2020 LA '84 Foundation:
Presentation I

- **Endurance Training Program Design:** ***An Evidence-Based, Physiological Perspective on "Why We Do What We Do"***

2020 LA '84 Foundation: *Presentation I*

- **Endurance Training Program Design:** ***An Evidence-Based, Physiological Perspective on "Why We Do What We Do"***

Dr. Jeffrey I. Messer

Faculty - Exercise Physiology, Exercise Science Department, Mesa Community College, Mesa, AZ.

Volunteer Assistant Coach, Boy's Cross-Country, Desert Vista High School, Phoenix, AZ.

jeff.messer@mesacc.edu
(*480*) 461 – 7378

Presentation Overview

- Part I: Speaker Background
- Part II: What This Presentation Is Not
- Part III: Training Program Philosophy
- Part IV: Training – Art & Science

Presentation Overview

- **Part V: Maximal Aerobic Power ($\dot{V}O_{2}$-$_{MAX}$)**
- **Part VI: Lactate Threshold (*LT*)**
- **Part VII: Running Economy (*RE*)**
- **Part VIII: The Long Run (*LR*)**

Presentation Overview

- Part IX: Protein Requirements & Protein Distribution in Endurance Athletes
- Part X: Mitochondrial Quality versus Mitochondrial Quantity
- Part XI: Acknowledgments
- Part XII: Questions & Discussion

Presentation Overview

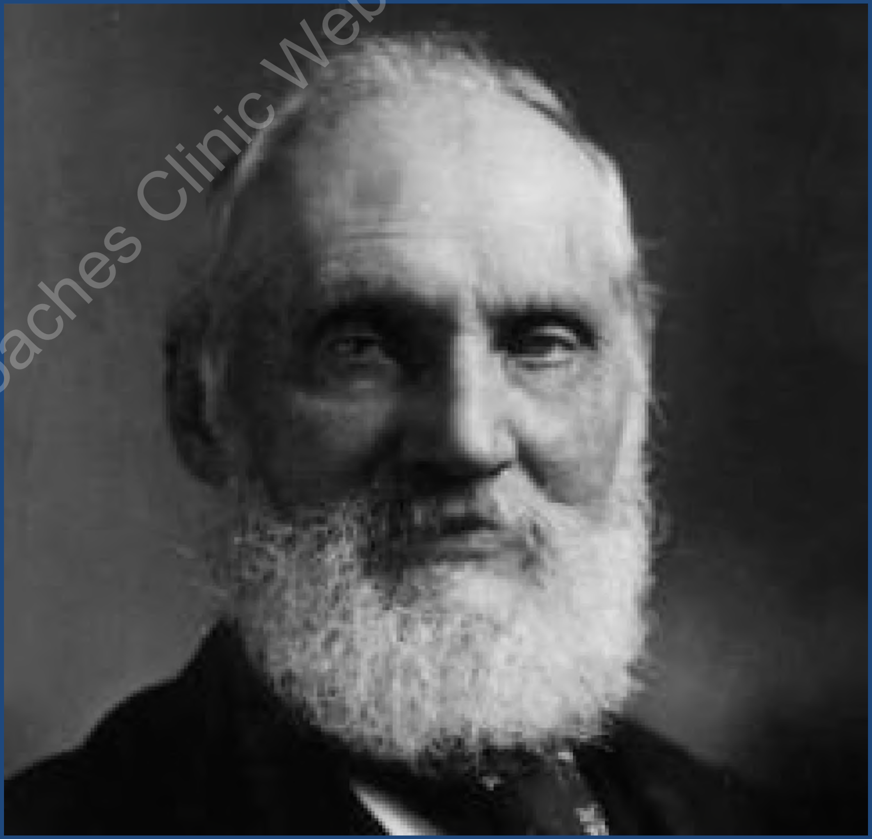
- **Part XIII: Appendices**

Part I

Speaker Background

Evidence-Based Inquiry

- "I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind"



Lord Kelvin

Evidence-Based Inquiry

- "If I have seen further than others, it is by standing upon the shoulders of giants"

Isaac Newton

Speaker Background

- Education – **Ph.D. in exercise physiology w/ concentration in exercise biochemistry (*Arizona State University, 2004*)**
  - M.S. Exercise Science (*Arizona State University, 1995*)
  - M.B.A. (*Duke University, 1992*)
  - B.A. Economics (*Wesleyan University, 1984*)

- Experience – Darien High School (*2.0 Years*), Desert Vista High School (*2.5 Years*), Queen Creek High School (*1.5 Years*), Xavier College Preparatory (*6.5 Years*), & Desert Vista High School (*2013 / 2014 / 2015 / 2016 / 2017 / 2018 / 2019*)

Speaker Background

- **Coaching Influences**
  - **Chris Hanson / Ellie Hardt / Dave Van Sickle**
  - ***Dan Beeks, Michael Bucci, Renato Canova, Robert Chapman, Steve Chavez, Liam Clemons, Bob Davis, Erin Dawson, Marty Dugard, Jason Dunn, John Hayes, Brad Hudson, Jay Johnson, Tana Jones, Arthur Lydiard, Steve Magness, Joe Newton, Dan Noble, Jim O' Brien, Tim O'Rourke, Rene Paragas, Haley Paul, Louie Quintana, Ken Reeves Alberto Salazar, Jerry Schumacher, Tom Schwartz, Brian Shapiro, Scott Simmons, Mando Siquieros, Renee Smith-Williams, Doug Soles, Danna Swenson, Bill Vice, Joe Vigil, Mark Wetmore, & Chuck Woolridge***

Speaker Background

- Tara Erdmann, 2:14 / 4:54
- Kari Hardt, 2:11 / 10:26
- Baylee Jones 2:16 / 4:55 / 10:36
- Danielle Jones, 2:09 / 4:39 / 10:09
- Haley Paul, 2:13 / 4:51

- Desert Vista High School: 2016, 2014, & 2013 Arizona State High School Girls' Cross-Country Team Champions
- Xavier College Preparatory: 2012, 2011, 2010, 2009, 2008, and 2007 Arizona State High School Girls' Cross-Country Team Champions
- Two (*2*) Foot Locker National (*FLN*) Championship qualifiers

Speaker Background

- Sarah Penney, 2:11 / 10:39
- Mason Swenson, 2:16 / 4:59 / 10:56
- Jessica Tonn, 2:13 / 4:50 / 10:21
- Sherod Hardt, 4:10 / 8:59
- Garrett Kelly, 4:17 / 9:18
- 4 x 1,600-m Relay (20:14 / 20:52 / 21:37 XCP) & 4 x 800-meter Relay (8:57 XCP / 9:01 DVHS)

- Desert Vista High School: 2002, 2017, & 2018 Arizona State High School Boys' Cross-Country Team Champions
- 2012 Mt. SAC Relays 4 x 1,600-m Event – 3 teams / 12 student-athletes averaged 5:13 per split
- Four (*4*) time NXN team participant across two schools & two genders (*XCP, DVHS*) and one (*1*) time NXN individual qualifier

Part II

What This Presentation Is Not

“What this presentation is *not*”

Xavier College Preparatory or Desert Vista High School Training Philosophies or Training Programs

https://www.highschoolrunningcoach.com/

Part III

Training Program Philosophy

Program Philosophy

- Emphasize Plan, Structure, & Discipline
- Cumulative, Consistent Aerobic Development
- Conjugate Periodization

Program Philosophy

- Consistent Patterns of Weekly, Phasic, Seasonal, and Annual Training
- Individualization & Development
- Shared Responsibility

Part IV

Training - Art & Science

Art & Science: Energetic Demands of a 5-Kilometer Race

Energy Source Comparisons for Middle Distance and Distance Events

"*Classic*" Model

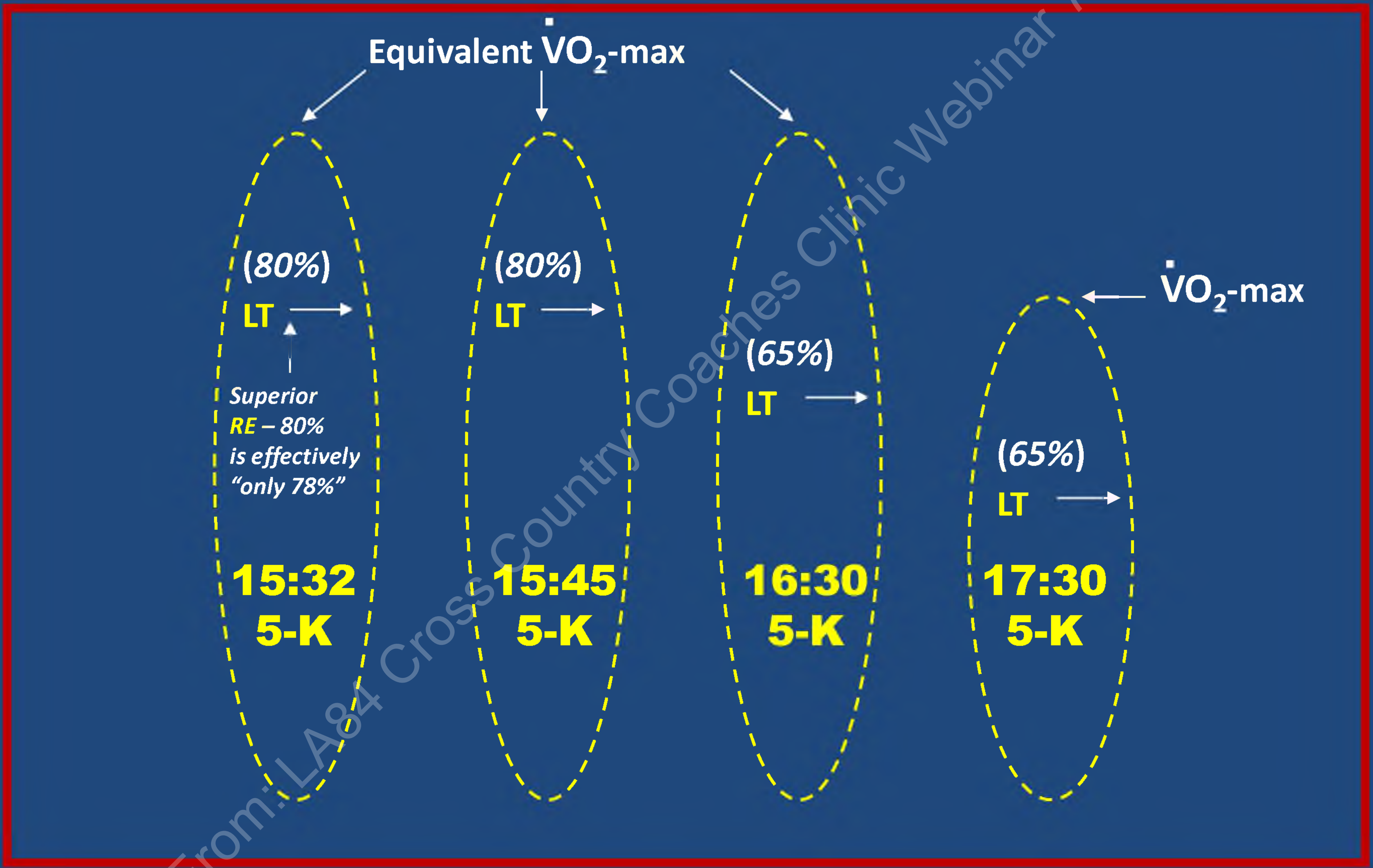
Energy Source	400	800	1,500	5,000	10,000	Mar
Aerobic (%)	18.5	35.0	52.5	80.0	90.0	97.5
Anaerobic (%)	81.5	65.0	47.5	20.0	10.0	2.5

"*Current*" Model

Energy Source	400	800	1,500	5,000	10,000	Mar
Aerobic (%)	43.5	60.5	77.0	94.0	97.0	99.0
Anaerobic (%)	56.5	39.5	23.0	6.0	3.0	1.0

*The "*current*" model was determined using the latest methodology in oxygen uptake kinetics and with a much more elite subject population than the "*classic*" model.

