Understanding Blood Lactate to Optimize Training and Performance

Matt Van Dyke

- “Training needs to be as specific as possible not always to the energy demands of the sport, but to the desired cellular outcomes. Then at other times in the training cycle, we focus on training the tissues to the desired energy systems used in the activity.”

-Dr. David Bacharach

Covered in Presentation

- Lactate “Myths”
- Why Lactate is Good for Athletes
- Lactate Kinetics
- Reasons to Improve Lactate Kinetics
- Training Methods to Improve Lactate Kinetics
- Nutritional Needs to Support Lactate and this Training

Lactate “Myth” #1

- Lactate is only produced during intense exercise bouts
  - Created at all times
    - Clearance almost equal to production
      - Red Blood Cells
    - Production increases as intensity increases
    - Clearance matches to certain point
    - Eventually accumulation occurs
      - “Lactate Threshold”
      - Determined by training status

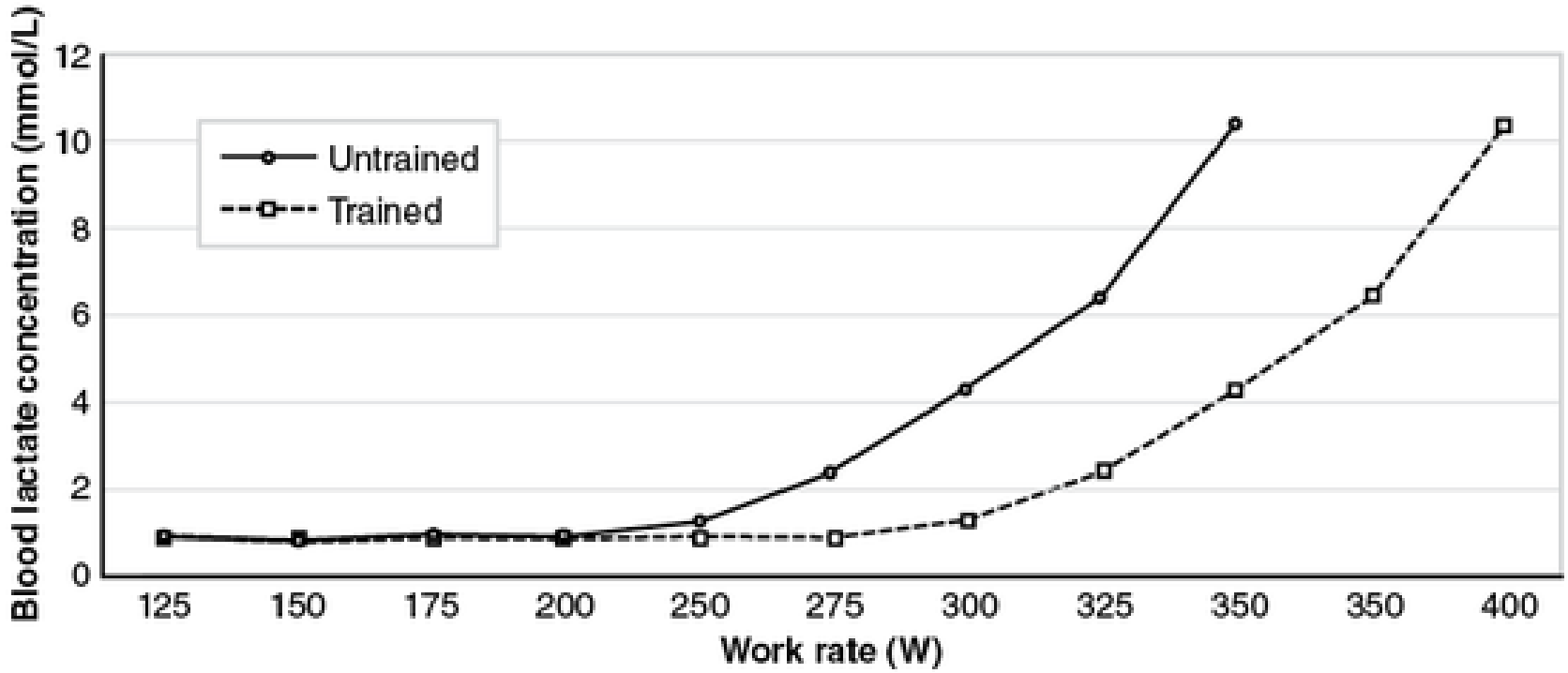


FIGURE 6.10 The lactate threshold training effect.

Lactate “Myth” #2

- Lactate is a cause of delayed muscle soreness
  - Constantly moved around the body
    - Slightly higher concentration in the cells than blood
  - Not enough pH change to alter cell function
  - High levels can affect nerve endings
    - The “burn” felt during intense activity
    - Typically cleared after 2-4 min
      - Dependent on training levels
    - In blood for a few hours, not enough to cause changes

Lactate “Myth” #3

- Lactate causes drop in muscle pH
  - Result of the cell attempting to prevent a drop in pH
    - Indirect marker of pH changes inside the cell
  - Works to reduce muscle acidity
  - Allows muscle to work longer

Lactate is a Positive for Athletes

- Assists in maintaining pH of the muscle
  - Just one of many buffering methods
    - Intracellular
  - Muscular pH is the biggest factor in repeat-sprint abilities
    - Interferes with muscle contractility
    - Prevents recovery

Lactate is a Positive for Athletes

- Gives an idea of energy systems being used
  - High-intensities
    - Lactate production represents even greater production of H^+ ions
    - Rapid appearance leads to reduced exercise intensity
    - Training allows for improved clearance and better tolerance of pH changes
    - Muscle force maintained longer
    - Leads to increased time to exhaustion

