2019 LA84 Foundation Cross-Country Coaches Clinic: *Presentation II*

- **Endurance Training Program Design:** An Evidence-Based, Physiological Perspective on “Why We Do What We Do”
2019 LA84 Foundation Cross-Country Coaches Clinic: *Presentation II*

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

**Dr. Jeffrey I. Messer**

Chair, Exercise Science Department, & Faculty, Exercise Physiology, 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

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Presentation Overview

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

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Presentation Overview

- Part V: Maximal Aerobic Power ($VO_{2MAX}$)
- 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

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Presentation Overview

• Part XIII: Appendices
Part I

Speaker Background
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, Dana Castoro, 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, 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

- 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)
- 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 (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/

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Part III

Training Program Philosophy

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Program Philosophy

• Emphasize Plan, Structure, & Discipline

• Cumulative, Consistent Aerobic Development

• Conjugate Periodization

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Program Philosophy

• Consistent Patterns of Weekly, Phasic, Seasonal, and Annual Training

• Individualization & Development

• Shared Responsibility

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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

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>400</th>
<th>800</th>
<th>1,500</th>
<th>5,000</th>
<th>10,000</th>
<th>Mar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerobic (%)</td>
<td>18.5</td>
<td>35.0</td>
<td>52.5</td>
<td>80.0</td>
<td>90.0</td>
<td>97.5</td>
</tr>
<tr>
<td>Anaerobic (%)</td>
<td>81.5</td>
<td>65.0</td>
<td>47.5</td>
<td>20.0</td>
<td>10.0</td>
<td>2.5</td>
</tr>
</tbody>
</table>

"Current" Model

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>400</th>
<th>800</th>
<th>1,500</th>
<th>5,000</th>
<th>10,000</th>
<th>Mar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerobic (%)</td>
<td>43.5</td>
<td>60.5</td>
<td>77.0</td>
<td>94.0</td>
<td>97.0</td>
<td>99.0</td>
</tr>
<tr>
<td>Anaerobic (%)</td>
<td>56.5</td>
<td>39.5</td>
<td>23.0</td>
<td>6.0</td>
<td>3.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

*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

Equivalent VO₂-max

(80%) LT
Superior RE – 80% is effectively “only 78%”
15:32 5-K

(80%) LT
15:45 5-K

(65%) LT
16:30 5-K

(65%) LT
17:30 5-K

VO₂-max

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Part V

Maximal Aerobic Power ($VO_2$-max)
Maximal Aerobic Power ($VO_2$-max)

- **Endurance / Aerobic Training** …
  - Improves $VO_2$-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

Convection

Airway

Lungs

Diffusion

Pulmonary Circulation

CO$_2$ O$_2$

CO$_2$ O$_2$

Pulmonary Circulation

Convection

Right

Left

Heart

Diffusion

Systemic Circulation

CO$_2$ O$_2$

CO$_2$ O$_2$

Muscle

CO$_2$ O$_2$

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Training Increases VO$_2$-max

• Typical training regimen
  – ~ 70% VO$_2$-max
  – 30 - 40 minutes * day$^{-1}$
  – 4 - 5 days * week$^{-1}$
  – 3 - 5 months

• Typical increase in VO$_2$-max ~ 10 - 20%
  – Subjects who were previously sedentary
    • Larger % increases
  – Subjects with higher initial VO$_2$-max
    • Smaller % increases
    • Essentially all of the increase due to increased maximal $Q$

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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$_2$max
    • Wibom et al.: 6 wk, 4 d/wk, 36 min/d, 70% VO$_2$max
    • Howald et al.: 6 wk, 5 d/wk, 30 min/d, 72 % VO$_2$max

• 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$^{-1}$)

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Adaptive Increase in VO$_2$-max Is Dependent Upon Training Stimulus

- More strenuous regimens elicit greater increases

  - Protocol (8 healthy subj, age 20-42, 6 d/wk exercise, 10 wk):
    - 3 d/wk: Interval cycling 6 x 5’ @ 100% VO$_2$max: 2’ @ 50%
    - 3 d/wk: Run steady rate as far as possible in 40’
  - Results:
    - Mean increase in VO$_2$max = 44% ! (*from 38.2 to 55.0 ml/kg/min*)
    - Increased VO$_2$max 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 $Q_{\text{max}}$

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

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

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 et al. (2007)