Art & Science: Physiological Correlates of Endurance Performance Potential



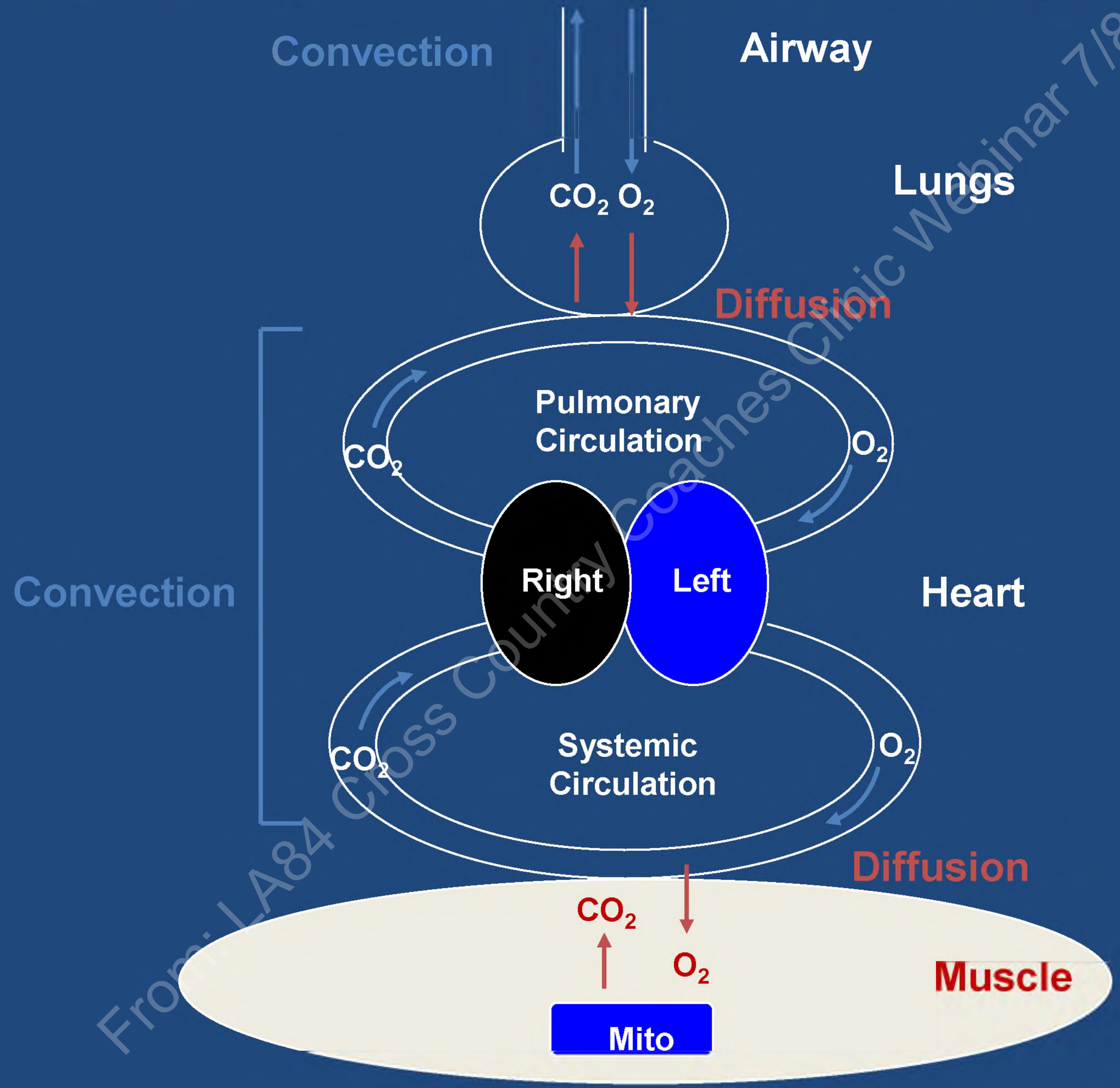
Part V

Maximal Aerobic Power ($\dot{V}O_2$-*max*)

Maximal Aerobic Power ($\dot{V}O_2$*-max*)

- Endurance / Aerobic Training …
  - Improves $\dot{V}O_2$-max or, more specifically, …
  - Enhances cardiovascular function (*maximal cardiac output*)
  - Increases total blood volume
  - Enhances capillary density
  - Improves the detraining response
  - Elevates mitochondrial content

Improving the Maximal Rate of O_2 Delivery



Training Increases $\dot{V}O_2$-max

- Typical training regimen
  - ~ 70% $\dot{V}O_2$-max
  - 30 - 40 minutes * day^{-1}
  - 4 - 5 days * $week^{-1}$
  - 3 - 5 months
- Typical increase in $\dot{V}O_2$-max ~ 10 - 20%
  - Subjects who were previously sedentary
    - Larger % increases
  - Subjects with higher initial $\dot{V}O_2$-max
    - Smaller % increases
    - *Essentially all of the increase due to increased maximal $\dot{Q}$*

Training and VO_2-max: 3 Human Studies

(Gollnick et al.; Wibom et al.; and Howald et al.)

- Training
  - Cycle ergometer
  - Training period, Frequency, Duration, Intensity
    - Gollnick et al.: 5 months, 4 d/wk, 1 hr/d, 75-90% VO_2max
    - Wibom et al.: 6 wk, 4 d/wk, 36 min/d, 70% VO_2max
    - Howald et al.: 6 wk, 5 d/wk, 30 min/d, 72 % VO_2max
- Improvements in VO_2-max (*i.e. Aerobic Capacity*)
  - Gollnick: 13% (46.5 to 52.5 ml · min^{-1} · kg^{-1})
  - Wibom: 9.6% (44.0 to 48.2 ml · min^{-1} · kg^{-1})
  - Howald: 14% (43.2 to 49.4 ml · min^{-1} · kg^{-1})

Adaptive Increase in VO_2-max Is Dependent Upon Training Stimulus

- More strenuous regimens elicit greater increases
- Hickson et al. (*J. Appl. Physiol. 42: 372-376, 1977*)
  - Protocol (*8 healthy subj, age 20-42, 6 d/wk exercise, 10 wk*):
    - 3 d/wk: Interval cycling 6 x 5' @ 100% VO_2max: 2' @ 50%
    - 3 d/wk: Run steady rate as far as possible in 40'
  - Results:
    - Mean increase in VO_2max = 44% ! (*from 38.2 to 55.0 ml/kg/min*)
    - Increased VO_2max correlated with improved endurance
    - One subject continued to train an additional 3 wks - total increase was 77% (*22.8 to 41.0 ml/kg/min*)

Training Increases Ventricular Size and $\dot{Q}_{max}$

(*Adapted from: Rerych, S.M. et al. Am. J. Cardiol. 45: 244-252, 1980*)

		Heart Rate (b/min)	EDV (ml)	SV (ml)	Ejection Fraction (%)	Cardiac Output (l/min)	Total Blood Volume (liters)
Rest	Before	74	133	95	73	6.9	8.7
	After	61*	167*	112*	67	6.7	11.4*
Maximal Exercise	Before	185	166	144	87	26.6	8.0
	After	181	204*	176*	86	32.0*	10.8*

18 college swim athletes studied before and after 6 mo. intensive training
Mean age = 19 yrs; 6 females, 12 males

Aerobic High-Intensity Intervals

- **Helgerud, J., Hoydal, K., Wang, E., Karlsen, T., Berg, P., Bjerkaas, M., Simonsen, T., Helgesen, C., Hjorth, N., Bach, R., & Hoff, J. (*2007*). Aerobic High Intensity Intervals Improve $VO_{2\text{-}MAX}$ more than Moderate Training, Medicine and Science in Sports and Exercise, 39(*4*), 665-671**

Helgerud et al. (*2007*)

- **Long, slow distance running (*LSD*)**
  - **Continuous run @ 70% of HR_{MAX} (*137 bpm*) for 45-minutes**
- **Lactate threshold running (*LT*)**
  - **Continuous run @ 85% of HR_{MAX} (*171 bpm*) for 24.25-minutes**

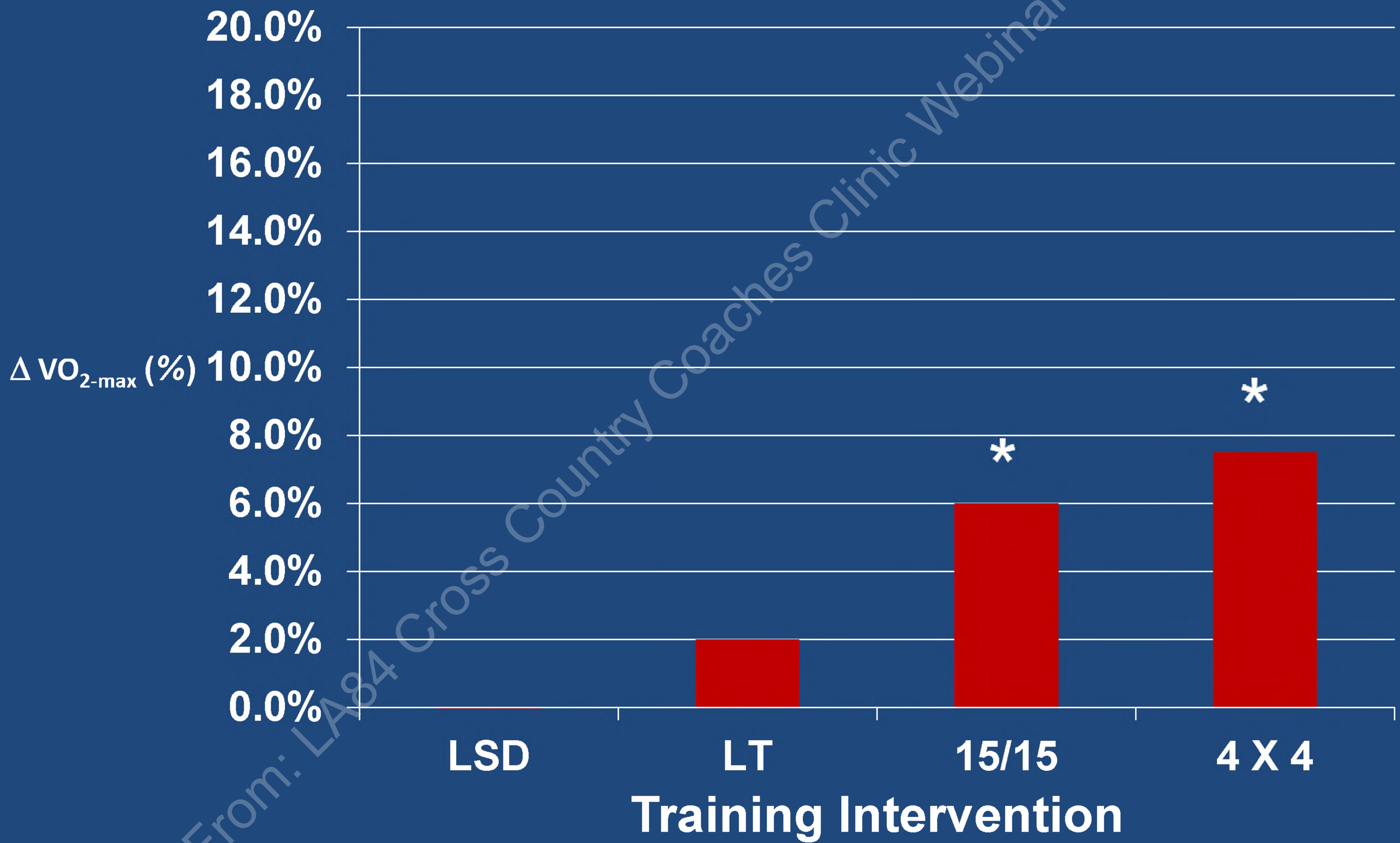
Helgerud et al. (*2007*)

- 15 / 15 interval running (*15 / 15*)
  - 47 repetitions of 15-second interval runs @ 90 - 95% of HR_{MAX} (*180 - 190 bpm*) interspersed w/ 15-second active recovery periods @ 70% of HR_{MAX} (*140 bpm*)
- 4 x 4 interval running (*4 x 4*)
  - 4 x 4-minute interval runs @ 90 - 95% of HR_{MAX} (*180 - 190 bpm*) interspersed w/ 3-minute active recovery periods @ 70% of HR_{MAX} (*140 bpm*)

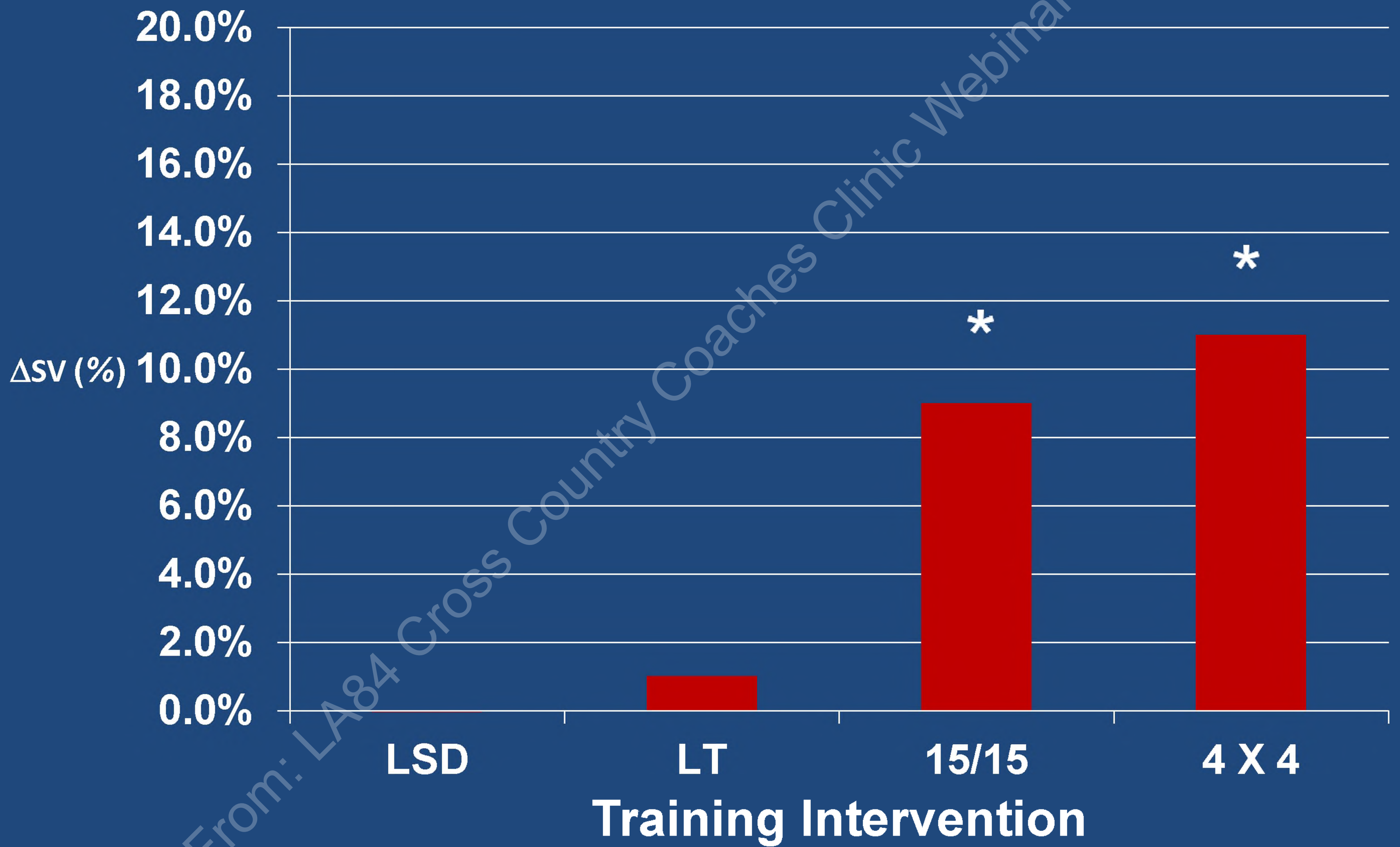
Helgerud et al. (*2007*)

Which training intervention is relatively more effective in eliciting improvement(*s*) in maximal aerobic capacity, stroke volume, running economy, and / or lactate threshold?