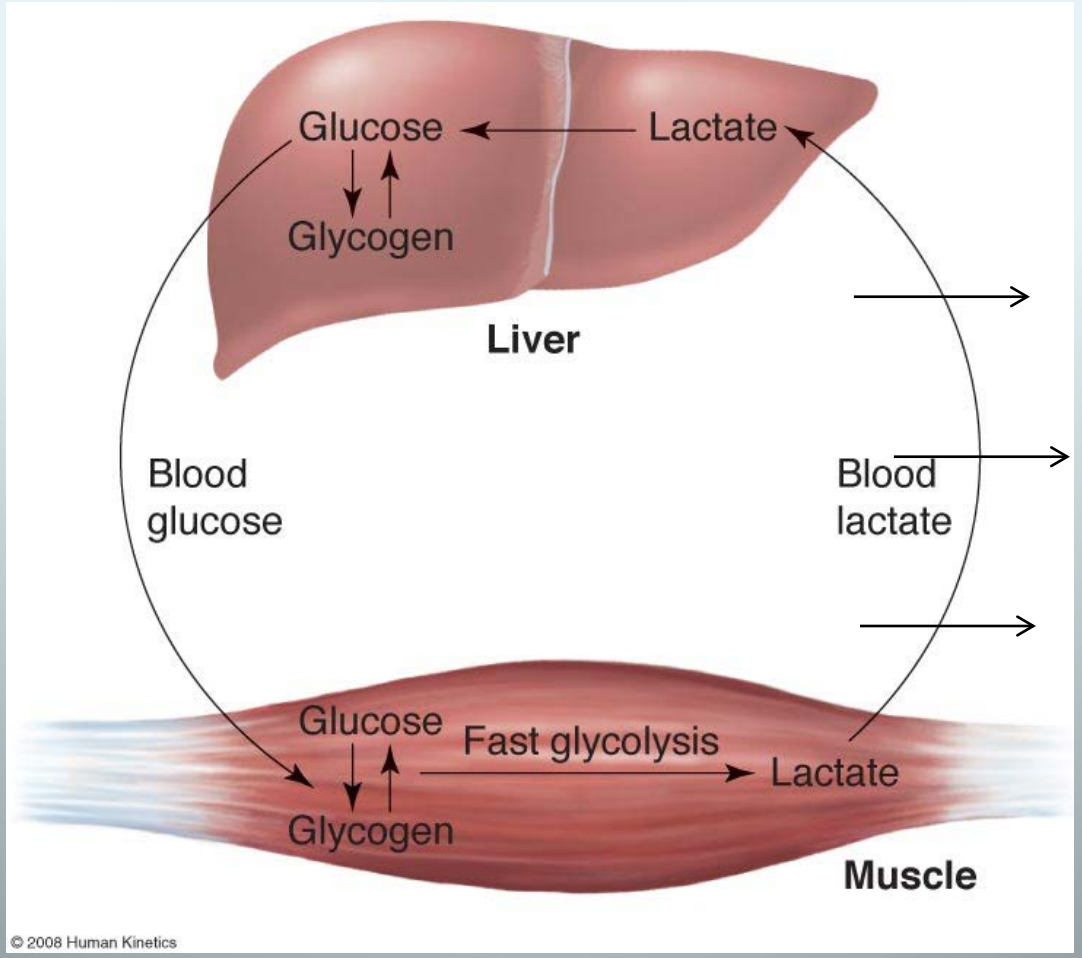
Lactate is a Positive for Athletes

- Keeps substrates available for glycolysis
  - Repeated high-intensity exercise requires rapid ATP synthesis
  - Lactate accepts H^+ ions
    - allows NAD to continue glycolysis
    - Body can produce more lactate, but not NAD
    - Production is good, but must be able to leave cell at some point

Lactate is a Positive for Athletes

- Utilized as an energy substrate
  - Oxidative Fibers use lactate as an energy source
    - Preferred substrate by the heart
      - Primary fuel source during exercise
    - Used as a gluconeogenic precursor in the liver
      - Allows exercise to continue by “recycling”

Lactate as an Energy Substrate



Kidney

Heart

Oxidative Fiber

Lactate Kinetics

- Advantageous to remove lactate from cell to prevent a drop in pH
- Monocarboxylate transporters (MCT's) are used
  - Not the only mechanism of lactate removal
  - Found on both the cell and mitochondrial membranes
  - Blood lactate post-exercise inversely related to MCT concentration
  - 2 main transporters identified for use during exercise
    - MCT1 and MCT4

Lactate Kinetics

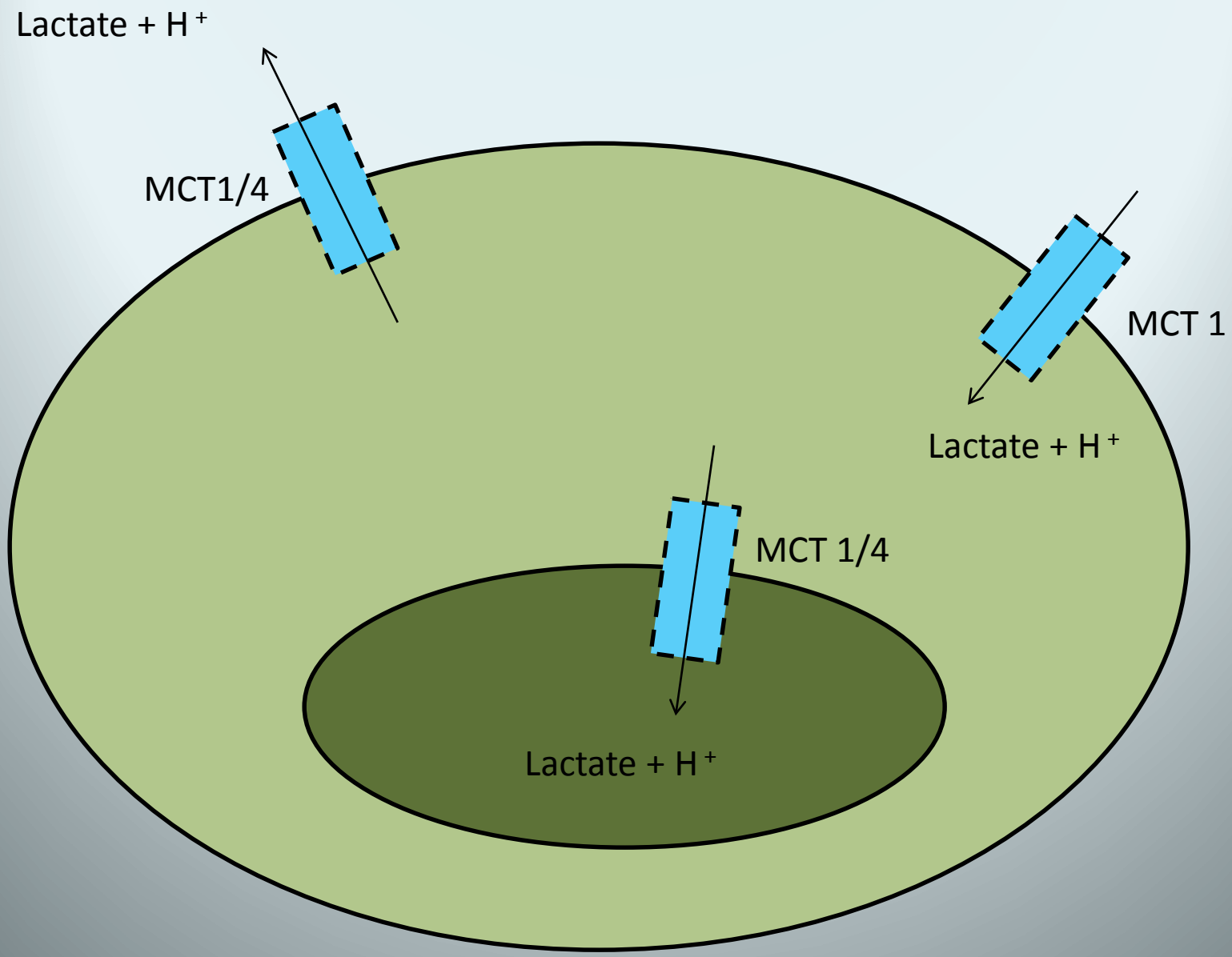
- MCT1
  - Facilitate removal and uptake of lactate
  - Located mostly on oxidative fibers
    - Primary role is uptake of lactate for energy
      - From blood or nearby glycolytic cells
    - Moves lactate accumulated during intense activity into the mitochondrial network or to more oxidative fibers
      - Converted to usable energy
    - Generally more responsive to training

