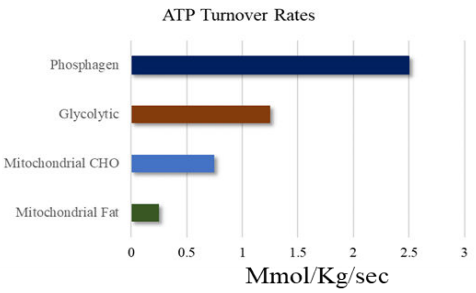
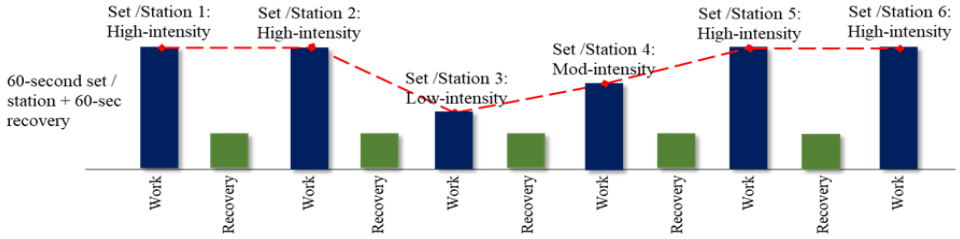
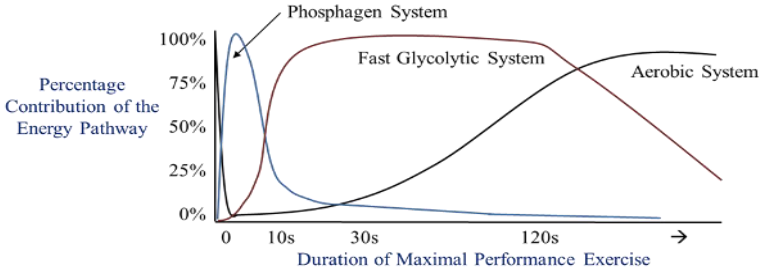
Connecting Energy Pathways with Resistance Training

Bioenergetics of Effective Programming







Developed by:

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NASM CPT, CES, PES, CNC, CSNC & CWC; ACE CPT & HC; ACSM EP-C; CSCS; CISSN

Engage.. Ignite.. Empower..©

Agenda …

110-minutes:

1. Introduction to the energy pathways.
2. Discussion on the nature of resistance training – interval-format.
3. Physiological review of the 2 anaerobic energy systems:
    a. Phosphagen system and effective programming for this system.
    b. Glycolytic system and effective programming for this system.
4. HIIT training v. Fitness Industry version of HIIT.
5. Interval training solutions.

Introduction …

Aerobic Pathway (oxidative)

Largest energy source.
Produces ATP slowly.
Uses all 3 macronutrients.

Anaerobic Systems

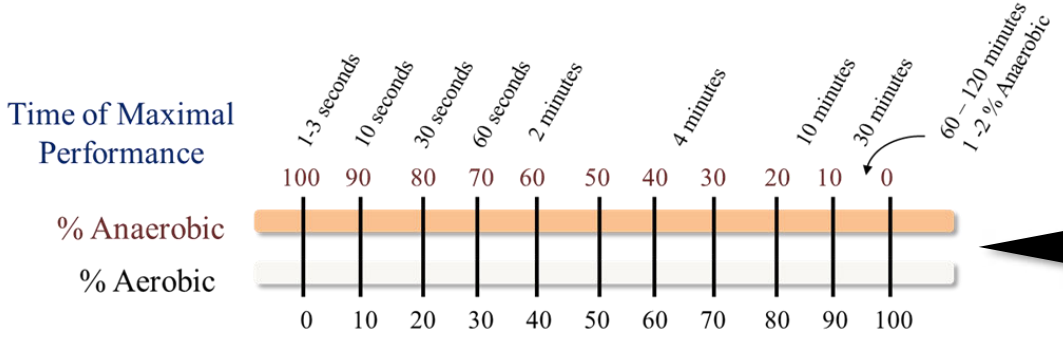
Phosphagen System

Fastest, but smallest energy source.
Involve no macronutrients as fuel.
Relies upon phosphocreatine.

Glycolytic System

Fast, largest anaerobic energy source.
Uses carbohydrates only.
Metabolic by-product = $lactate^- + H^+$.

Myth of Intensity v. Availability: Simplistic view = dichotomous nature of aerobic v. anaerobic – anaerobic contributes at higher intensities.