Helgerud et al. (*2007*)



Helgerud et al. (*2007*)



Helgerud et al. (*2007*)

Potential Interpretation: Long, slow distance training and / or threshold training may not be particularly effective in improving maximal aerobic capacity in already well-conditioned individuals

Helgerud et al. (*2007*)

- **Physiological Correlate**
  - $\dot{V}O_{2MAX} = \dot{Q}_{MAX} * (a\text{-}v)O_{2DIFF}$ (*Fick Principle*)
  - $\dot{Q}_{MAX} = HR_{MAX} * SV_{MAX}$
  - **Endurance Training (*ET*) does not Increase HR_{MAX}**
  - **Thus, one Focus of ET should be Enhancement of SV_{MAX}**

Helgerud et al. (*2007*)

Potential Application: Consistent (*for example, weekly*) incorporation of a workout or workouts emphasizing approx. 4-minute repetitions @ 90 – 95% of HR_{MAX} may induce a very potential stimulus for enhancement of both maximal stroke volume and maximal aerobic capacity

Mitochondrial Content: Effects of Training

(*Adapted from: Howald, H. et al. Pflugers Archives, 403: 369-376, 1985*)

Mitochondrial Volume Density (*% of Total Cell Volume*)	Untrained	Trained
Type I Fibers	6.18%	8.36% (*35%*)
Type IIa Fibers	4.54%	7.02% (*55%*)
Type IIx Fibers	2.33%	3.55% (*52%*)

Skel. Muscle Capillarization: Effects of Training and Detraining

(*Adapted from: Klausen, K. et al. Acta Physiol. Scand. 113: 9-16, 1981*)

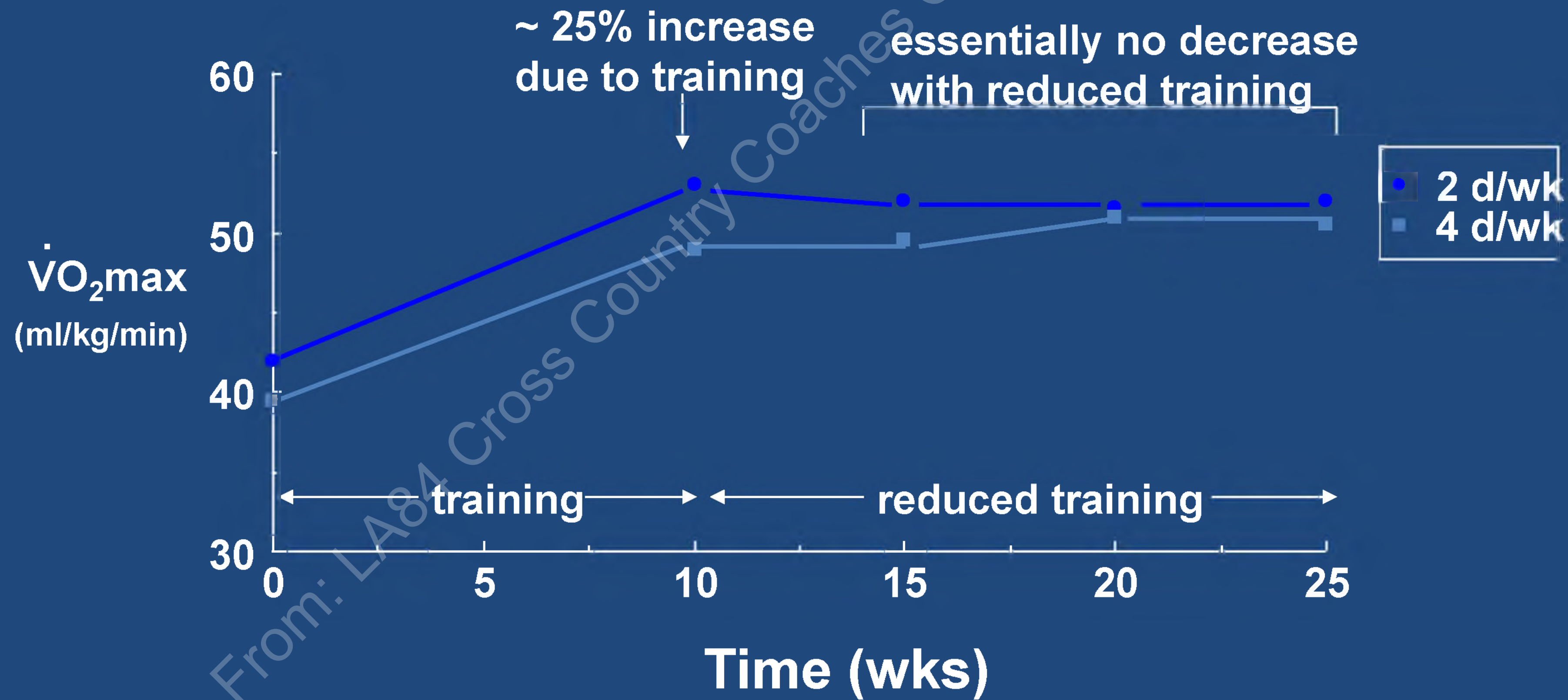
	Before Training	Weeks After Training 0	4	6
Capillaries per fiber	2.07 ± 0.11	120.3 ± 7.9	106.3 ± 7.3	106.8 ± 7.5
Caps around each fiber				
ST	5.35 ± 0.29	123.4 ± 7.9	108.6 ± 4.9	103.7 ± 7.8
FTa	5.14 ± 0.13	120.8 ± 5.9	108.6 ± 5.6	108.6 ± 7.0
FTb	4.27 ± 0.17	129.7 ± 6.9	115.0 ± 4.3*	112.2 ± 2.9

Detraining values are expressed as % pretraining value
All values at "0 weeks' posttraining are significantly higher than pretraining
All values during detraining are significantly lower than the "0 weeks" values except for *
Values are means ± SE (n = 5 - 6)

Detraining Effects On $\dot{V}O_2$-max

(Hickson and Rosenkotter, Med. Sci. Sports Exerc. 13: 13-16, 1981)

- Protocol
  - Training as before (6 d/wk, 40 min/d, 10 wk)
  - After 10th wk training reduced to either 2 or 4 d/wk



VO_2-max and HIIT

- Bacon, A.P., Carter, R.E., Ogle, E.A., & Joyner, M.J. (*2013*). VO_2-max Trainability and High Intensity Interval Training in Humans: A Meta-Analysis, PLOS, September, 8:9, e73182.

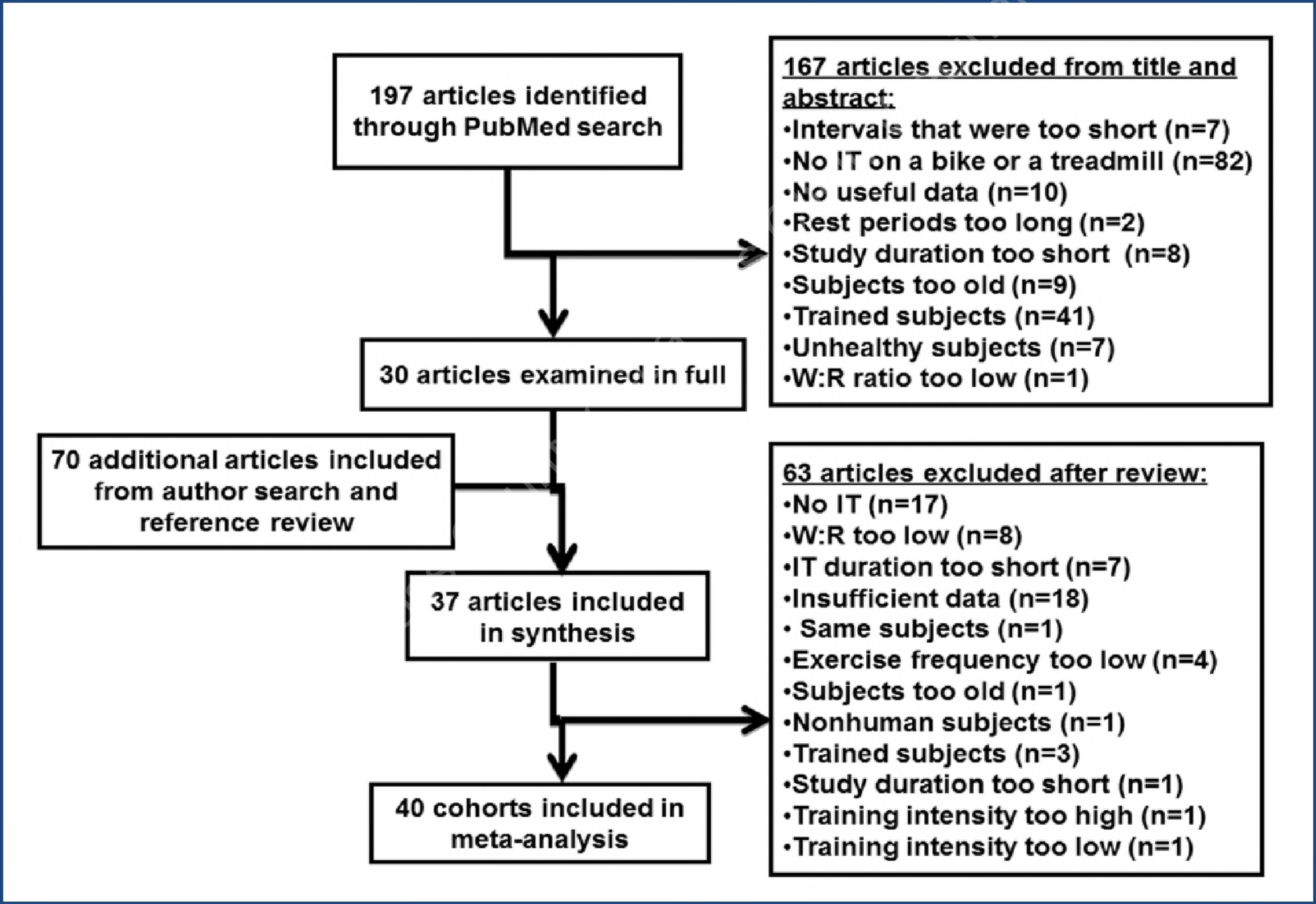
- Analysis reviewed studies published in English from 1965 – 2012
- Study inclusion criteria involved 6- to 13-week training periods, ≥ 10-minutes of HIIT in a representative training session (*i.e.workout*), and a ≥ 1:1 work:rest ratio

VO_2-max and HIIT

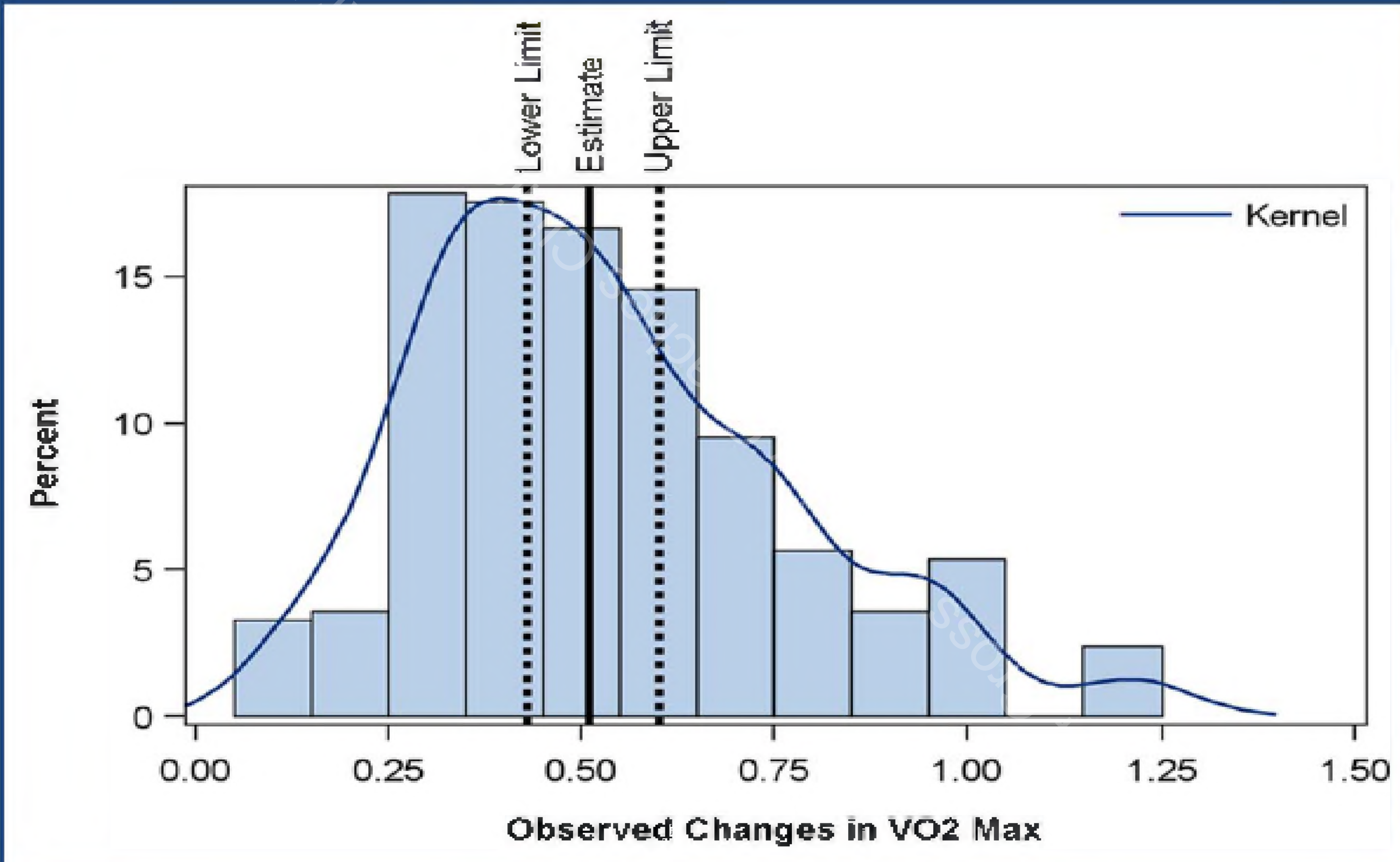
- **Authors note "*conventional wisdom*" that repetitions of 3- to 5-minutes are thought to be particularly effective in invoking enhanced aerobic capacity**