• **Long, slow distance running (LSD)**
  
  – Continuous run @ 70% of HR\textsubscript{MAX} (137 bpm) for 45-minutes

• **Lactate threshold running (LT)**

  – Continuous run @ 85% of HR\textsubscript{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 \( HR_{\text{MAX}} \) (180 - 190 bpm) interspersed w/ 15-second active recovery periods @ 70% of \( HR_{\text{MAX}} \) (140 bpm)

• 4 x 4 interval running (4 x 4)
  – 4 x 4-minute interval runs @ 90 - 95% of \( HR_{\text{MAX}} \) (180 - 190 bpm) interspersed w/ 3-minute active recovery periods @ 70% of \( HR_{\text{MAX}} \) (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)

Training Intervention

LSD  LT  15/15  4 X 4

Δ VO₂-max (%)
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

– $\dot{V}O_2^{\text{MAX}} = \dot{Q}_\text{MAX} \times (a-v)O_2^{\text{DIFF}}$ (Fick Principle)

– $\dot{Q}_\text{MAX} = HR_\text{MAX} \times SV_\text{MAX}$

– Endurance Training (ET) does not Increase $HR_\text{MAX}$

– Thus, one Focus of ET should be Enhancement of $SV_\text{MAX}$
Potential Application: Consistent (for example, weekly) incorporation of a workout or workouts emphasizing approx. 4-minute repetitions @ 90 – 95% of $HR_{\text{MAX}}$ 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)*

<table>
<thead>
<tr>
<th>Mitochondrial Volume Density (% of Total Cell Volume)</th>
<th>Untrained</th>
<th>Trained</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type I Fibers</strong></td>
<td>6.18%</td>
<td>8.36%</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>(35%)</strong></td>
</tr>
<tr>
<td><strong>Type IIa Fibers</strong></td>
<td>4.54%</td>
<td>7.02%</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>(55%)</strong></td>
</tr>
<tr>
<td><strong>Type IIx Fibers</strong></td>
<td>2.33%</td>
<td>3.55%</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>(52%)</strong></td>
</tr>
</tbody>
</table>

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### Skel. Muscle Capillarization: Effects of Training and Detraining


<table>
<thead>
<tr>
<th></th>
<th>Before Training</th>
<th>Weeks After Training</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Capillaries per fiber</td>
<td>2.07 ± 0.11</td>
<td>120.3 ± 7.9</td>
</tr>
<tr>
<td>Caps around each fiber</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST</td>
<td>5.35 ± 0.29</td>
<td>123.4 ± 7.9</td>
</tr>
<tr>
<td>FTa</td>
<td>5.14 ± 0.13</td>
<td>120.8 ± 5.9</td>
</tr>
<tr>
<td>FTb</td>
<td>4.27 ± 0.17</td>
<td>129.7 ± 6.9</td>
</tr>
</tbody>
</table>

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)

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Detraining Effects On \( \dot{\text{VO}_2}\)-max


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

\begin{itemize}
  \item ~25\% increase due to training
  \item Essentially no decrease with reduced training
\end{itemize}

\[ \text{\( \dot{\text{VO}_2}\)-max (ml/kg/min)} \]

\[ \text{Time (wks)} \]

\[ \text{© Jeff Messer 2019} \]
VO₂-max and HIIT


- 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

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VO₂-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 (VO₂-max) involve 3- to 5-minute intervals and relatively high intensities (≥ 85% of VO₂-max)
VO$_2$-max and HIIT

197 articles identified through PubMed search

30 articles examined in full

70 additional articles included from author search and reference review

167 articles excluded from title and abstract:
- Intervals that were too short (n=7)
- No IT on a bike or a treadmill (n=82)
- No useful data (n=10)
- Rest periods too long (n=2)
- Study duration too short (n=8)
- Subjects too old (n=9)
- Trained subjects (n=41)
- Unhealthy subjects (n=7)
- W:R ratio too low (n=1)

37 articles included in synthesis

63 articles excluded after review:
- No IT (n=17)
- W:R too low (n=8)
- IT duration too short (n=7)
- Insufficient data (n=18)
- Same subjects (n=1)
- Exercise frequency too low (n=4)
- Subjects too old (n=1)
- Nonhuman subjects (n=1)
- Trained subjects (n=3)
- Study duration too short (n=1)
- Training intensity too high (n=1)
- Training intensity too low (n=1)

40 cohorts included in meta-analysis
VO₂-max and HIIT
**VO₂-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


- **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

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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