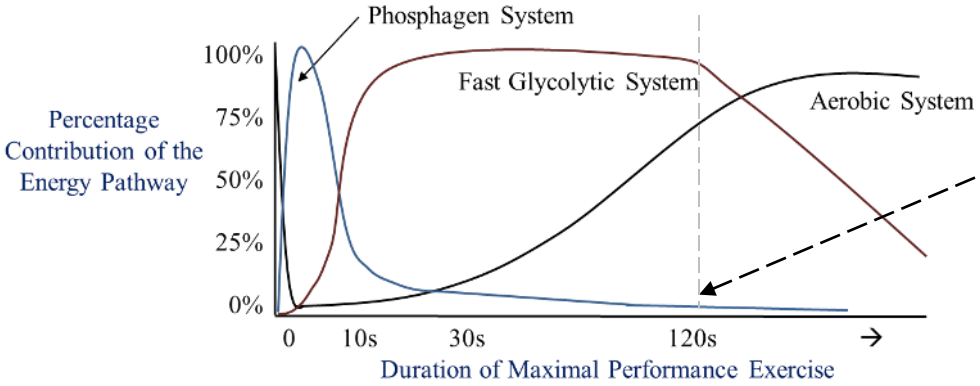
Example: 10 sit-to-stands

Reference: Pocari J, Bryant, CX, and Comana, F (2015). *Exercise Physiology*. Philadelphia, PA. The FA Davis Company.

Introduction …

The Reality

- Simultaneous and coordinated use of all 3 system all the time.



Anaerobic capacity varies:

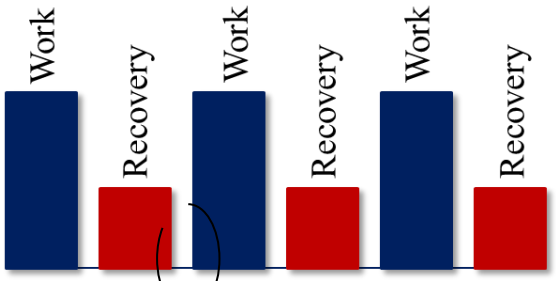
- 2-min = early-stage depletion.
- Sustainable up to 3-min (females) and 4-min (males).

Duration of Event	Event Intensity	Primary Energy System
0-to-6 seconds	Extremely High	Phosphagen*
6-to-30 seconds	Very High	Phosphagen (1st) and Fast Glycolytic (2nd)
30-to-120 seconds	High	Fast Glycolytic
2-to-3 minutes	Moderate	Fast Glycolytic (1st) and Oxidative (2nd)
> 3 minutes	Lower	Oxidative

		Carbohydrates	
Event	Phosphagen	Glycolytic	Aerobic
100 meters: ~10 kcal	70-to-80%	20-to-30%	Insignificant
Marathon: 2,500 kcal+	Insignificant	5-to-10%	90-to-95%
Soccer (Football): 600 kcal	Less than 10%	Approximately 70%	Approximately 20%

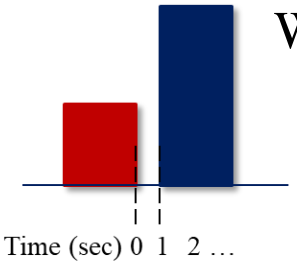
Introduction …

What is the Nature of Resistance Training?



Interval-type format:

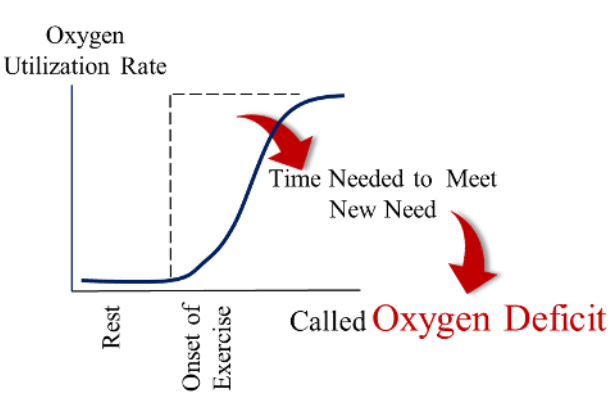
- Short work interval + short recovery interval.
- Format ramps immediately from passive / light-active rest to work.