- **Current analysis strongly supports this perspective; the nine (*9*) studies that associate with the greatest increases in maximal aerobic capacity (*VO_2-max*) involve 3- to 5-minute intervals and relatively high intensities (*≥ 85% of VO_2-max*)**

VO_2-max and HIIT



VO_2-max and HIIT



VO_2-max and HIIT

Potential Interpretation: **Emphasize repetitions of, for example, 800-m, 1,000-m, and 1,200-m in order to provide a robust stimulus for enhancement of maximal aerobic capacity (*and include very brief, for instance, repetitions of 150-m and 200-m to provide a complementary stimulus for enhancement of both maximal aerobic capacity and running economy, Gibala et al., 2012*)**

Adaptations to Aerobic Interval Training

- Seiler, S., Joranson, K., Olesen, B.V., & Hetlelid, K.J. (*2013*). Adaptations to Aerobic Interval Training: Interactive Effects of Exercise Intensity and Total Work Duration, Scandinavian Journal of Medicine and Science in Sports, 23, 74 – 83.
- Experimental Objective: To compare the effects of three distinct 7-week interval training programs varying in duration but matched for effort in trained cyclists

Adaptations to Aerobic Interval Training

- **Experimental design**
  - Thirty-five (*35*) well-trained (*pre-training* VO_2*-peak* = *52* ± *6 ml* O_2 * kg^{-1} * min^{-1}) cyclists
  - Four distinct seven-week training protocols
  - Average of approximately five (*5*) training sessions per week for the seven-week training period
  - All participants completed pre- and post- maximal aerobic capacity testing and time trial evaluation

Adaptations to Aerobic Interval Training

- Experimental design
  - One group (*six males, two females*) engaged strictly in low-intensity, continuous training four to six times per week {*"long, slow distance"*}
  - One group (*seven males, two females*) executed two weekly sessions of 4 x 16-minutes (*w/ a three-minute recovery*) in addition to two-to-three weekly, low-intensity, continuous training sessions {*"threshold training"*}

Adaptations to Aerobic Interval Training

- **Experimental design**
  - **One group (*nine males*) executed two weekly sessions of 4 x 8-minutes (*w/ a two-minute recovery*) in addition to two-to-three weekly, low-intensity, continuous training sessions {*"Supra-threshold, sub-VO_2-max training"*}**
  - **One group (*seven males, two females*) executed two weekly sessions of 4 x 4-minutes (*w/ a two-minute recovery*) in addition to two-to-three weekly, low-intensity, continuous training sessions {*"VO_2-max training"*}**

Adaptations to Aerobic Interval Training

Table 3. Physiological test results before and after training

	Low ($n = 8$)		4 × 16 min ($n = 9$)		4 × 8 min ($n = 9$)		4 × 4 min ($n = 9$)	
	PRE mean (SD)	POST	PRE	POST	PRE	POST	PRE	POST
Weight (kg)	80.4 (12.5)	79.5* (12.2)	83.8 (10.8)	81.6* (11.0)	89.7 (11.3)	88.1* (10.9)	79.9 (13.3)	78.7 (12.9)
Body fat (%)	20.8 (7.2)	20.0* (7.2)	22.2 (5.4)	20.7 (5.2)	20.5 (5.3)	19.5* (6.1)	18.4 (2.9)	17.7 (3.9)
HF_{peak}	182 (12)	182 (9)	183 (9)	178* (8)	185 (7)	180* (8)	179 (7)	177 (8)
$V_{E\ Peak}$(L/min)	157 (35)	159 (40)	155 (35)	158 (39)	168 (19)	180* (21)	149 (35)	159 (37)
Lactate $_{peak}$ (mmol/L)	14.9 (1.6)	13.7* (1.0)	14.8 (1.6)	13.9 (1.5)	14.1 (2.0)	13.4 (1.4)	13.8 (1.5)	14.0 (2.1)
RPE $_{peak}$	19.4 (0.5)	19.5 (0.5)	19.3 (0.7)	19.6 (0.5)	19 (0.7)	19.2 (0.7)	19.4 (0.5)	19.8 (0.3)
VO_{2peak} (L/min)	4.2 (0.7)	4.3 (0.7)	4.3 (0.5)	4.5* (0.7)	4.7 (0.5)	5.1* (0.5)	4.0 (0.8)	4.2 (0.9)
(ml kg/min)	52.7 (8.0)	54.5 (6.9)	51.1 (5.8)	54.4* (5.2)	52.8 (4.8)	58.3* (5.8)	50.4 (5.8)	53.2 (7.6)
Power $_{VO2peak}$ (W)	349 (44)	358 (48)	361 (51)	372* (50)	378 (52)	410* (27)	343 (68)	361* (72)
(W/kg)	4.5 (0.6)	4.6 (0.6)	4.3 (0.4)	4.6* (0.4)	4.2 (0.5)	4.7* (0.5)	4.3 (0.4)	4.6* (0.5)
$Power_{4\ mM}$ (W)	222 (42)	239* (38)	228 (51)	249* (45)	241 (41)	280* (33)	220 (49)	238* (55)
TTE80% (min)	10.86 (2.6)	12.14 (3.2)	8.52 (1.8)	13.83* (4)	11.88 (4.1)	22.7* (12)	9.7 (2.8)	15.84* (7.1)

*$P < 0.05$ vs the pre-test value.

Adaptations to Aerobic Interval Training

The 4 x 8-minute group realized superior improvement in maximal aerobic capacity, peak power output, and endurance time trial performance

Adaptations to Aerobic Interval Training

Potential Interpretation: By slightly reducing training intensity below near-VO_2-max intensity and extending total training volume (*32-minutes relative to 16-minutes*), participants training at approximately 90% of maximal heart rate achieved greater overall adaptive effects than participants training at a higher, relative intensity

Adaptations to Aerobic Interval Training

Potential Application: Emphasize "*combination workouts*" that incorporate a spectrum of repetitions (*for example, 2 x 1,200-m, 4 x 800-m, & 6 x 400-m*) and thus provide a complementary, aggregate stimulus for the improvement of both physiological characteristics (*VO_2-max*) and assessment measures (*time trial performance*)

Part VI

Lactate Threshold (*LT*)

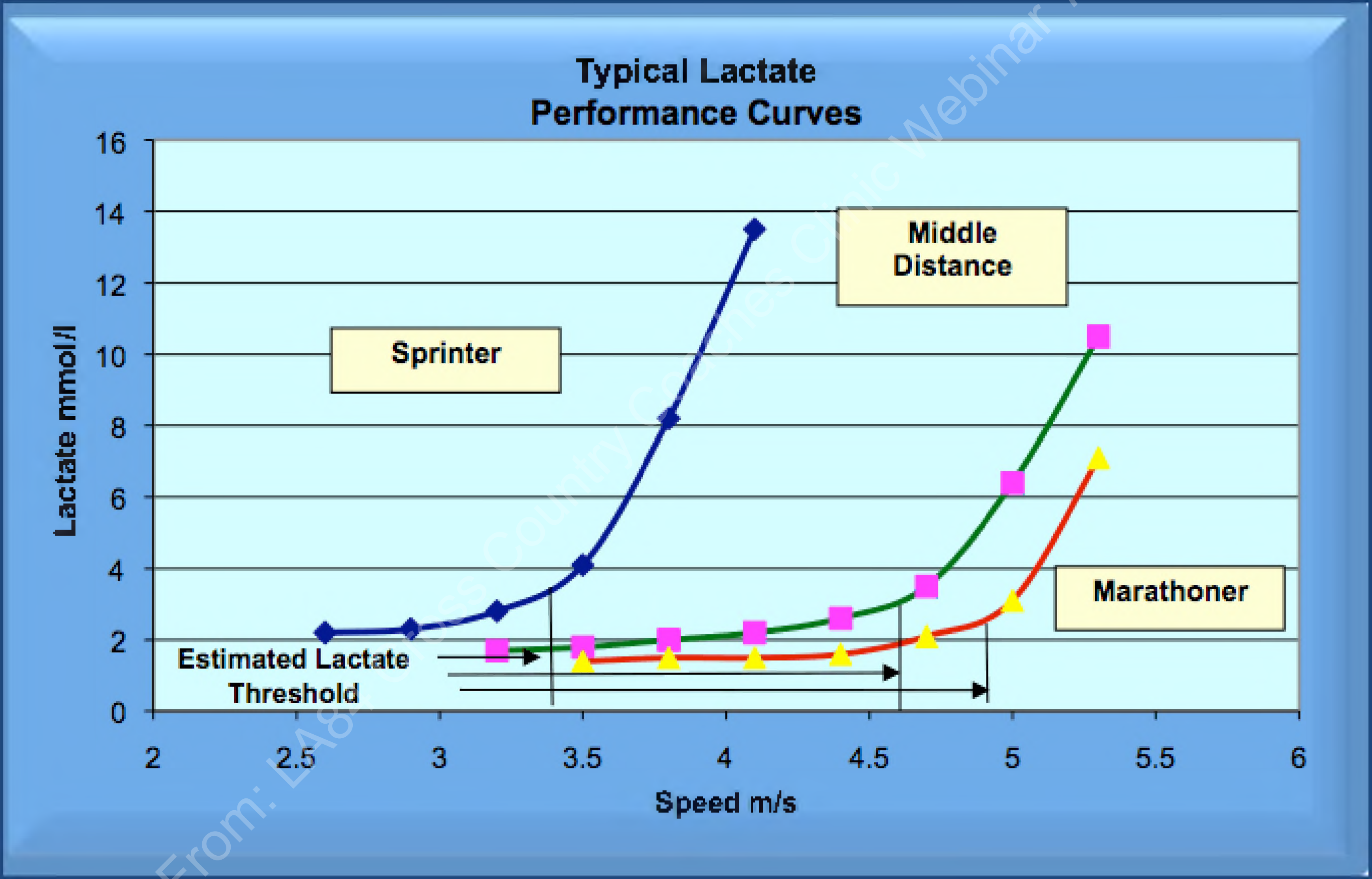
Lactate Threshold

The *lactate threshold* is the *maximal* effort or *intensity* that an athlete *can maintain for an extended period of time with little or no increase in lactate in the blood*. It is an effort or intensity and not a specific lactate level. It is most often described as a speed or pace such as meters per second, or times to achieve certain distances such as minutes per mile or kilometer for running and minutes per 100-m in swimming, or as a power measure such as watts

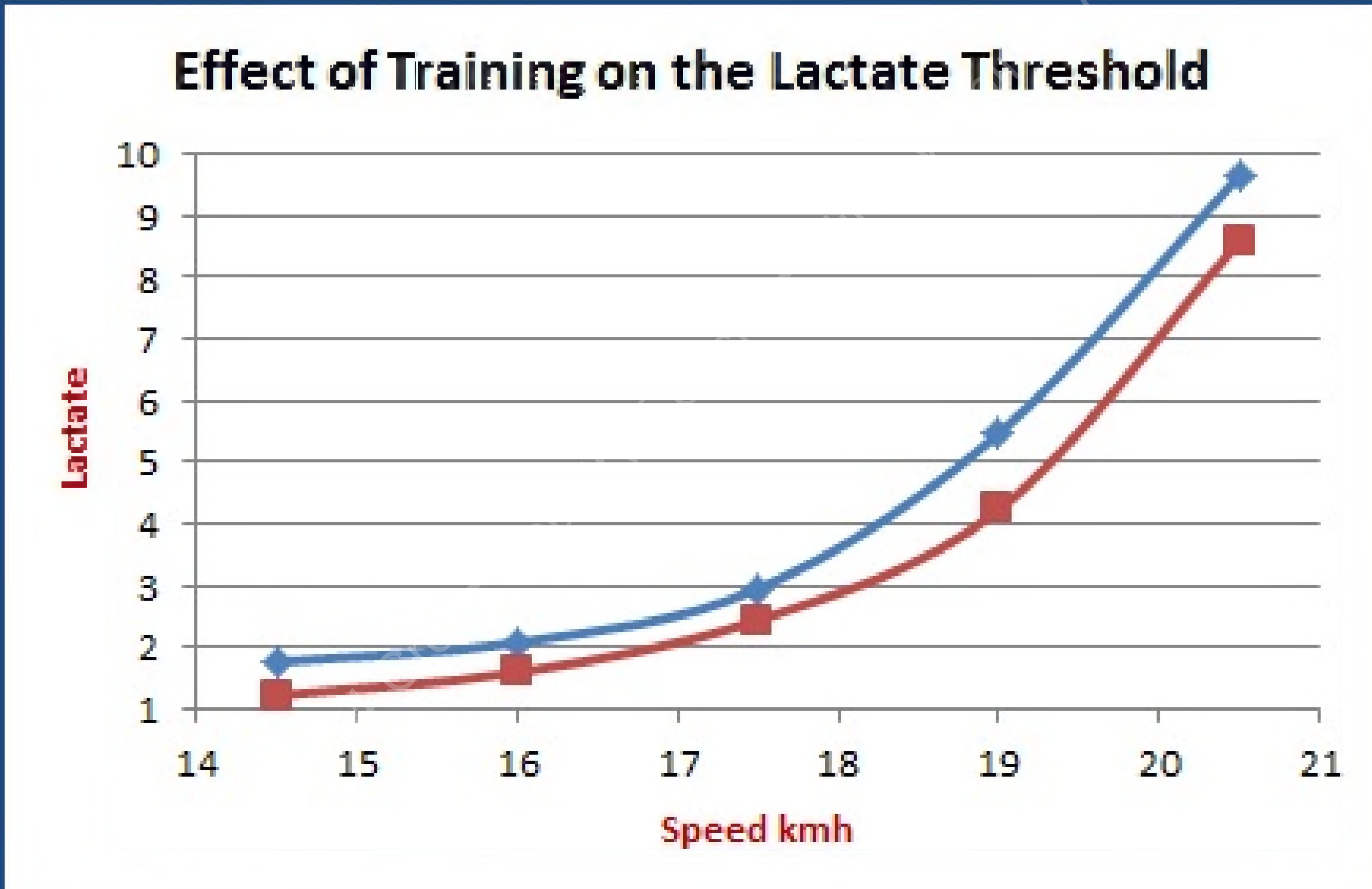
Lactate Threshold

- **Billat, V.L. (*1996*). Use of Blood Lactate Measurements for Prediction of Exercise Performance and for Control of Training Recommendations for Long Distance Running, Sports Medicine, 22, 157 – 175.**
- **Multiple decades of experimental work such as Billat (*1996*) has catalyzed a general scientific and practitioner's consensus that an *improvement in lactate threshold* results in an *improvement in endurance performance***