<table>
<thead>
<tr>
<th></th>
<th>Low (n = 8)</th>
<th>4 × 16 min (n = 9)</th>
<th>4 × 8 min (n = 9)</th>
<th>4 × 4 min (n = 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PRE mean (SD)</td>
<td>POST</td>
<td>PRE</td>
<td>POST</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>80.4 (12.5)</td>
<td>79.5* (12.2)</td>
<td>83.8 (10.8)</td>
<td>81.6* (11.0)</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>20.8 (7.2)</td>
<td>20.0* (7.2)</td>
<td>22.2 (5.4)</td>
<td>20.7 (5.2)</td>
</tr>
<tr>
<td>HF_{peak}</td>
<td>182 (12)</td>
<td>182 (9)</td>
<td>183 (9)</td>
<td>178* (8)</td>
</tr>
<tr>
<td>V_{E, peak} (L/min)</td>
<td>157 (35)</td>
<td>159 (40)</td>
<td>155 (35)</td>
<td>158 (39)</td>
</tr>
<tr>
<td>Lactate_{peak} (mmol/L)</td>
<td>14.9 (1.6)</td>
<td>13.7* (1.0)</td>
<td>14.8 (1.6)</td>
<td>13.9 (1.5)</td>
</tr>
<tr>
<td>RPE_{peak}</td>
<td>19.4 (0.5)</td>
<td>19.5 (0.5)</td>
<td>19.3 (0.7)</td>
<td>19.6 (0.5)</td>
</tr>
<tr>
<td>VO_{2peak} (L/min)</td>
<td>4.2 (0.7)</td>
<td>4.3 (0.7)</td>
<td>4.3 (0.5)</td>
<td>4.5* (0.7)</td>
</tr>
<tr>
<td>(ml kg/min)</td>
<td>52.7 (8.0)</td>
<td>54.5 (6.9)</td>
<td>51.1 (5.8)</td>
<td>54.4* (5.2)</td>
</tr>
<tr>
<td>Power VO_{2peak} (W)</td>
<td>349 (44)</td>
<td>358 (48)</td>
<td>361 (51)</td>
<td>372* (50)</td>
</tr>
<tr>
<td>(W/kg)</td>
<td>4.5 (0.6)</td>
<td>4.6 (0.6)</td>
<td>4.3 (0.4)</td>
<td>4.6* (0.4)</td>
</tr>
<tr>
<td>Power_{4mM} (W)</td>
<td>222 (42)</td>
<td>239* (38)</td>
<td>228 (51)</td>
<td>249* (45)</td>
</tr>
<tr>
<td>TTE80% (min)</td>
<td>10.86 (2.6)</td>
<td>12.14 (3.2)</td>
<td>8.52 (1.8)</td>
<td>13.83* (4)</td>
</tr>
</tbody>
</table>

*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.
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


• 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

Typical Lactate Performance Curves

Lactate mmol/l

Speed m/s

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Lactate Threshold

Effect of Training on the Lactate Threshold

![Graph showing the effect of training on lactate threshold](image-url)
Lactate Threshold

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


- 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


• Eight (8) male middle- & long-distance runners
• Mean Age: 20 years old
• Initial VO₂-max: 68.7 mL O₂ * kg⁻¹ * min⁻¹
• Study Duration: 14-weeks
• One (1) 20-minute threshold session * week⁻¹ @ 85% vVO₂-max
• Percentage (%) LT Improvement: 4.3

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Lactate Threshold

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


• 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

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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

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
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%
- Only heavy weight training (HWT) and explosive training (EXP) presented a % change significantly lower than zero

Millet et al. (2012): -12.52% change in RE consequent to HWT emphasizing half-squat and heel raises

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

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• 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


- 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.

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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)

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Plyometric Training & Endurance Performance

• Mean weekly endurance training volume of $67.2 \pm 18.9$ 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

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## Plyometric Training & Endurance Performance

<table>
<thead>
<tr>
<th></th>
<th>Plyometric</th>
<th>Control</th>
<th>Plyometric</th>
<th>Control</th>
<th>Plyometric</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2.4-km TT</strong></td>
<td>7.6 to 7.3-minutes</td>
<td>3.9% faster</td>
<td>2.4 km TT</td>
<td>8.0 to 7.9-minutes</td>
<td>1.3% faster</td>
<td></td>
</tr>
<tr>
<td><strong>20-m Sprint</strong></td>
<td>3.92 to 3.83 seconds</td>
<td>2.3% faster</td>
<td>20-m Sprint</td>
<td>3.97 to 3.94 seconds</td>
<td>0.8% faster</td>
<td></td>
</tr>
<tr>
<td><strong>CMJA</strong></td>
<td>36.1 to 39.3 cm</td>
<td>8.9% higher</td>
<td>CMJA</td>
<td>34.1 to 36.3 cm</td>
<td>6.5% higher</td>
<td></td>
</tr>
</tbody>
</table>