Lactate Kinetics

- MCT4
  - Located mostly on glycolytic fibers
    - Moves lactate out of the cell
    - Glycolytic fibers produce highest amounts of lactate
  - Large variation between subjects
  - Respond to training, but do not increase at same rate as MCT1
  - Body becomes better at oxidizing lactate due to exercise, rather than tolerating it

14 total MCTs, only 6 have known function

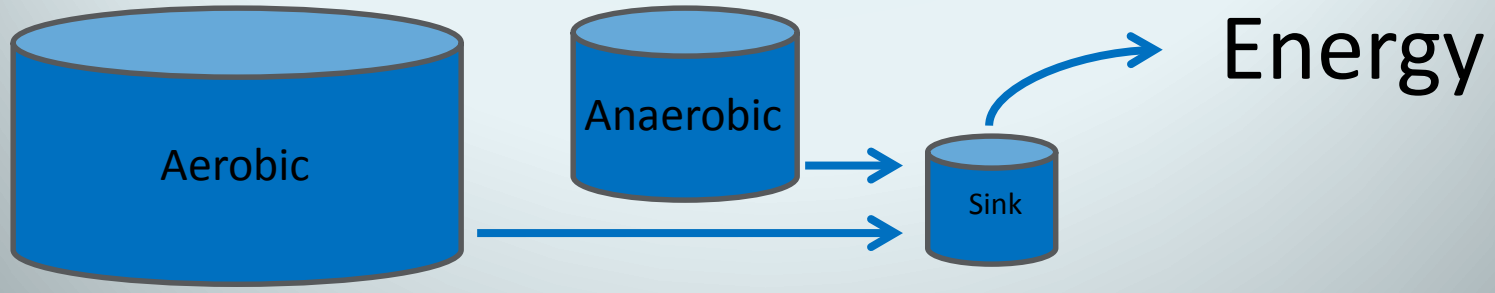
	Primary role	Location
MCT 1	Lactate influx/efflux	Majority of tissues (**oxidative** > glycolytic)
MCT 2	Uptake of lactate into brain	Brain, liver, kidney, sperm tails, skeletal muscle, heart
MCT 3	Lactate efflux from retina and choroid	Retina and choroid
MCT 4	Lactate efflux from glycolytic muscle fibers	Most tissues (**glycolytic** muscle fibers, astrocytes, WBCs, chondrocytes)
MCT 8	Transports thyroid hormone	Most tissues (liver, kidney, heart, skeletal muscle, brain, pituitary, thyroid)
MCT 10	Transports aromatic AAs (F, Y, H, W)	Intestine, kidney, liver, skeletal muscle, heart, placenta


Lactate + H +
MCT1/4
MCT 1
Lactate + H +
MCT 1/4
Lactate + H +

Reasons to Improve Lactate Kinetics

- Ultimate goal is to buffer and keep ATP:ADP ratio consistent
  - PCr works very rapidly, but has a very small fuel tank
  - Glycolysis works rapidly as well with a much bigger reserve tank, but creates waste (H^+)
  - Aerobic system has a huge tank, but takes a while to get going (20-40 sec.)

Reasons to Improve Lactate Kinetics



Reasons to Improve Lactate Kinetics

- Controlling pH maintains force production
  - Fatigue is a complex process
- Lactate levels reflect even higher levels of H^+
  - Drop in pH leads to a decline in tension development and contributes to muscle fatigue
  - Active binding sites reduced with calcium reduction and/or reduced rate of cycling
    - Ca^{2+} and H^+ compete for binding site on troponin
    - Both responsible, still unsure which is the leading cause

Reasons to Improve Lactate Kinetics

- Increased repeat-sprint ability
  - Athletes better able to buffer H^+ have increased repeat-sprint abilities
    - Reduction of muscle acidity benefits athletes in high-intensity sports, with short rest bouts
      - Particularly team sports
  - Combination of base endurance and high-intensity training led to best performance increases

How to Improve Lactate Kinetics

- A lot of what we are already doing
- Adaptations are specific to training
  - Both intensity and time
    - Raises question: Which training methods are optimal?
  - Base Endurance Training
  - High-Intensity Training