Lactate Threshold



Lactate Threshold



Lactate Threshold

Question: ***Do We Know*** **How to Consistently, Significantly Improve Lactate Threshold?**

Lactate Threshold

- **Londeree, B. (*1997*). Effect of Training on Lactate / Ventilatory Thresholds: A Meta-Analysis, Medicine and Science in Sports and Exercise, 29, 837 – 843.**
- **This research synthesis concluded that *highly-trained individuals* may need to *train at much higher than lactate threshold intensities* in order to enhance the lactate threshold**

Lactate Threshold

- **Sjodin, B., Jacobs, I., & Svedenhag, J. (*1982*). Changes in Onset of Blood Lactate Accumulation (*OBLA*) and Muscle Enzymes after Training at OBLA, European Journal of Applied Physiology, 49, 45 – 57.**

- **Eight (*8*) male middle- & long-distance runners**
- **Mean Age: 20 years old**
- **Initial VO_2-max: 68.7 mL 0_2 * kg^{-1} * min^{-1}**
- **Study Duration: 14-weeks**
- **One (*1*) 20-minute threshold session * $week^{-1}$ @ 85% vVO_2-max**
- **Percentage (*%*) LT Improvement: *4.3***

Lactate Threshold

- Tanaka, K., Watanabe, H., & Konishi, Y. (*1986*). Longitudinal Association between Anaerobic Threshold and Distance Running Performance, European Journal of Applied Physiology, 55, 248 –252.

- Twenty (*20*) male middle-distance runners
- Age: 19 - 23 years old
- Initial VO_2-max: 64.4 mL 0_2 * kg^{-1} * min^{-1}
- Study Duration: 17-weeks
- Two (*2*) or more weekly sessions at V_{LT} or slightly above V_{LT} (*70 ± 5% VO_2-max*) for a total weekly duration of 60- to 90-minutes
- Percentage (*%*) LT Improvement: *3.8*

Lactate Threshold

- Yoshida, T., Udo, M., & Chida, M. (*1990*). Specificity of Physiological Adaptation to Endurance Training in Distance Runners and Competitive Walkers, European Journal of Applied Physiology, 61, 197 - 201.

- Six (*6*) female middle- & long-distance runners
- Mean Age: 19 years old
- Initial VO_2-max: 51.8 mL 0_2 * kg^{-1} * min^{-1}
- Study Duration: 8-weeks
- Six (*6*) 20-minute threshold sessions * $week^{-1}$ @ 91% vVO_2-max
- Percentage (%) LT Improvement: *10.3*

Lactate Threshold

Question: ***Do We Know*** **How to Consistently, Significantly Improve Lactate Threshold?**

Lactate Threshold

- **Perhaps young runners might benefit from a combination of (*approximate*) LT and supra-LT training**
  - **Threshold Training (*Progression Runs versus Tempo Runs*)**
  - **"*Critical Velocity*" Training – "*Tinman*"**
    - ***$v\Delta_{50}$ Training***

Part VII

Running Economy (*RE*)

Running Economy

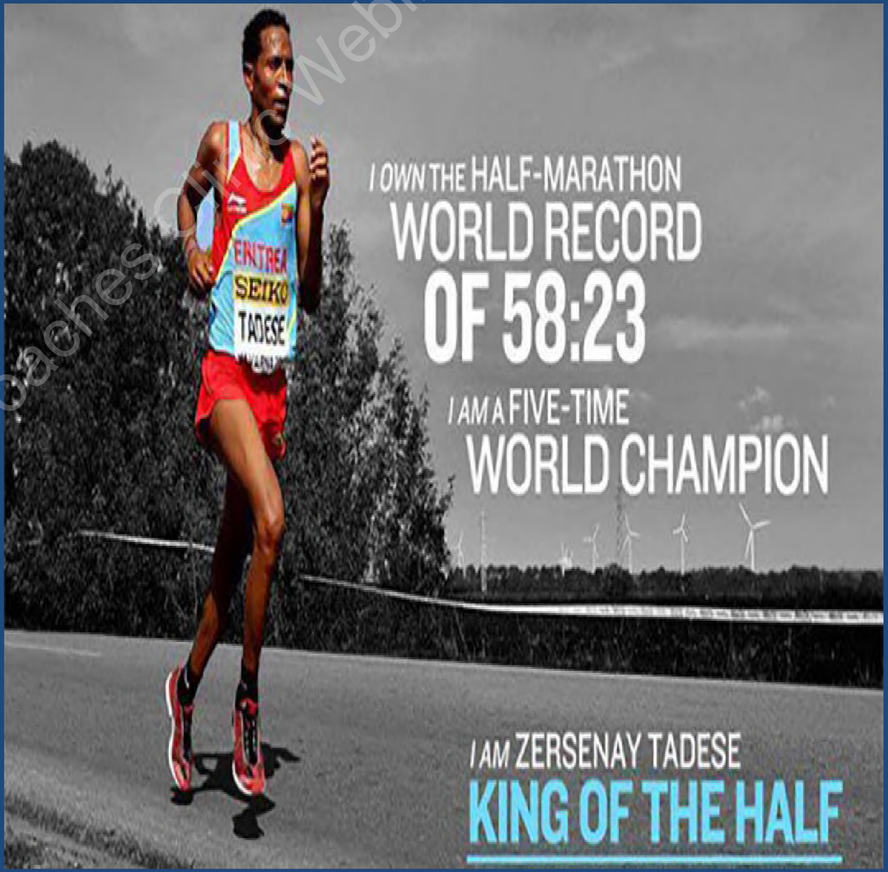
- The "oxygen cost" (*i.e. rate of oxygen consumption*) of running at a specific speed
- Example:
  - Runner A consumes 55 milliliters of O_2 * kg^{-1} * min^{-1} at 10 miles*$hour^{-1}$
  - Runner B consumes 50 milliliters of O_2 * kg^{-1} * min^{-1} at 10 miles*$hour^{-1}$
- Accordingly, Runner B is more economical

Running Economy (*RE*)

- **Plyometric Training and Ascent (*Hill*) Training …**
  - **Improve running economy or, more specifically …**
  - **Enhance so-called elastic energy return within the musculotendinous unit**
  - **Recruit / Train muscle spindles (*through rapid stretch / shortening cycle repetitions*) (*NOTE: muscle spindles contain the contractile proteins actin and myosin and thus possess a contractile apparatus that can contribute to skeletal muscle force and power production*)**

Explosive Training, Heavy Weight Training, & Running Economy

- Denadai, B.S., de Aguiar, R.A., de Lima, L.C.R., Greco, C.C., & Caputo, F. (*2016*), Explosive Training and Heavy Weight Training are Effective for Improving Running Economy in Endurance Athletes: A Systematic Review and Meta-Analysis, Sports Medicine.



Denadai et al. (*2016*)

Objective: To Evaluate the Effect of Concurrent Training on Running Economy (*RE*) in Endurance Athletes

Denadai et al. (*2016*)

- Searched PubMed database
- Searched Web of Science database
- Reviewed reference lists from selected studies
- Searched studies published up to August 15th, 2015
- Incorporated Inclusion / Exclusion Criteria
- One-hundred and nineteen (*119*) relevant studies were identified

Denadai et al. (*2016*)

Ultimately, sixteen (*16*) studies were formally assessed to meet all requisite criteria and thus be sufficiently rigorous to be included in the quantitative analysis

Denadai et al. (*2016*)

- Percentage (*%*) change in RE ranged from -12.52 to +0.72
- Overall, concurrent training had a positive effect: *-3.93%*
- Millet et al. (*2012*): -*12.52%* change in RE consequent to HWT emphasizing half-squat and heel raises
- Only heavy weight training (*HWT*) and explosive training (*EXP*) presented a % change significantly lower than zero
- Saunders et al. (*2006*): -3.63% change in RE consequent to EXP emphasizing foundational plyometric movements

Denadai et al. (*2016*)

- Short- and medium-term training periods (*6- to 14-weeks*) of concurrent training were sufficient to enhance RE in recreationally-trained endurance runners

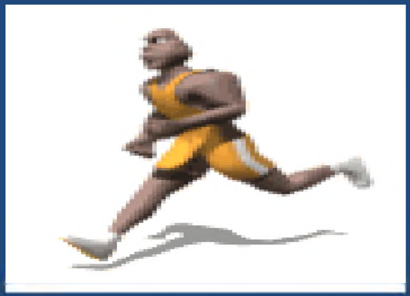
- Relatively longer training periods (*14- to 20-weeks*) in combination with relatively high weekly training volumes of endurance running were requisite to enhancing RE in highly-trained individuals

Denadai et al. (*2016*)

- **Practical applications:**
  - **Consistently incorporate age-appropriate, beginning- and intermediate-level plyometric training throughout the season for both novice and experienced endurance athletes in order to duly emphasize foundational RE enhancement**
  - **Consider the eventual, selective incorporation of specific, lower-limb, heavy resistance exercises in order to further amplify foundational improvements in RE**

Plyometric Training & Endurance Performance

- Ramirez-Campillo, R., Alvarez, C., Henriquez-Olguin, C., Baez, E.B., Martinez, C., Andrade, D.C., & Izquierdo, M. (*2014*). Effects of Plyometric Training on Endurance and Explosive Strength Performance in Competitive Middle- and Long-Distance Runners, Journal of Strength and Conditioning Research, 28(*1*), 97 – 104.
- Primary study objective was to assess the effect(*s*) of concurrent endurance and plyometric training on both endurance time trial performance and explosive strength in competitive middle- and long-distance runners



Plyometric Training & Endurance Performance

- 36 participants (*14 women, 22 men*)
- Mean age of 22.7 ± 2.7 years
- Minimum of 2-years of competitive national and / or international experience
- Personal best performances ranging from 3:50 to 4:27 (*min:sec, 1,500-m*) and 2:32 to 2:52 (*hours:min, marathon*)

Plyometric Training & Endurance Performance

- **Mean weekly endurance training volume of 67.2 ± 18.9 kilometers**

- **Mean pre-study 2.4-km time trial performance of approximately 7.8-minutes (*i.e. 5-minute, 13-second per mile pace for approximately 1.5-miles*)**

Plyometric Training & Endurance Performance

- **Six (*6*) week plyometric training intervention**
- **Two (*2*) plyometric training sessions per week**
- **Less than thirty (*30*) minutes per session**
- **All plyometric training involved depth jumps (*2 x 10 jumps from a 20 cm box, 2 x 10 jumps from a 40 cm box, and 2 x 10 jumps from a 60 cm box*)**
- **Fifteen *(15*) second rest intervals between repetitions and two (*2*) minute rest intervals between sets**

Plyometric Training & Endurance Performance

Plyometric	Control	Plyometric	Control	Plyometric	Control
2.4-km TT	2.4 km TT	20-m Sprint	20-m Sprint	CMJA	CMJA
7.6 to 7.3-minutes 3.9% faster	8.0- to 7.9-minutes 1.3% faster	3.92 to 3.83 seconds 2.3% faster	3.97 to 3.94 seconds 0.8% faster	36.1 to 39.3 cm 8.9% higher	34.1 to 36.3 cm 6.5% higher

Plyometric Training & Endurance Performance

Potential Interpretation: Incorporate plyometric training into the ongoing endurance training of student-athletes in order to both enhance muscular strength / power and improve endurance performance

Uphill Interval Training

- **Barnes, K.R., Kilding, A.E., Hopkins, W.G., Mcguigan, M.R., & Laursen (*2012*). Effects of Different Uphill Interval-Training Programs on Running Economy and Performance, Journal of Science and Medicine in Sport, 15, S33.**

Barnes et al. (*2012*)

- **Introduction**
  - Uphill running is a form of running-specific resistance training
  - Optimal parameters for prescribing uphill interval training are unknown
  - Dose-response approach might yield specific insight as to program design

Barnes et al. (*2012*)

- **Methods**
  - **Twenty well-trained runners performed VO_2-max, running economy and 5-k time trial assessments**
  - **Subsequent random assignment to one of five intensities of uphill interval training**
  - **20 x 10-sec. intervals at 120% of $_vVO_2$-max w 18% grade / 2 x 20-min. intervals at 80% of $_vVO_2$-max w 4% grade**

Barnes et al. (*2012*)

- Results
  - Improvement in *running economy was greatest at the highest intensity of hill interval training*
  - There was no clear optimum for improvement of 5-K time trial performance

Barnes et al. (*2012*)

- **Discussion**
  - **Uphill interval training @ 95% $_{v}VO_2$-max (*8 x 2-min intervals*) produced greatest improvements in most physiological measures related to performance**
  - **However, running economy improved most dramatically at the greatest (*120% $_{v}VO_2$-max*) intensity**

Barnes et al. (*2012*)

- **Conclusion(*s*)**
  - **"Until more data are obtained, runners can assume that any form of high-intensity uphill interval training will benefit 5-k time trial performance"**
  - **Integrate short- and intermediate- / long-hill repetitions into hill training workouts**

Part XIII

The Long Run (*LR*)

The Long Run (*LR*)

- Endurance / Aerobic Training …
  - Improves aerobic conditioning or, more specifically, …
  - Enhances cardiovascular function
  - Increases total blood volume
  - Enhances capillary density
  - Improves the detraining response
  - Elevates mitochondrial content

The Long Run (*LR*)

Thus, the long run is (*in simplest terms*) a relatively robust manifestation of foundational aerobic / endurance training

The Long Run (*LR*)

- **Goals of a Long Run**
  - **Induce significant skeletal *muscle glycogen depletion***
  - **Induce comprehensive *skeletal muscle fiber recruitment***
  - **MANY others*!***

The Long Run & Glycogen Depletion

- **Baar, K. (*2013*). New Ideas About Nutrition And The Adaptation To Endurance Training, Gatorade Sport Science Exchange (*GSSE*), Volume 26, # 115, 1 - 5.**

- ***PGC-1*α is an acronym for peroxisome proliferator-activated receptor gamma co-activator 1 alpha**

- ***"from a molecular perspective, the key to endurance training adaptations is to maximize PGC-1*α *activity with training"***

The Long Run & Glycogen Depletion

- Baar, K. (*2013*). New Ideas About Nutrition And The Adaptation To Endurance Training, Gatorade Sport Science Exchange (*GSSE*), Volume 26, # 115, 1 - 5.