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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


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• 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 VO2-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 VO2-max w 18% grade / 2 x 20-min. intervals at 80% of VO2-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% \( \dot{V}O_2\)-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% \( \dot{V}O_2\)-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

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The Long Run ($LR$)

Thus, the long run is \textit{(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


- *PGC-1α* 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-1α activity with training”
The Long Run & Glycogen Depletion


- 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


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

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

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The Long Run & Glycogen Depletion

• Summary of the previous two (2) slides

- Glycogen $\rightarrow$ Increased AMPK activity $\rightarrow$ Increased PGC-1$\alpha$ activity $\rightarrow$ mitochondrial biogenesis

- Glycogen $\rightarrow$ Increased p38MAPK activity $\rightarrow$ Increased PGC-1$\alpha$ activity $\rightarrow$ 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?

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The Long Run & Glycogen Depletion


- 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


- 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

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

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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\(^{-1}\))

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Protein Distribution in Endurance Athletes

Protein Distribution in Endurance Athletes

Distribution of dietary protein intake throughout the day among athletes

Reference: by Jenna B. Gillen et al. JISNEM 2017, Apr;27(2):105-114

Designed by @YLMSportScience

Protein intake (grams)

- 58% of the athletes below the recommended 20 g per serving
- 36%
- 8%

This survey of athletes revealed they habitually consume > 1.2 g protein/kg/d, but the distribution throughout the day may be suboptimal to maximize the skeletal muscle adaptive response to training.

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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


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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)
Part X

Mitochondrial Quality versus Mitochondrial Quantity
Mitochondrial Quality versus Mitochondrial Quantity

- Bishop, D., Granata, C., & Eynon, N. (2014). Can We Optimise the Exercise Training Prescription to Maximise Improvements in Mitochondrial Function and Content, Biochimica et Biophysica Acta, 1840, 1266-1275.

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Mitochondrial Quality versus Mitochondrial Quantity

**Objective:** To review relevant literature focused primarily on the effects of exercise / training on both mitochondrial function *(quality)* and mitochondrial content *(quantity)*
Fig. 1. Mitochondrial respiration and citrate synthase activity in humans of differing training status [32–39]. SED = sedentary, ACT = active, TRA = trained, MT = moderately-trained, WT = well-trained, and HT = highly-trained.
Mitochondrial Quality versus Mitochondrial Quantity (*Bishop et al.*)

Potential Interpretation: There is a disconnect across various sub-groups (*sedentary, active, well-trained, highly-trained, etc.*) between mitochondrial content (*as assessed by maximal citrate synthase activity*) and mitochondrial function (*as assessed by maximal rate of respiration*)
Mitochondrial Quality versus Mitochondrial Quantity (*Bishop et al.*)

Fig. 2. The relationship between A) training intensity and B) training volume and training-induced changes in mitochondrial respiration in rats [58–60]. Studies were excluded if they did not provide precise information about the training prescription or if they used “mixed training” (i.e., a combination of continuous, moderate-intensity training, and high-intensity interval training).
Mitochondrial Quality versus Mitochondrial Quantity (*Bishop et al.*)

Potential Interpretation: Training intensity exerts a relatively more profound impact on maximal mitochondrial function (*as assessed by maximal rate of respiration, or* $V_{MAX}$) than training volume ($R^2 = 0.74$ versus $R^2 = 0.14$)
Fig. 4. The relationship between training intensity and training volume and training-induced changes in citrate synthase activity of rats in the red soleus (A and B respectively), the red vastus (C and D respectively), and the white vastus (E and F respectively) [54,58,60,63,93–103]. Studies were excluded if they did not provide precise information about the training prescription or if they used “mixed training” (i.e., a combination of continuous, moderate-intensity training, and high-intensity interval training).
Mitochondrial Quality versus Mitochondrial Quantity (*Bishop et al.*)

**Potential Interpretation:** Training volume exerts a relatively more profound impact on mitochondrial content (*as assessed by percentage (%) change (Δ) in citrate synthase content*) than training intensity (*R^2 = 0.88 & 0.66 versus R^2 = 0.12 & 0.01*)
Mitochondrial Quality versus Mitochondrial Quantity (*Bishop et al.*)