Base Endurance Training

- Allows cells to clear lactate rapidly
  - Maximizes MCT concentration
  - Increases mitochondrial density
- Adaptations lead to faster recovery
  - Increased PCr re-synthesis
    - H^+ ions affects phosphate, preventing ATP re-synthesis
  - Athletes with greatest glycolytic rate in first high-intensity bout had the most drastic decrease in performance with repeat-efforts

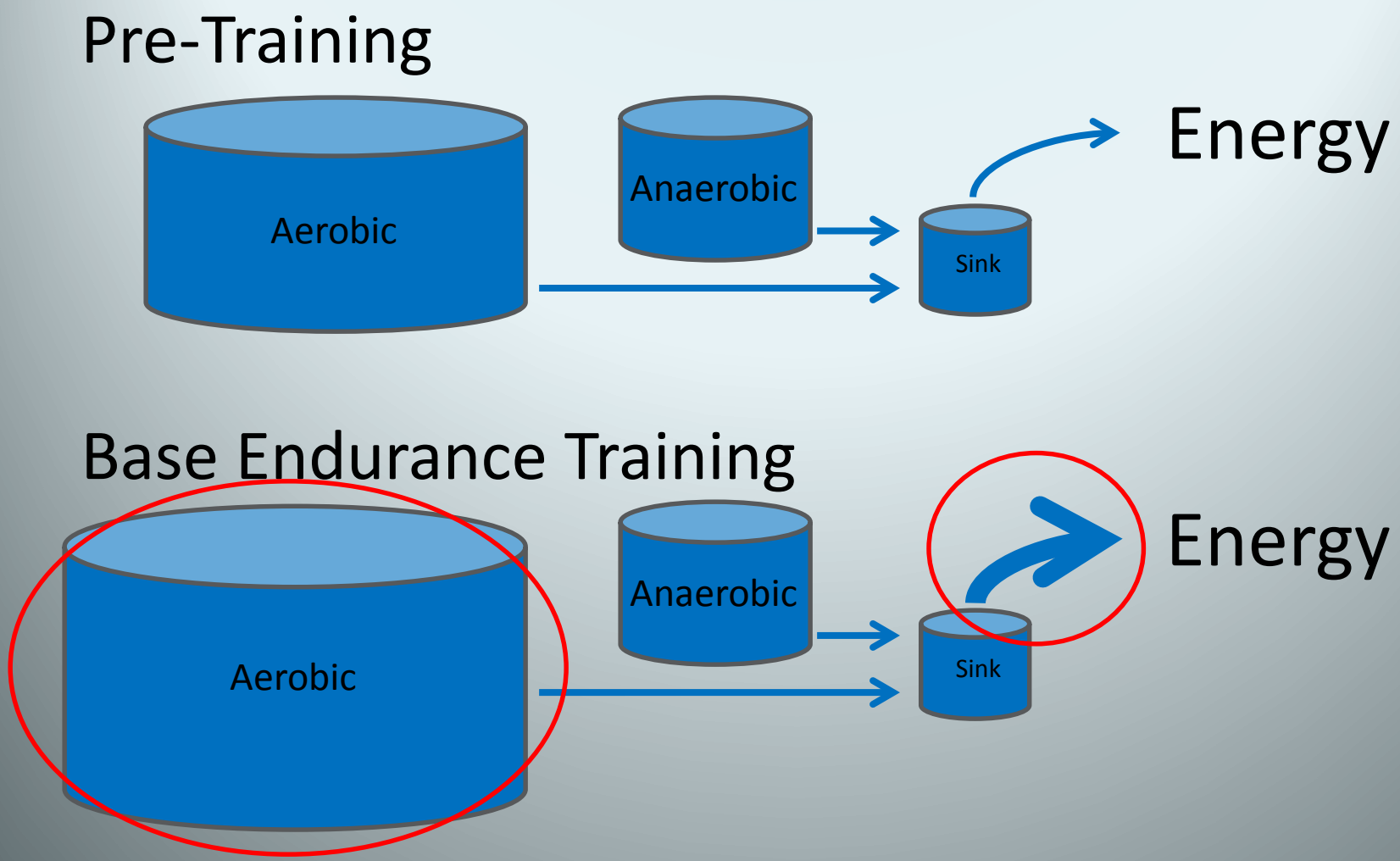
Base Endurance Training

- Low intensity activity
  - Dynamic training that increases blood flow at low intensities
  - Time is key in base training
    - One hour
    - Can be accumulated in multiple bouts
  - Allows aerobic training without adaptation of glycolytic fibers
  - Circuit training is beneficial, but not optimal

Base Endurance Training

- Examples:
  - Dynamic stretching
  - Brisk walking between exercise sets
  - Low intensity calisthenics
  - Single leg stability training
- Good foundation to build on, must also train specifically to sport

Base Endurance Training



High-Intensity Training

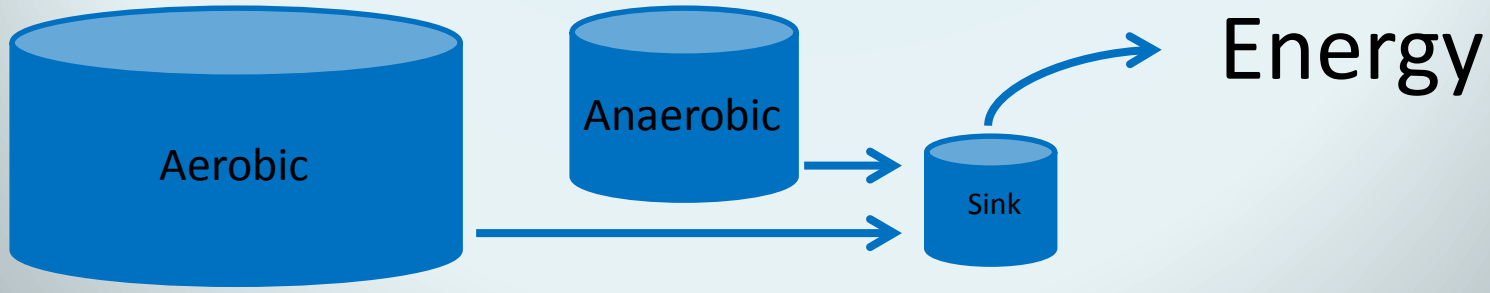
- Allows cells to tolerate more lactate
- Results in increased muscle buffering,
  - Increases repeat-sprint ability
  - High-rep, short rest time
- Maintains MCT concentration
  - Ensure intensity is not too high
    - MCT's decrease acutely
      - Decreased intensity until "sink" is cleared
    - Allow proper recovery times in training
      - Conversational without labored breathing