- Glycogen depletion activates adenosine monophosphate-activated protein kinase (*AMPK*)

- "*AMPK is one of the most potent regulators of PGC-1α activity*"

The Long Run & Glycogen Depletion

- Baar, K. (*2013*). New Ideas About Nutrition And The Adaptation To Endurance Training, Gatorade Sport Science Exchange (*GSSE*), Volume 26, # 115, 1 - 5.

- Glycogen depletion activates p38 mitogen-activated protein kinase (*p38MAPK*)

- *p38MAPK is a similarly potent regulator of PGC-1α activity*

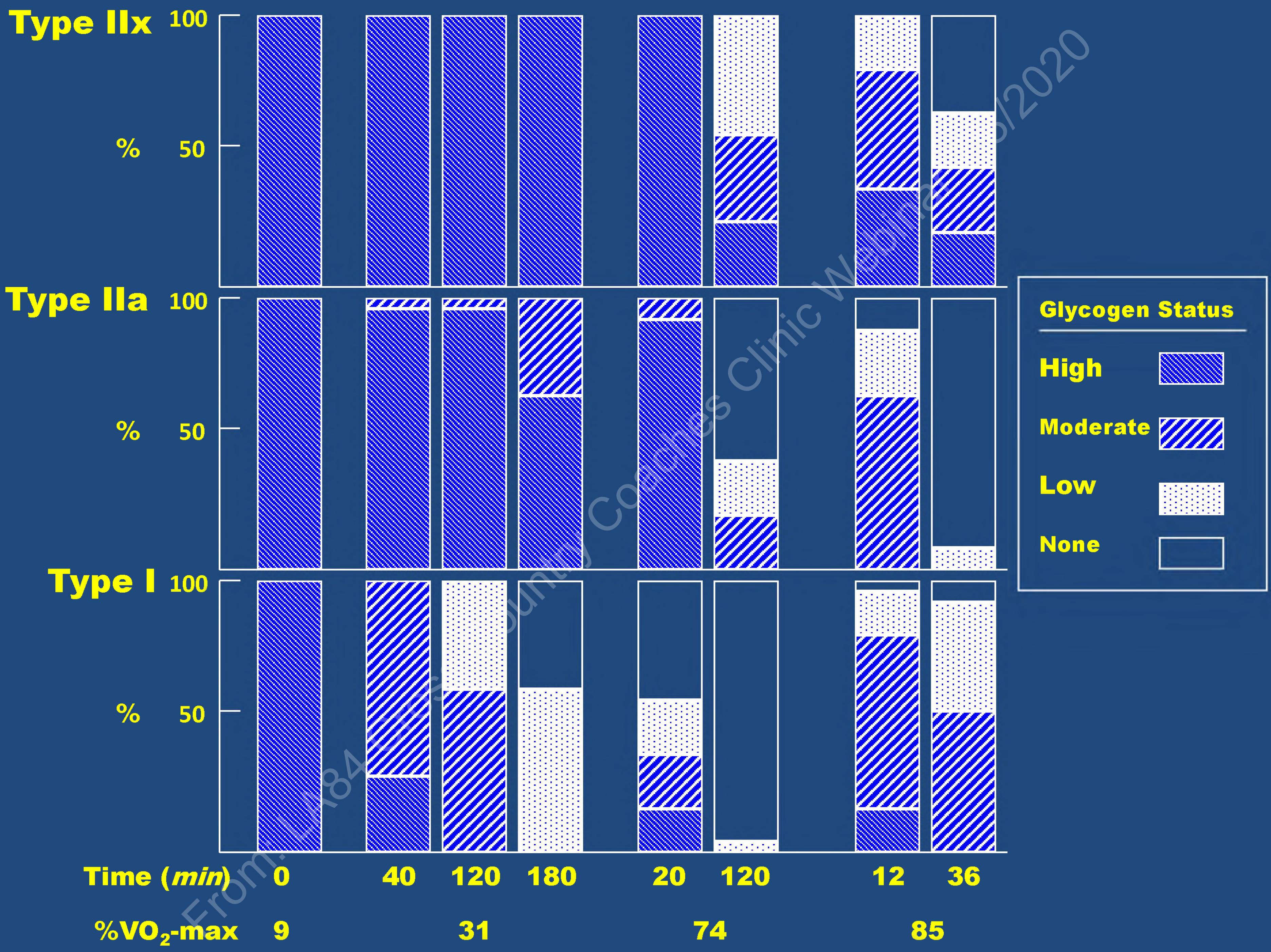
The Long Run & Glycogen Depletion

- **Summary of the previous two (2) slides**
  - *Glycogen* ↓ **--→ Increased AMPK activity --→ Increased PGC-1α activity -→** ***mitochondrial biogenesis*** ↑
  - *Glycogen* ↓ **--→ Increased p38MAPK activity --→ Increased PGC-1α activity -→** ***mitochondrial biogenesis*** ↑

The Long Run & Glycogen Depletion

- The following slide is adapted from Horton, E.S. & Terjung R.L. (*Editors*), Exercise, Nutrition, and Energy Metabolism, MacMillan, New York, 1988.

- ***Is glycogen depleted via a long run?***



Type IIx
Type IIa
Type I
100
%
50
Glycogen Status
High
Moderate
Low
None
Time (min) 0 40 120 180 20 120 12 36
%VO_2-max 9 31 74 85

The Long Run & Glycogen Depletion

- **Horton, E.S. & Terjung R.L. (*Editors*), <u>Exercise, Nutrition, and Energy Metabolism</u>, MacMillan, New York, 1988.**

- ***Lower-limb skeletal muscle glycogen is significantly depleted across all three fibers types with 1) moderate-intensity, long duration aerobic exercise and / or 2) high-intensity, intermediate duration aerobic exercise***

The Long Run & Glycogen Depletion

- **Horton, E.S. & Terjung R.L. (*Editors*), Exercise, Nutrition, and Energy Metabolism, MacMillan, New York, 1988.**
- ***Moreover, there is significant muscle fiber recruitment across Type I, Type IIa, and Type IIx muscle fibers with 1) moderate-intensity, long duration aerobic exercise and / or 2) high-intensity, intermediate duration aerobic exercise***

The Long Run (*LR*)

- ***GOALS*** **of a Long Run**
  - **Induce significant skeletal** ***muscle glycogen depletion***
  - **Induce comprehensive** ***skeletal muscle fiber recruitment***

The Long Run (*LR*)

- ***OUTCOMES*** **of a Long Run**
  - **Induce significant skeletal** ***muscle glycogen depletion***
  - **Induce comprehensive** ***skeletal muscle fiber recruitment***

The Long Run (*LR*)

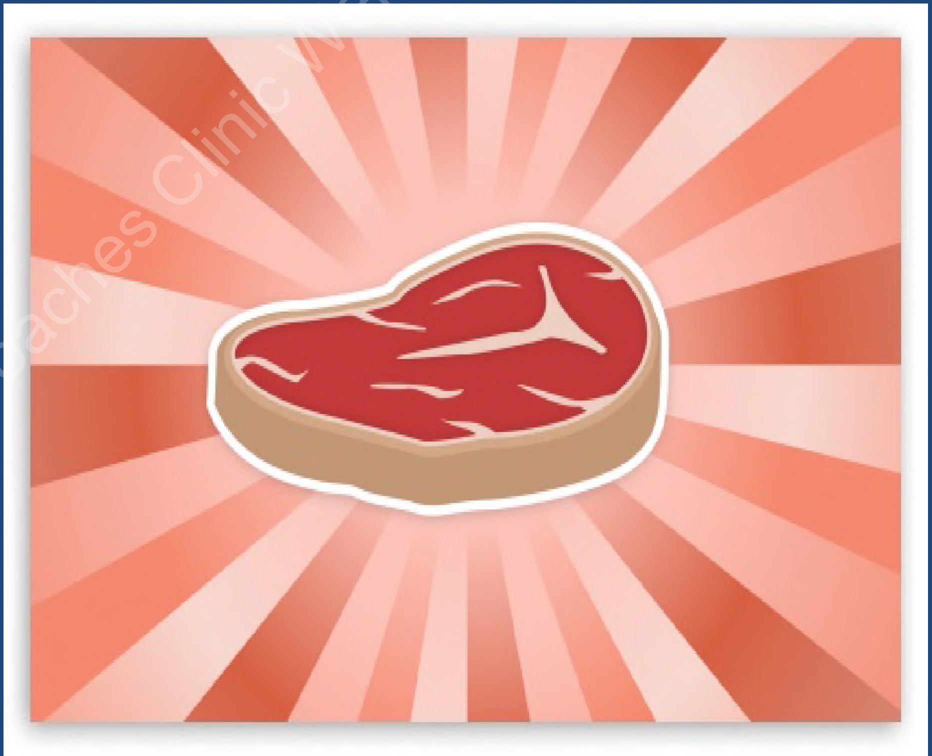
- ***ADAPTIVE OUTCOMES*** of a Long Run
  - Robust stimulus to induce mitochondrial biogenesis
  - Robust stimulus to recruit and thus train ALL muscle fiber types (*I*, *IIa*, ***and*** *IIx*)

Part IX

Protein Requirements & Protein Distribution in Endurance Athletes

Protein Requirements in Endurance Athletes

- Kato, H., Suzuki, K., Bannal, M., & Moore, D. (*2016*). Protein Requirements Are Elevated after Exercise as Determined by the Indicator Amino Acid Oxidation Method, PLoS One, 11(*6*), 1-15.



Protein Requirements in Endurance Athletes

Objective: To quantify the recommended protein intake in endurance athletes during an acute, three-day training period using the indicator amino acid oxidation (*IAAO*) method

Protein Requirements in Endurance Athletes

- Six male, endurance-trained adults
- Mean VO_2-peak = 60.3 $\pm$ 6.7 ml $* kg^{-1} * min^{-1}$
- Acute training session (*20-km treadmill run*)
- Post-training consumption of variable protein mass

- Utilize labeled phenylalanine method in order to quantify both estimated average protein requirement and recommended protein intake

Protein Requirements in Endurance Athletes

- **Current Recommended Dietary Allowance (*RDA*) is 0.8 grams PRO * kg^{-1} body mass * day^{-1}**
- **Current recommendations for endurance athletes are 1.2 – 1.4 grams PRO * kg^{-1} body mass * day^{-1}**

Protein Requirements in Endurance Athletes

- Experimental results yield an estimated, average, post-training protein requirement of 1.65 grams PRO * kg^{-1} body mass * day^{-1}

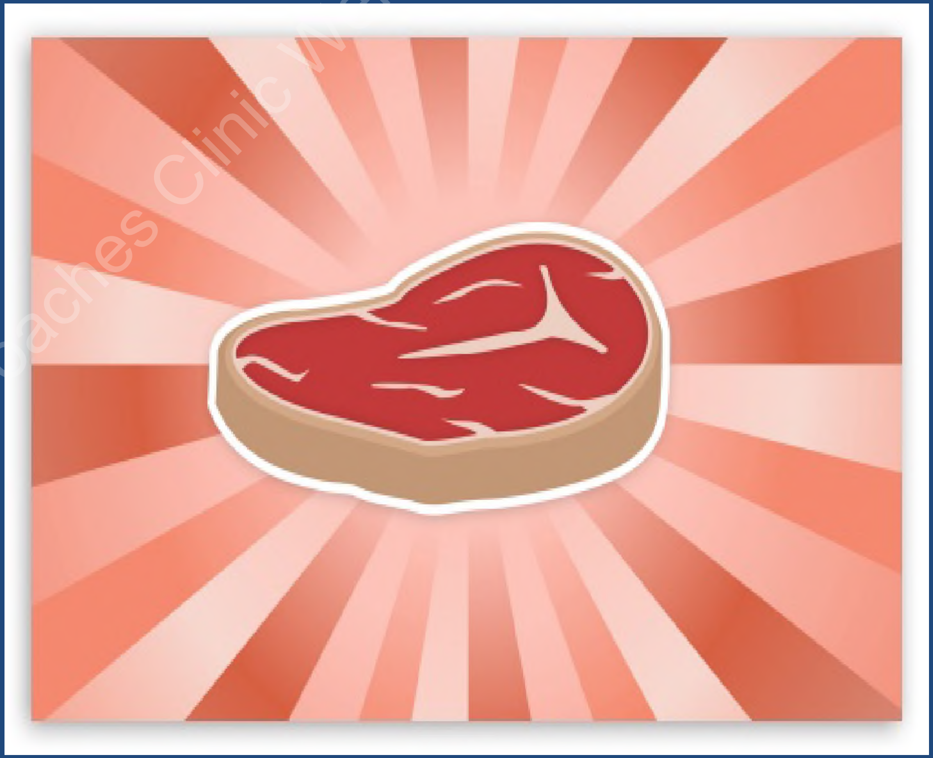
- Experimental results yield an estimated, average, post-training recommended protein intake of 1.83 grams PRO * kg^{-1} body mass * day^{-1}