- **A**
  - $R^2 = 0.01$
  - Citrate Synthase Change (%) vs. Training Intensity (m/min)

- **B**
  - $R^2 = 0.88$
  - Citrate Synthase Change (%) vs. Training Volume (m/wk)

- **C**
  - $R^2 = 0.12$
  - Citrate Synthase Change (%) vs. Training Intensity (m/min)

- **D**
  - $R^2 = 0.66$
  - Citrate Synthase Change (%) vs. Training Volume (m/wk)

- **E**
  - $R^2 = 0.70$
  - Citrate Synthase Change (%) vs. Training Intensity (m/min)

- **F**
  - Citrate Synthase Change (%) vs. Training Volume (m/wk)
Mitochondrial Quality versus Mitochondrial Quantity (*Bishop et al.*)

**Potential Interpretation:** There is a strong relationship between training volume and skeletal muscle mitochondrial content (*as assessed by percentage {\%} increase in citrate synthase*) across multiple muscle fiber types (*red soleus, red vastus, and white vastus*)
Mitochondrial Quality versus Mitochondrial Quantity (*Bishop et al.*)

Fig. 5. Individual changes in mitochondrial respiration during training and de-training [56]. Pre_IT = pre interval training, Post_IT = post interval training, Post_DT = post de-training.
Mitochondrial Quality versus Mitochondrial Quantity (Bishop et al.)

Potential Interpretation: An interval training-induced increase in maximal mitochondrial function is reversed over one (1) to three (3) weeks with the cessation of interval training.
Mitochondrial Quality versus Mitochondrial Quantity (*Bishop et al.*)

![Graph showing enzyme activity changes](graph.png)

**Fig. 6.** Changes in the activities of cytochrome c oxidase (COX), citrate synthase (CS) and succinate dehydrogenase (SDH) during training cessation in humans. Values are based on results from the few studies that have measured changes in enzyme activity during the cessation of training [66,67,69,70]. Values on the y-axis are percent of pre-training values.
Mitochondrial Quality versus Mitochondrial Quantity (*Bishop et al.*)

**Potential Interpretation:** However, rates of regression in distinct components of maximal mitochondrial function appear to differ both across mitochondrial enzymes and across different fiber types.
Mitochondrial Quality versus Mitochondrial Quantity (Bishop et al.)

Current, Summary Interpretation: Training intensity appears to be an important determinant of maximal mitochondrial function albeit not mitochondrial content; by contrast, training volume appears to be an important determinant of training-induced adaptation in muscle mitochondrial content albeit not function (caveat: training intensity & mitochondrial content in type IIx fibers?)
Mitochondrial Quality

• Hypothesis that training intensity may be a critical determinant of improvements in maximal rate of mitochondrial respiration (MAPR)

• Multiple studies evidence a trend toward greater MAPR with higher training intensities

• Absence of evidence correlating training intensity with enhanced mitochondrial content
Mitochondrial Quantity

- Hypothesis that training volume may be a critical determinant of enhanced mitochondrial content
- Recent research suggests that improvements in MAPR are not proportional to training volume in humans
- Multiple studies evidence a strong correlation between training volume and improvements in mitochondrial content

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Mitochondrial Quality and Quantity

Potential Interpretation: Training intensity appears to be an important determinant of improvements in mitochondrial function (quality) but not mitochondrial content; by contrast, training volume appears to be a similarly important determinant of improvements in mitochondrial content (quantity) albeit not mitochondrial function.
Mitochondrial Quality versus Mitochondrial Quantity

MacInnis et al. (2017)

- Ten (10), young, active males ($VO_2\text{-peak} = 46.2 \pm 2 \text{ ml O}_2 \text{ * kg}^{-1} \text{ * min}^{-1}$)

- 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)

• 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 O₂ respiratory rates {JO₂}*)

• Mitochondrial QUALITY was assessed (*mitochondrial mass-specific JO₂*)
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)
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 et 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
Acknowledgments
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- Jordan Furseth (DVHS, ‘16)
- McKenna Gaffney (XCP, ‘13)
- Savannah Gaffney (XCP, ‘14)
- Sophi Johnson (DVHS, ‘15)
- Baylee Jones (DVHS, ‘17)
- Danielle Jones (DVHS, ‘17)
- 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)
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- Elise Richardson (DVHS, ‘14)
- Emily Smith (DVHS, ‘16)
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- Kate Yanish (XCP, ‘12)
- Aubrey Worthen (DVHS, ‘16)

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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 Lungen)
- 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

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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

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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

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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

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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

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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

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