High-Intensity Training

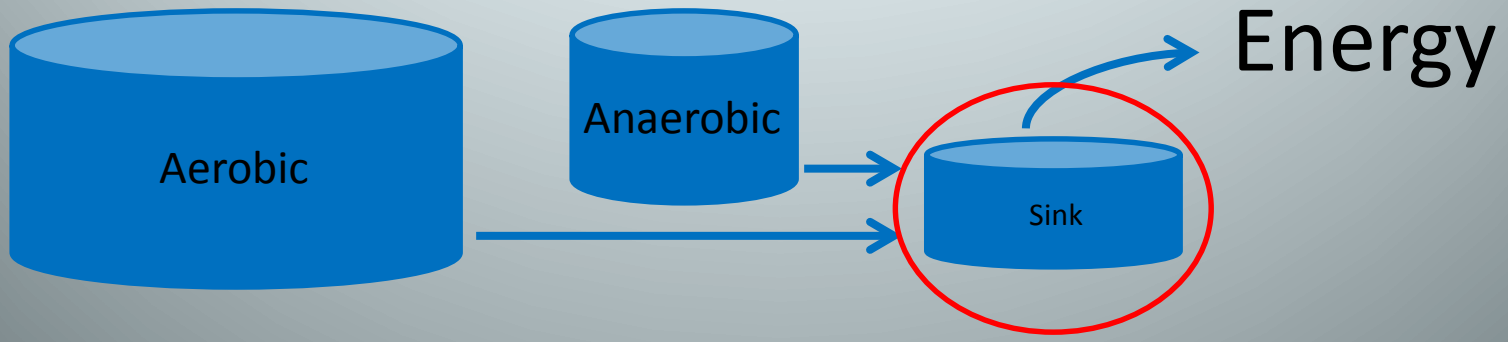
- H^+ production increases with training intensity
  - Higher trained athletes produce more lactate
    - Need higher intensities to adapt
  - Ensures cell is able to tolerate pH changes due to higher intensities
  - To a certain point

High-Intensity Training

Pre-Training



High-Intensity Training



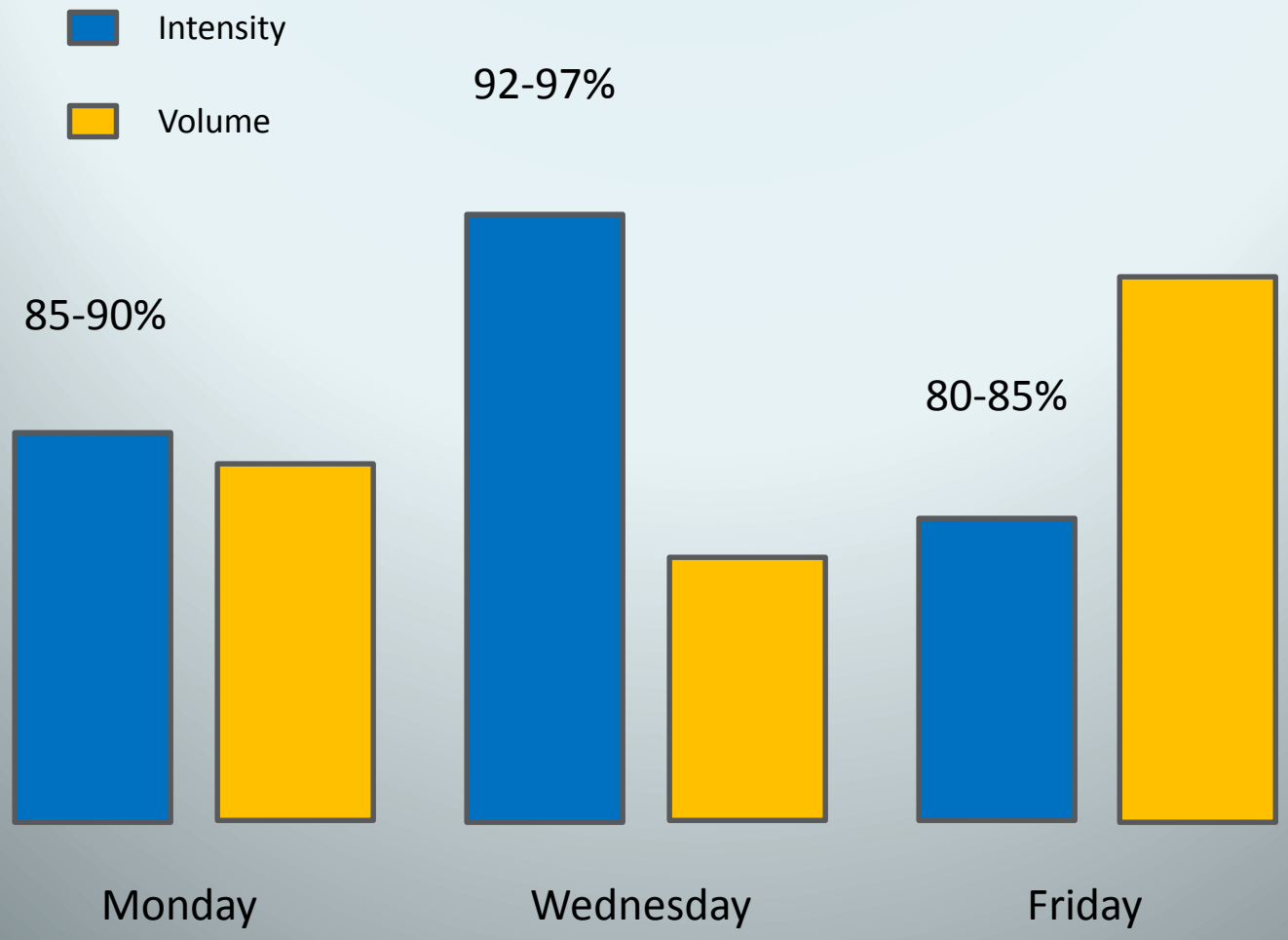
Specific Training Methods

- General Preparatory Period
  - Work on base endurance during this time
    - Full range of motion and increased blood flow
      - Extended dynamic warm-up
      - Stability training
      - Walking between sets
  - Can complete circuit training at this time
    - Lays foundation for future high-intensity training
    - Be aware of intensity