Protein Requirements in Endurance Athletes

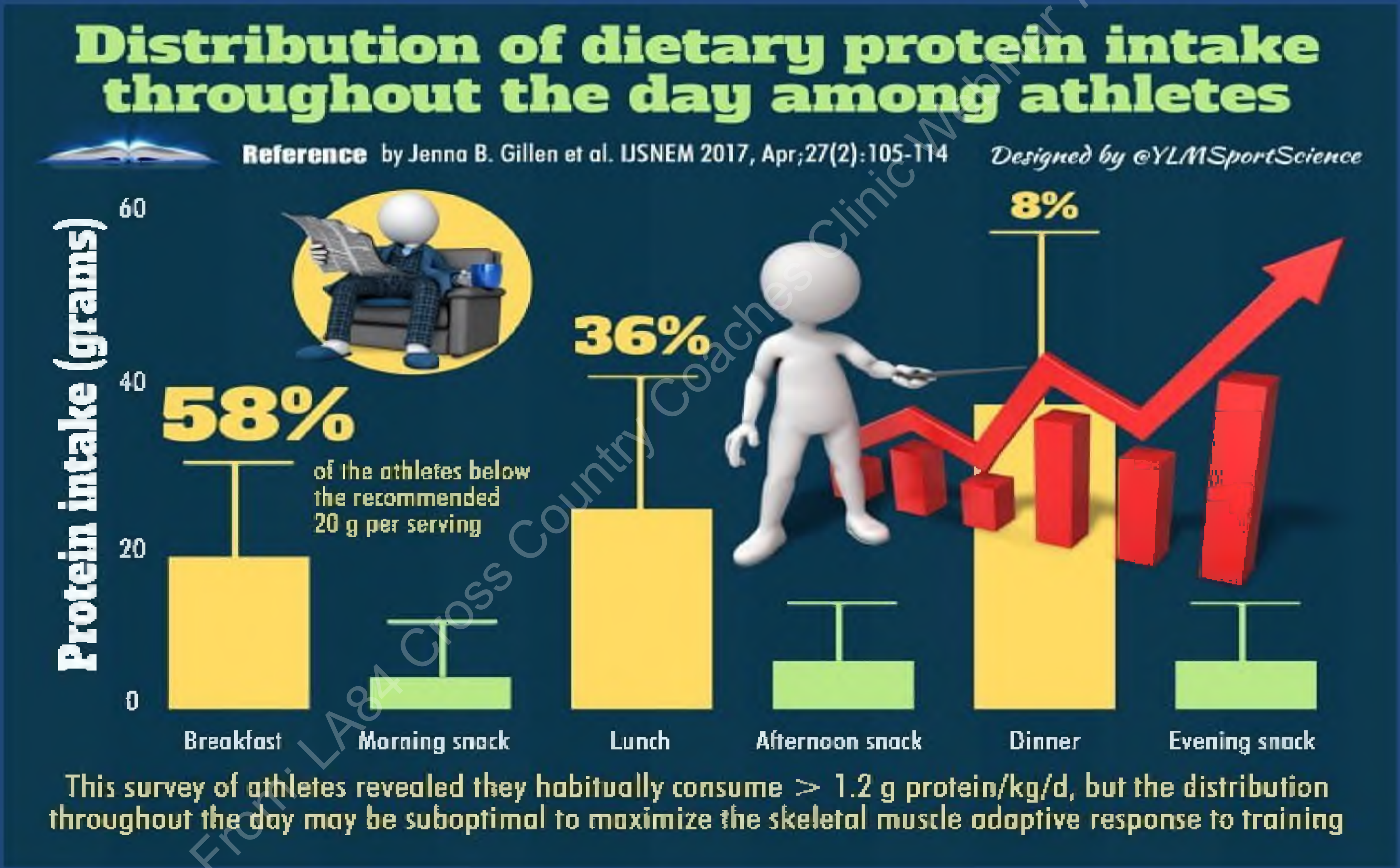
Potential Interpretation: The metabolic demand for protein intake (*1.83 grams PRO * kg^{-1} body mass * day^{-1}*) in trained endurance athletes engaged in high-volume and / or high-intensity training is not only greater than their sedentary counterparts but also greater than current recommendations for endurance athletes (*1.2 – 1.4 grams PRO * kg^{-1} body mass * day^{-1}*)

Protein Distribution in Endurance Athletes

- **Gillen, J.B., Trommelen, J., Wardenaar, F.C., Brinkmans, N.Y.J., Versteegen, J.J., Jonvik, K.L., Kapp, C., de Vries, J., van den Borne, J.J.G.C., Gibala, M.J., & van Loon, L.J.C. (*2017*). Dietary Protein Intake and Distribution Patterns of Well-Trained Dutch Athletes, International Journal of Sport Nutrition and Exercise Metabolism, 27(*2*), 105-114.**



Protein Distribution in Endurance Athletes

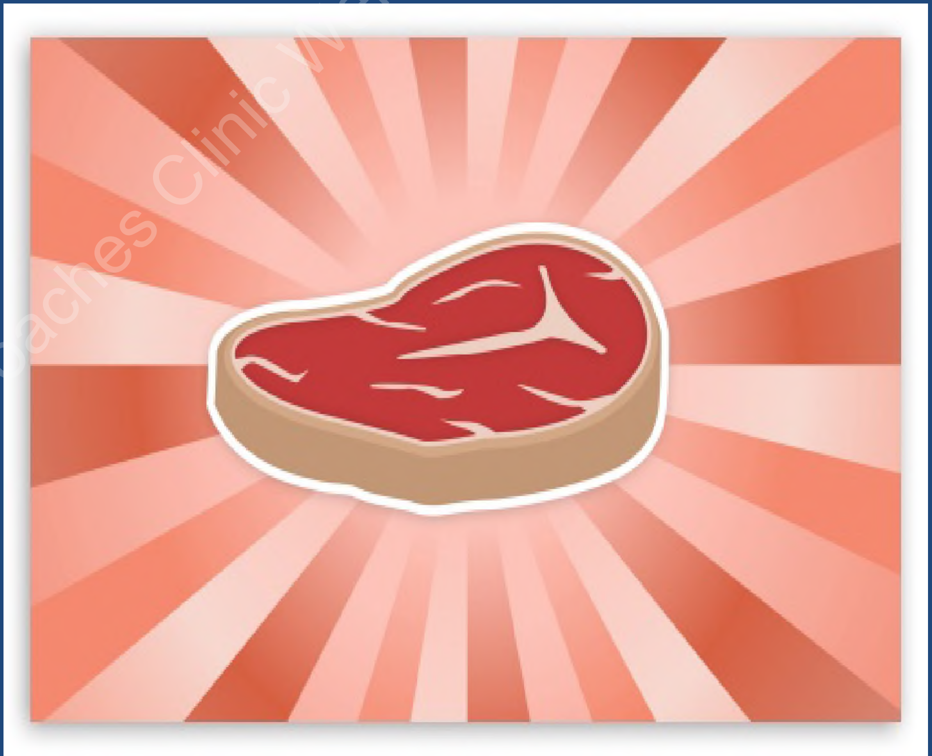


Protein Distribution in Endurance Athletes

- **Experimental results indicate that surveyed athletes habitually consume more than 1.20 grams PRO * kg^{-1} body mass * day^{-1}**
- **Experimental results additionally suggest that the *distribution of protein intake* throughout a day may be *decidedly suboptimal* to *maximize* the skeletal muscle *adaptive response to training***

Protein Distribution in Endurance Athletes

- **Witard, O.C., Garthe, I., & Phillips, S.M. (*2019*). Dietary Protein for Training Adaptation and Body Composition Manipulation in Track and Field Athletes, International Journal of Sport Nutrition and Exercise Metabolism 29(*2*), 165-174.**

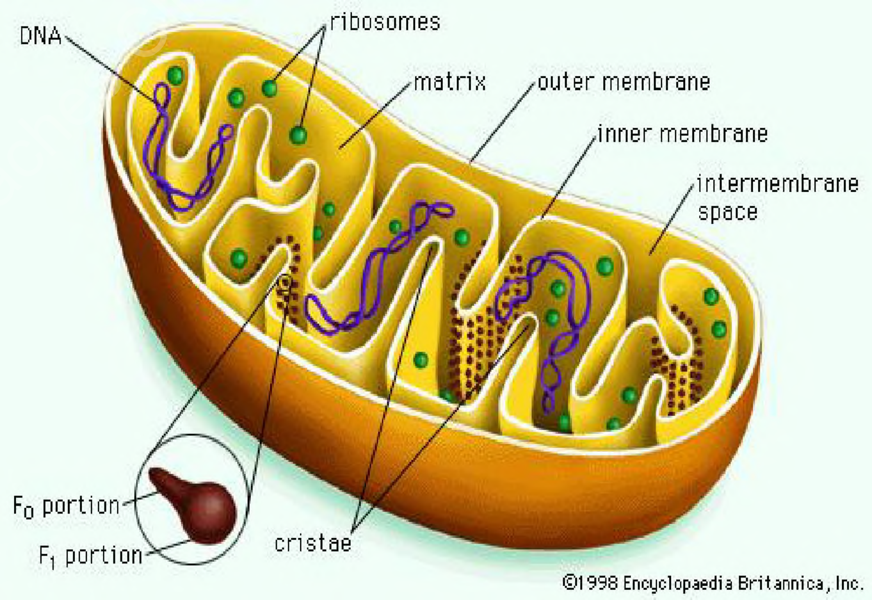


Protein Distribution in Endurance Athletes

Potential Interpretation: The skeletal muscle adaptive response to training in trained endurance athletes engaged in high-volume and / or high-intensity training may be enhanced and, indeed, optimized through relatively even distribution of daily protein intake across the waking cycle (*Witard et al., {2019}, Table II*)

Mitochondrial Quality versus Mitochondrial Quantity

- **MacInnis, M.J., Zacharewicz, E., Martin, B.J., Haikalis, M.E., Skelly, L.E., Tarnopolsky, M.A., Murphy, R.M., & Gibala, M.J. (*2017*). Superior Mitochondrial Adaptations in Human Skeletal Muscle after Interval compared to Continuous Single-Leg Cycling Matched for Total Work, Journal of Physiology, 595, 2955-2968.**



MacInnis et al. (*2017*)

- Ten (*10*), young, active males (*VO_2-peak = 46.2 ± 2 ml O_2 * kg^{-1} * min^{-1}*)
- Single-leg cycle ergometry
- All subjects could thus perform high-intensity interval training (*HIIT*), moderate-intensity continuous training (*MICT*), AND serve as their own control

MacInnis et al. (*2017*)

MacInnis et al. (*2017*)

- **HIIT** legs performed six (*6*) sessions of 4 x 5-minutes @ 65% of mean W_{peak} interspersed by 2-minute active recovery periods @ 20% of mean W_{peak}

- **MICT** legs performed six (*6*) sessions of 30-minutes @ 50% of mean W_{peak}

- Consequently, total work was equivalent across the HIIT and MICT training

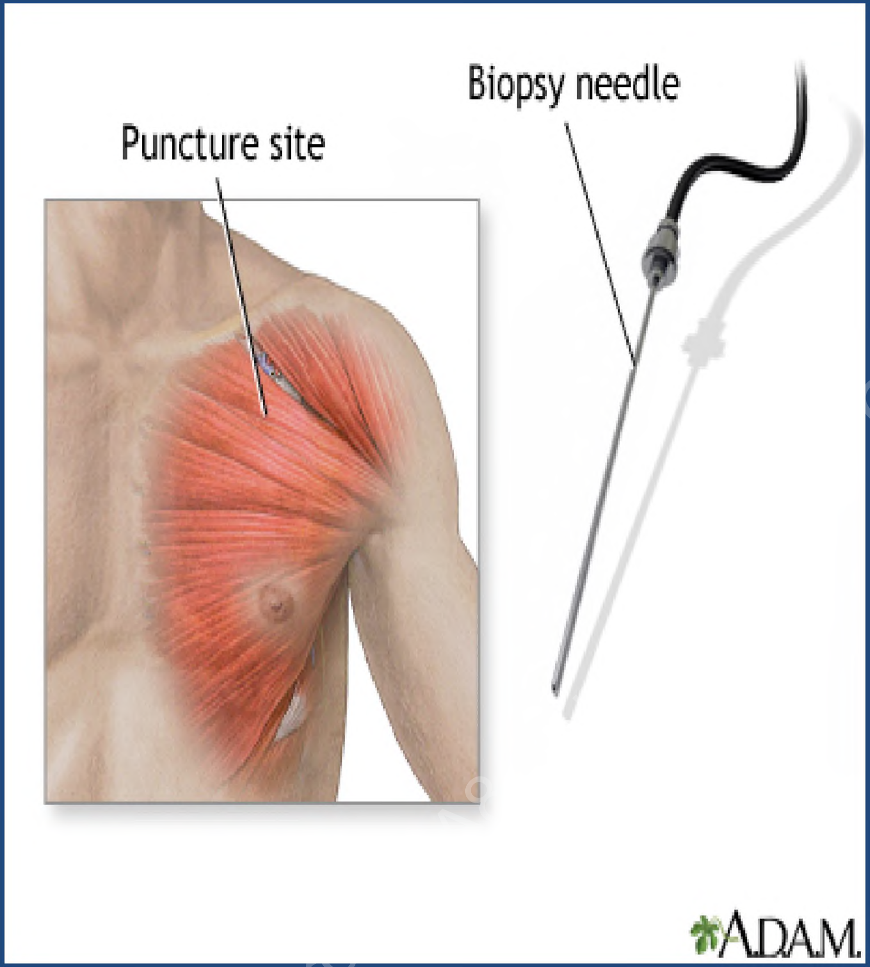
MacInnis et al. (*2017*)

