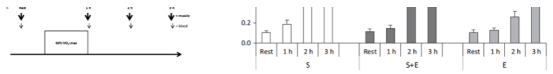
"metabolic fluctuations caused by the succession of on- and off-transients during intermittent exercise are critical (for adaptation)"

Combes et al. Physiol Rep 3: e12462, 2015.

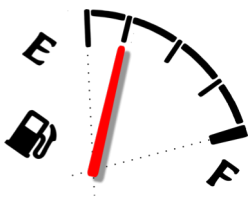
Combined speed endurance and endurance exercise amplify the exercise-induced PGC-1α and PDK4 mRNA response in trained human muscle

60 min continuous at ~60% VO_2max or 6 x 30-s 'all out' sprints (or both)

"in trained subjects, speed endurance exercise provides a stimulus for muscle (adaptation) that is not evident with endurance exercise"



Skovgaard et al. Physiol Rep 4: e12864, 2016.



https://pixabay.com/en/fuel-meter-meter-indication-end-311685/

Take Home Point

Interval exercise training is a powerful stimulus to elicit physiological remodeling that is similar, or superior, to traditional endurance training; however, the precise role of exercise intensity, duration, and frequency in determining specific responses, the time course for changes, inter-individual variation in responsiveness, and the integrated cellular regulators of training adaptation, remain fruitful areas of investigation.