Specific Training Methods

- Modified Undulated Training
  - Train the body in a high-intensity manner each day
  - Timed sets for specific energy system training
    - Keeps from “pulling” athletes in too many directions
  - Deload weeks revert back to aerobic training
    - Longer circuits
    - Residual effects and increase MCT concentration

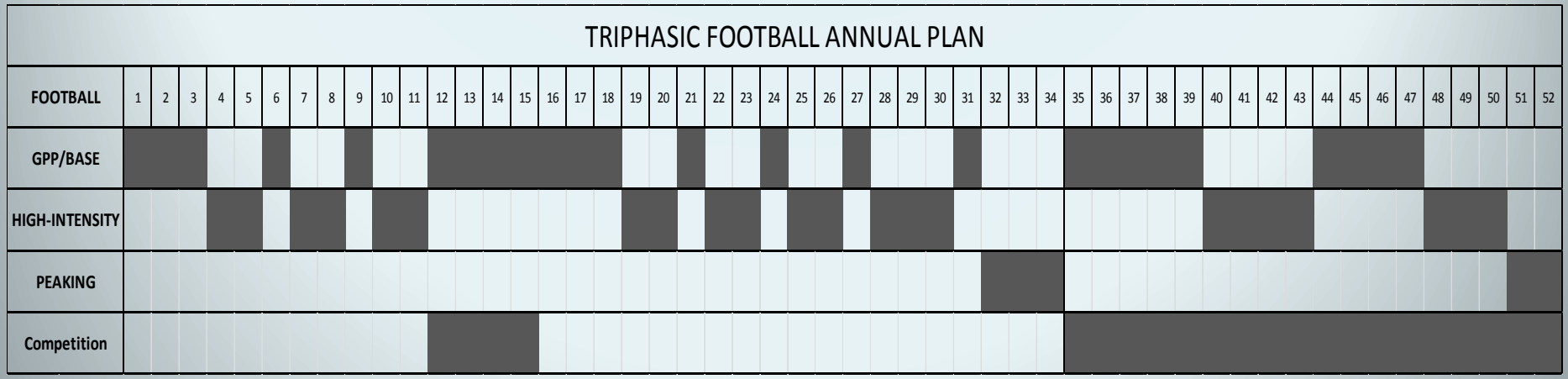
Modified Undulated Training

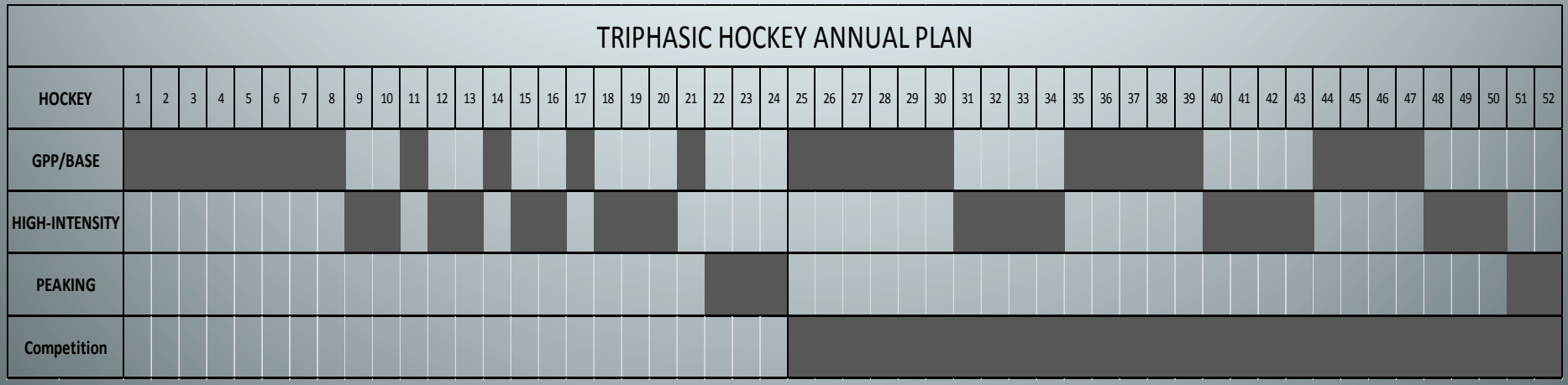


Specific Training Methods

- Repeat-Sprint Training
  - Most closely related to high-intensity team sports
  - Biometric training
    - Percent drop-off
      - Ensures no athlete is overtraining
      - Rate of Recovery Training
      - Time between reps
        - » Set goal time with set rest times, once athlete misses two reps they are finished
      - Heart rate recovery
        - » 120 bpm, once recovery is over 5 min the athlete is done
  - Be aware of use in large group and/or team setting

Specific Training Methods





Results of Combining these Training Methods

- Change in lactate threshold
  - Shift curve to right
    - Can now do more work at the same lactate accumulation
    - Able to clear lactate at a higher rate
      - Improved recovery
        - » ATP:ADP ratio
  - Able to tolerate higher lactate concentrations
    - Bigger waste tank

Nutrition Tactics to Support these Training Methods

- Need glycolysis in order to produce lactate
  - Carbohydrate intake vital for athletes in high-intensity sports
    - Allows for muscle glycogen storage
  - Body stores about 400g of muscle glycogen max
    - Can burn up to 100g of glycogen in a quality 400m sprint
      - only two to three 400m sprints could be completed per day
        - » After that begin to feel “sluggish”

Nutrition Tactics to Support these Training Methods

- Nutrient timing for recovery
  - Key for athletes with short breaks between exercise/competitions
    - Must restore muscle glycogen content quickly
      - High-glycemic carbohydrate
        - » Take advantage of glucose sensitivity
        - » Immediately post-exercise