- **Muscle biopsies were drawn from the vastus lateralis of HIIT & MICT legs both pre- and post-training**

- **Mitochondrial QUANTITY was assessed (*maximal O_2 respiratory rates {JO_2}*)**

- **Mitochondrial QUALITY was assessed (*mitochondrial mass-specific JO_2*)**

MacInnis et al. (*2017*)



MacInnis et al. (*2017*)

- **Notable Data**
  - **Whole muscle mitochondrial (*citrate synthase*) enzyme activity demonstrated significantly greater percentages increases (*39%*) consequent to HIIT training relative to MICT training (*11%*)**

MacInnis et al. (*2017*)

- **Notable Data**
  - **Similar whole muscle mitochondrial enzyme activity increases were significantly greater in multiple electron transport chain enzymes (*22% {HIIT} vs. -7% {MICT} for Complex I and 22% {HIIT} vs. -9% {MICT} for Complex I + Complex II*)**

MacInnis et al. (*2017*)

- **Notable Data**
  - **Mitochondrial-specific JO_2 (*i.e. mitochondrial quality*) appears to be largely unaffected by short-term training intervention(s) and relatively modest differences between MICT and HIIT training intensities**
  - **However, Granata el al. (*2016*) has previously demonstrated that sprint interval training (SIT) is associated with increased mitochondrial-specific JO_2 (*i.e. enhanced mitochondrial quality*)**

MacInnis et al. (*2017*)

- **Potential Interpretation(*s*)**
  - **So-called high-intensity interval training should necessarily include both HIGH-intensity movement (*such as sprinting or near-sprinting*) and sufficient duration (*such as nine {9} weeks per Granata et al. {2016}*) in order to elicit improvement in mitochondrial quantity and / or mitochondrial quality**

Part XI

Acknowledgments

Acknowledgments

- **Mr. Tim O'Rourke & Mr. Michael Salmon** – ***Invitation***
- **LA '84 Foundation** – ***Host Institution***
- **Mesa Community College Exercise Science Department** – ***Colleagues & Friends***
- **Desert Vista High School Distance Runners** – ***Continuous Inspiration (to me) through Belief, Caring, Principle-Centered Living, & Commitment to Excellence***

Student-Athlete Acknowledgments

- Cassie (*Rios*) Bando (*XCP, '03*)
- Tara Erdmann (*Flowing Wells HS, '07*)
- Kari Hardt (*Queen Creek HS, '06*)
- Sherod Hardt (*Queen Creek HS, '10*)
- Garrett Kelly (*Desert Vista HS, '06*)
- Haley (*Paul*) Jones (*Desert Vista HS, '04*)
- Allison Maio (*XCP, '12*)
- Sarah Penney (*XCP, '09*)
- Kevin Rayes (*Arcadia HS, '09*)
- Jessica Tonn (*XCP, '10*)

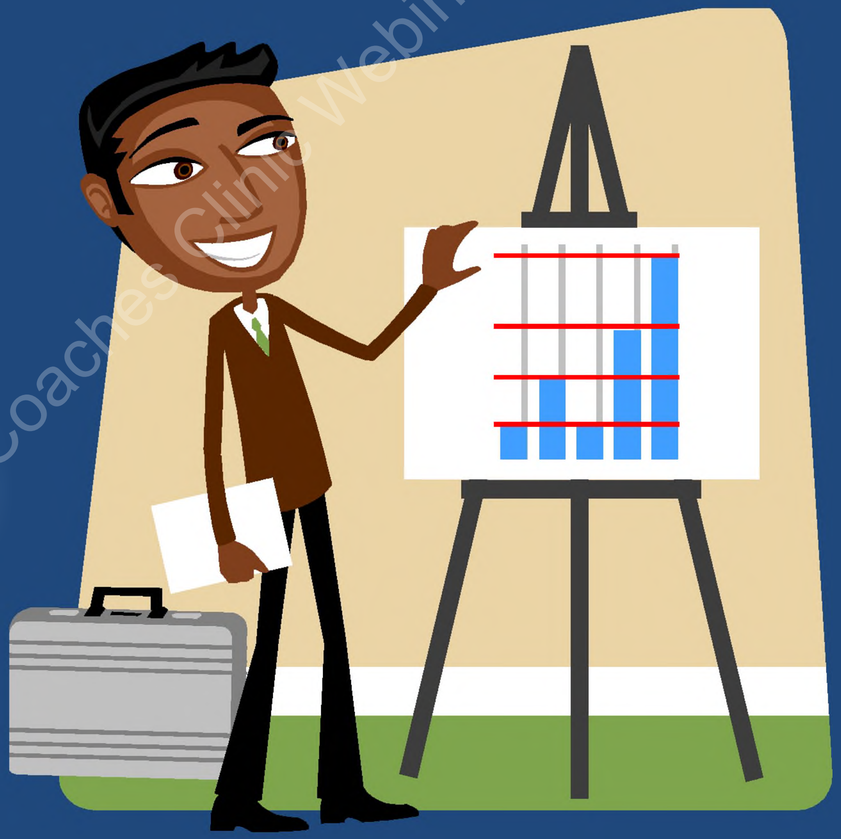
Student-Athlete Acknowledgments

- Michelle Abunaja (*DVHS, '14*)
- Shelby Brown (*XCP, '14*)
- Madi Bucci (*DVHS, '17*)
- Daylee Burr (*XCP, '11*)
- Sabrina Camino (*DVHS, '17*)
- Mandy Davis (*DVHS, '17*)
- Jordan Furseth (*DVHS, '16*)
- McKenna Gaffney (*XCP, '13*)
- Savannah Gaffney (*XCP, '14*)
- Sophi Johnson (*DVHS, '15*)
- Baylee Jones (*DVHS, '17*)
- Danielle Jones (*DVHS, '15*)
- Lauren Kinzle (*XCP, '15*)
- Natalie Krafft (*DVHS, '13*)
- Kyra Lopez (*DVHS, '15*)
- Jenna Maack (*DVHS, '13*)
- Samantha Mattice (*XCP, '14*)
- Jane Miller (*XCP, '16*)
- Jessica Molloy (*MBHS, '15*)
- Shannon Molvin (*XCP, '15*)
- Laura Orlie (*XCP, '12*)
- Caroline Pass (*DVHS, '16*)
- Tessa Reinhart (*DVHS, '15*)
- Elise Richardson (*DVHS, '14*)
- Emily Smith (*DVHS, '16*)
- Mason Swenson (*DVHS, '16*)
- Brittany Tretbar (*DVHS, '13*)
- Julianne Vice (*XCP, '14*)
- Kate Welty (*XCP, '14*)
- Haley Wolf (*DVHS, '18*)
- Kate Yanish (*XCP, '12*)
- Aubrey Worthen (*DVHS, '16*)

Part XII

Questions & Discussion

Questions & Discussion



Part XIII

Appendices

Appendix A: Warm-up A

- 1,000-meter jog
- Step-Outs with Torso Rotations (*4 Step-Outs with 6 Rotations per Step*)
- Forward Lunge with Right / Left Torso Rotation (*6 repetitions*)
- Forward Lunge with Rotating Twist & Reach (*6 repetitions*)
- Forward Lunge with Two-Arm Vertical Reach (*6 repetitions*)
- Modified Power Walks (*20 Repetitions*)
- Carioca (*2 x 8 repetitions*)
- Progressive Speed A-Skips (*24 Repetitions*)
- B-Skips (*24 repetitions*)
- Progressive Turnover High Knees (*50 repetitions*)
- Two (*2*) to Four (*4*) x 100-meter Strides
- WORKOUT or RUN

Appendix B: Warm-up B

- 1,000-meter jog
- Hip-Twist with Ankle Hops (*20 hop repetitions & 30 hop / twist repetitions*)
- Progressive Speed Base Rotations (*50 repetitions*)
- Lateral Lunge with Rotation (*6 repetitions / 3 per side*)
- Backward Lunge with Vertical Reach (*6 repetitions*)
- Forward Lunge with Hamstrings Group Stretch (*6 repetitions*)
- Modified Power Walks (*20 Repetitions*)
- Carioca (*2 x 8 repetitions*)
- Hamstrings Group Kicks (*Fifteen {15 }"touches" per leg*)
- B-Skips (*24 repetitions*)
- Progressive Turnover High Knees (*50 repetitions*)
- Two (*2*) to Four (*4*) x 100-meter Strides
- WORKOUT or RUN

Appendix C: Warm-up C

- **1,000-meter jog**
- **Ten (*10*) Alternating Knee Hugs with Heel Raise**
- **Ankling (*approximately 25- to 35-meters*)**
- **Hamstring Kicks (*Fifteen {15 }"touches" per leg*)**
- **Side Walking Lunge (*Eight {8} Rightward / Eight {8} Leftward Lunges*)**
- **Side Shuffle with Arm Swing (*Eight {8} Rightward / Eight {8} Leftward Shuffles*)**
- **Lateral A-Skips (*Twelve {12} Rightward / Twelve {12} Leftward Skips*)**
- **Backward Run (*approximately 30- to 50-meters*)**
- **Single Leg Skip (*approximately 20- to 40-meters; alternate lead leg*)**
- **Two (*2*) to Four (*4*) x 100-meter Strides**
- **WORKOUT or RUN**

Appendix D: Warmdown A

- Nick Swings (*4 right circles, 4 left circles*)
- Arm Swings (*4 forward circles, 4 backward circles*)
- Chest Stretch
- Trunk Rotation (*4 right circles, 4 left circles*)
- Rock Squat (*10 repetitions*)
- Quadriceps Group Stretch (*10 count per quadriceps group*)
- Piriformis Stretch (*10 count per quadriceps group*)
- Hamstrings Group Stretch (*10 count per hamstrings group*)
- Lunge Stretch (*10 count per lunge*)
- Gastrocnemius / Soleus Stretch (*10 count per leg*)

Appendix E: General Strength (*GS*) / Plyometric Routine I

- "*Runner's*" Push-ups (*30-seconds of continuous repetitions = 1 set*)
- "*Russian*" Twists (*30-seconds of continuous repetitions = 1 set*)
- Hyperextensions (*30-seconds of continuous repetitions = 1 set*)
- "*Prisoner*" Squats (*30-seconds of continuous repetitions = 1 set*)
- Ankle Hoops (*30-seconds of continuous repetitions = 1 set*)
- Split Squat Jumps (*30-seconds of continuous repetitions = 1 set*)

- 1 set of every GS / Plyometric movement = 1 circuit

- Perform continuous circuits utilizing a 30-second "*on*" / 20-second "*off*" work / recovery combination for a total of 10- to 20-minutes

Appendix F: General Strength (*GS*) / Plyometric Routine II

- Abdominal Crunches (*30-seconds of continuous repetitions = 1 set*)
- Rocket Jumps (*30-seconds of continuous repetitions = 1 set*)
- "*V*" Sit-Ups (*30-seconds of continuous repetitions = 1 set*)
- Supine Bridge with Alternating Leg Raises (*30-seconds of continuous repetitions = 1 set*)
- Right "*Plank*" with Left Leg Raises (*30-seconds of continuous repetitions = 1 set*)
- Left "*Plank*" with Right Leg Raises (*30-seconds of continuous repetitions = 1 set*)

- 1 set of every GS / Plyometric movement = 1 circuit

- Perform continuous circuits utilizing a 30-second "*on*" / 20-second "*off*" work / recovery combination for a total of 10- to 20-minutes

Appendix G: General Strength (*GS*) / Plyometric Routine III

- **Prone "*Plank*" with Alternating Leg Raises (*30-seconds of continuous repetitions = 1 set*)**
- **Continuous Hurdle Jumps (*30-seconds of continuous repetitions = 1 set*)**
- **Supine "*Plank*" with Alternating Leg Raises(*30-seconds of continuous repetitions = 1 set*)**
- **Scissor Jumps for Height (*30-seconds of continuous repetitions = 1 set*)**
- **Side-Ups (*30-seconds of continuous repetitions = 1 set*)**
- **Skips for Vertical Displacement (*30-seconds of continuous repetitions = 1 set*)**

- **1 set of every GS / Plyometric movement = 1 circuit**

- **Perform continuous circuits utilizing a 30-second "*on*" / 20-second "*off*" work / recovery combination for a total of 10- to 20-minutes**

Appendix H: General Strength (*GS*) / Plyometric Routine IV

- **Donkey Kicks (*30-seconds of continuous repetitions = 1 set*)**
- **Straight-Arm Prone Plank w/ Single Leg Stride (*30-seconds of continuous repetitions = 1 set*)**
- **Push-up to Prone Plank w/ Bilateral Hip / Knee / Ankle Flexion & Extension (*30-seconds of continuous repetitions = 1 set*)**
- **Donkey Whips (*30-seconds of continuous repetitions = 1 set*)**
- **Lateral Plank w/ Straight Leg Raise (*30-seconds of continuous repetitions = 1 set*)**
- **Modified Russian Twist (*30-seconds of continuous repetitions = 1 set*)**

- **1 set of every GS / Plyometric movement = 1 circuit**

- **Perform continuous circuits utilizing a 30-second "*on*" / 20-second "*off*" work / recovery combination for a total of 10- to 20-minutes**

Appendix I: General Strength (*GS*) / Plyometric Routine V

- Lateral Lunge Walks w/ Runner's Arms (*30-seconds of continuous repetitions = 1 set*)
- Lateral Shuffle w/ Runner's Arms (*30-seconds of continuous repetitions = 1 set*)
- Lateral A-Skips (*30-seconds of continuous repetitions = 1 set*)
- Lateral Plank w/ Lower Limb Ankle / Knee / Hip Flexion & Extension (*30-seconds of continuous repetitions = 1 set*)
- Lateral Plank w/ Straight Leg Raise (*30-seconds of continuous repetitions = 1 set*)
- Lateral Leg Swings (*30-seconds of continuous repetitions = 1 set*)

- 1 set of every GS / Plyometric movement = 1 circuit

- Perform continuous circuits utilizing a 30-second "*on*" / 20-second "*off*" work / recovery combination for a total of 10- to 20-minutes