Nutrient Timing

- Carbohydrate
  - Essential for glycogen re-synthesis
    - 1.2 g/kg/hr first four hours
    - Increased time to exhaustion in subsequent exercise
      - Increases muscle glycogen for anaerobic glycolysis
    - Increased hydration status (10% glucose)
      - Increased protein synthesis
      - Slower emptying leads to increased absorption

Nutrient Timing

- Carbohydrate + Protein
  - Carb consumed at 1.2 g/kg/hr still
    - Same as previous effects
  - Protein
    - Further improves hydration status
    - Increased net protein
      - Decreased breakdown or increased synthesis
        - » not fully known at this time
    - 4:1 or 3:1 ratio of carbs:protein is optimal
      - Glycogen re-synthesis is key
      - Body can uptake only so much protein at one time

Nutrient Timing

Phase	Objectives	Food Options
Energy Phase 10 min prior to and during a workout	Spare muscle glycogen and protein	Gatorade, Powerade, Honey, Most Cereals, Fruit
	Minimize muscle damage	Protein Shake, Dairy Products, Peanut Butter, Meats, Nuts
	Set the nutritional stage for a faster recovery following a workout	

Nutrient Timing

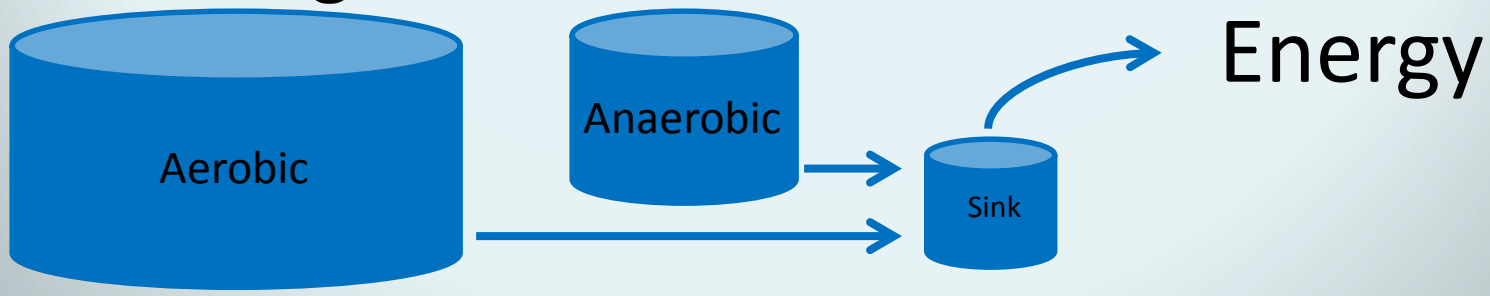
Phase	Objectives	Food Options
Anabolic Phase Within 45 min after a workout	Restore muscle glycogen stores	Gatorade, Powerade, Honey, Most Cereals, Fruit
	Shift body from catabolic to an anabolic state	Protein Shake, Dairy Products, Peanut Butter, Meats, Nuts

Nutrient Timing

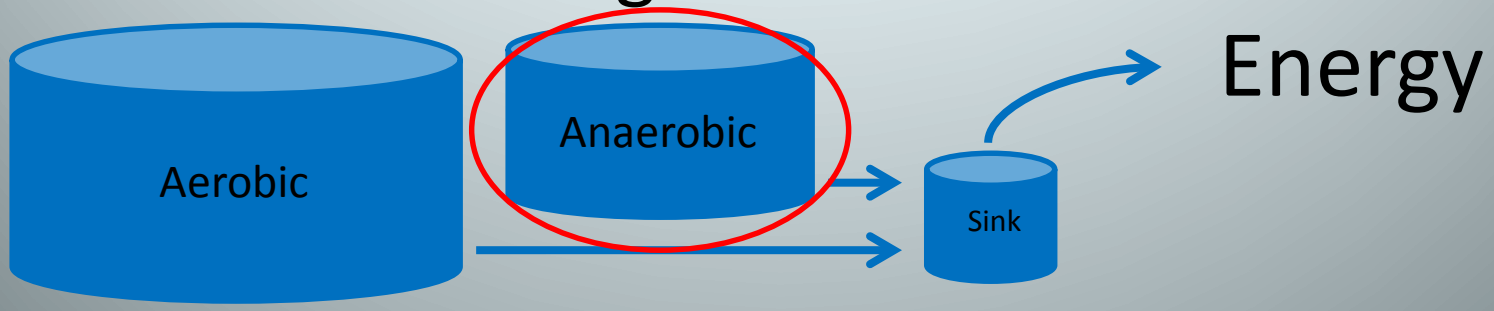
Phase		Objectives	Food Options
Growth Phase I	Rapid Segment The first 4 hours after a workout	Maintain increased insulin sensitivity Maintain the anabolic state	Protein Shake, Dairy Products, Peanut Butter, Meats, Nuts Pasta, Wheat Bread, Potatoes Oatmeal, Fruit, Vegetables
Growth Phase II	Sustained Segment The next 16-18 hours after a workout	Maintain positive nitrogen balance and stimulate protein synthesis Promote protein turnover and muscle development	

Nutrient Timing

Pre-Training



Post-Nutrient Timing

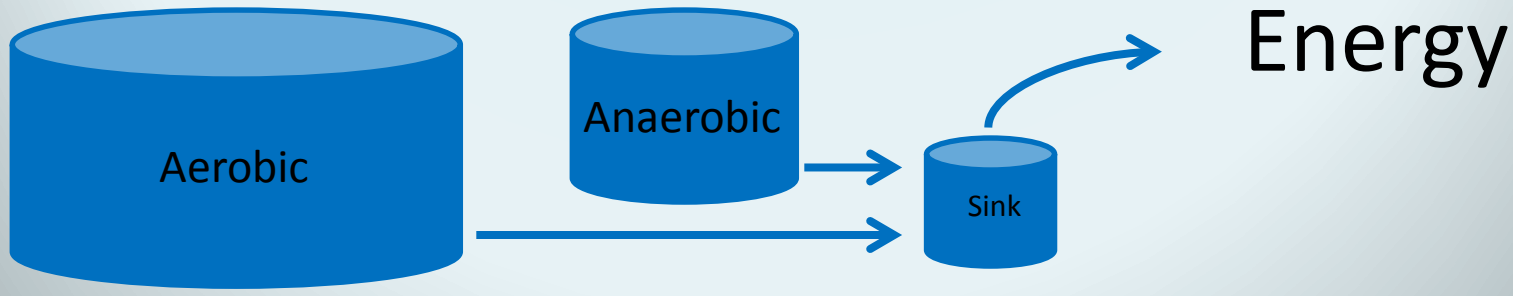


Conclusion

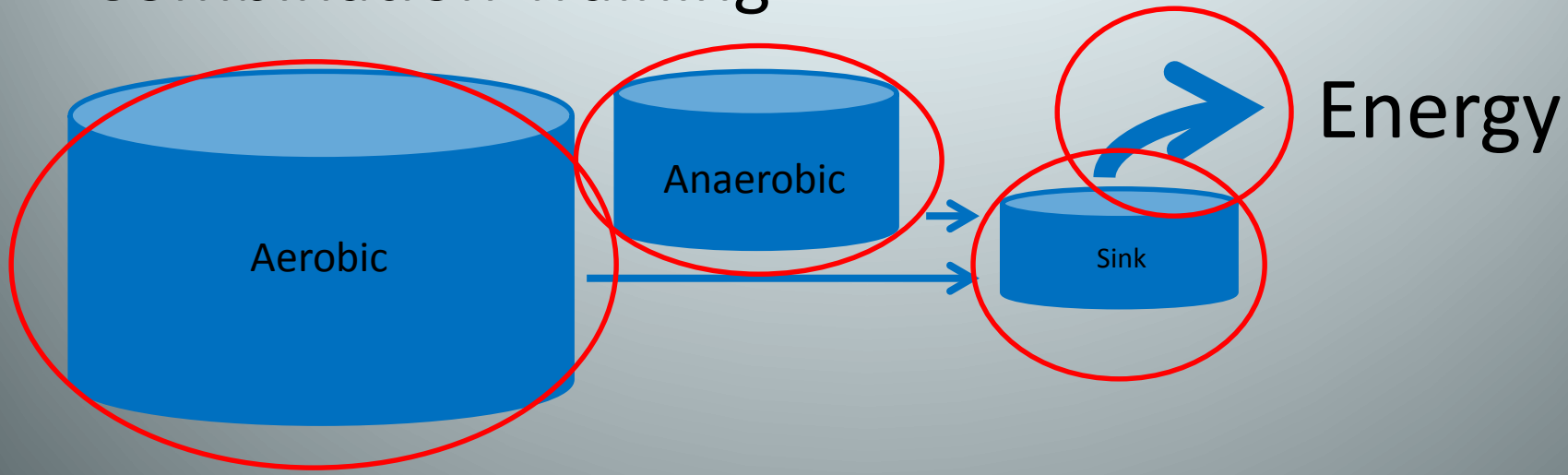
- Repeat-Sprint abilities rely on buffering
  - Lactate is one buffer in the body
  - Can be improved through training
    - Base Endurance training increases MCT concentration
    - High-intensity training increases tolerance
    - Nutrient Timing maximizes glycogen content

Conclusion

Pre-Training



Combination Training



Special Thanks

Dr. David Bacharach

Cal Dietz

References

- Bishop, D,. Edge, J., Thomas, C., Mercier, J. Effects of high-intensity training on muscle lactate transporters and postexercise recovery of muscle lactate and hydrogen ions in women. *AJP: Regulatory, Integrative and Comparative Physiology*. doi:10.1152/ajpregu.00863.2007
- Evertsen, F., Medbo, J., Bonen, A. Effect of training intensity on muscle lactate transporters and lactate threshold of cross-country skiers. *Acta Physiologica Scandinavica, 173*(2), 195-205. doi:10.1046/j.1365-201X.2001.00871.x
- Juel, C., Holten, M., Dela, F. Effects of strength training on muscle lactate release and MCT1 and MCT4 content in healthy and type 2 diabetic humans. *The Journal of Physiology*, 297-304. doi:10.1113/physiol.2003.058222.
- Bishop, D., Edge, J., Goodman, C. Muscle buffer capacity and aerobic fitness are associated with repeated-sprint ability in women. *European Journal of Applied* Physiology, 92, 540-547. doi:10.1007/s00421-004-1150-1.
- Edge, J., Hill-Haas, S., Goodman, C., Bishop, D. Effects of Resistance Training on H+ Regulation, Buffer Capacity, and Repeated Sprints. *Medicine & Science in Sports & Exercise, 38*(11), 2004-2011. doi:10.1249/01.mss.0000233793.31659.a3.
- Thomas, C., Bishop, D., Moore-Morris, T., Mercier, J. Effects of high-intensity training on MCT1, MCT4, and NBC expressions in rat skeletal muscles: influence of chronic metabolic alkalosis. *AJP: Endocrinology and Metabolism, 293,* E916-E922. doi:10.1152/ajpendo.00164.2007.
- Carsten, J., Christina, K., Jung Nielsen, J., Krustrup, P., Mohr, M., Bangsbo, J. Effect of high-intensity intermittent training on lactate and H+ release from human skeletal muscle. *AJP: Endocrinology and Metabolism, 286,* 245E-251. doi:10.1152/ajpendo.00303.2003.
- Thomas, C., Perrey, S., Lambert, K., Hugon, G., Mornet, D., Mercier, J. Monocarboxylate Transporters, Blood Lactate Removal After Supramaximal Exercise, And Fatigue Indexes In Humans. *Journal of applied Physiology, 98,* 804-809. doi:10.1152/japplphysiol.01057.2004.
- Pilegaard, H., Domino, K., Noland, T., Juel, C., Hellsten, Y., Halestrap, A., Bangsbo, J. Effect on high-intensity exercise training on lactate/H+ transport capacity in human skeletal muscle. American Journal of Physiology – Endocrinology and Metabolism, 276, E255-E261.
- Bishop, D., Edge, J., Thomas, C., Mercier, J. High-intensity exercise acutely decreases the membrane content of MCT1 and MCT4 and buffer capacity in human skeletal muscle. *Journal of applied Physiology, 102,* 616-621. doi:10.1152/japplphysiol.00590.2006.

Questions?