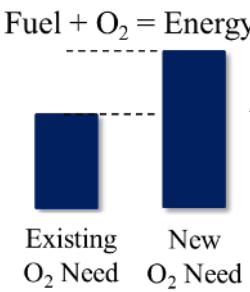


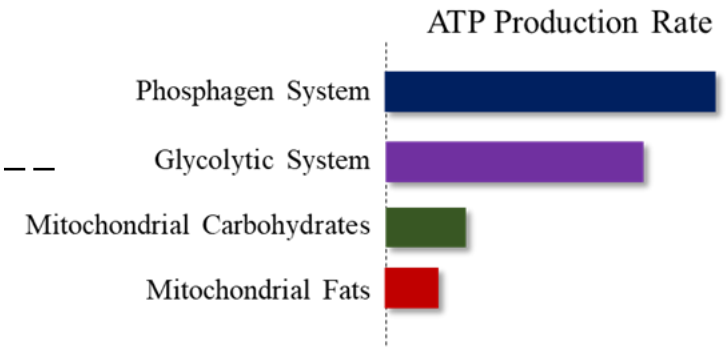
Who provides energy for the set?
(regardless of intensity)

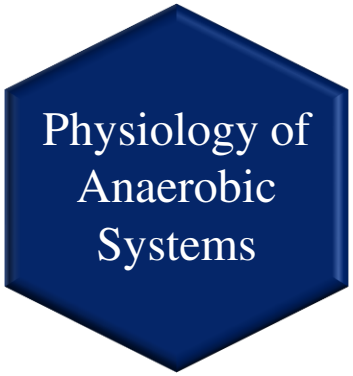
→ **Anaerobic Pathways** (why?)

↓ Simplest reason









Understand how they function to train effectively

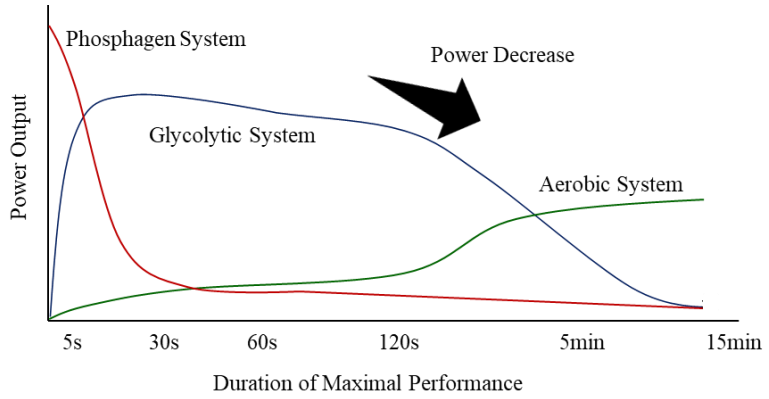

The
Phosphagen
System

Overview of Anaerobic Systems …

The First Energy System: Phosphagen System

2 Components:

- Adenosine Triphosphate (ATP) – located at myosin heads.
  - Approximately 3 oz. in adult body.
  - Fuels ~1-to-2 sec of maximal muscular performance*.
- Creatine-Phosphate (CrP) or phospho-creatine (PCr) – in sarcoplasm.
  - Approximately 4-to-6x the amount of ATP.
  - Fuels ~5-to-8 sec of maximal muscular performance*.
- Total combined = ~6-to-10 seconds of maximal performance*.



	Performance*	Effort*
Measurement	Objective	Subjective
Example	Time, load, watts	RPE
Calories	High	Variable
Outcome	Bigger, stronger, faster	??
EPOC	Larger	Small

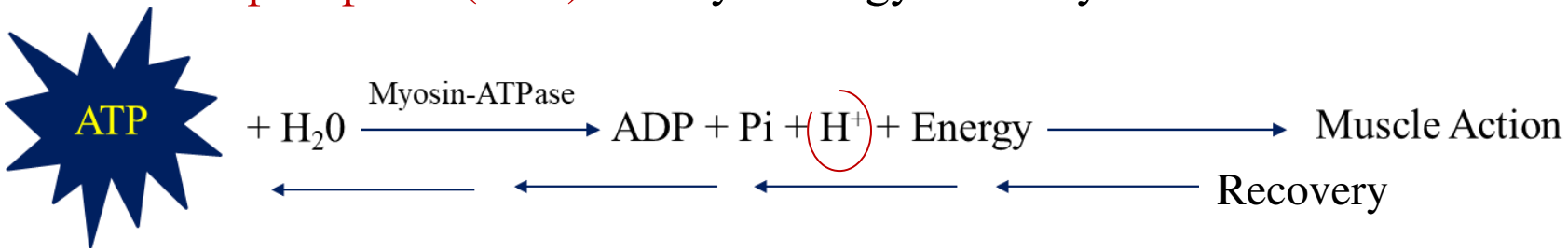
References:

1. Kenney WH, Wilmore JH, and Costill DL, (2021). *Physiology of Sport and Exercise (8th edition).* Champaign, IL. Human Kinetics.
2. Haff GG, and Triplett NT, (2016). *Essentials of Strength Training and Conditioning (4th edition).* Champaign, IL., Human Kinetics.

Overview of Energy Pathways …

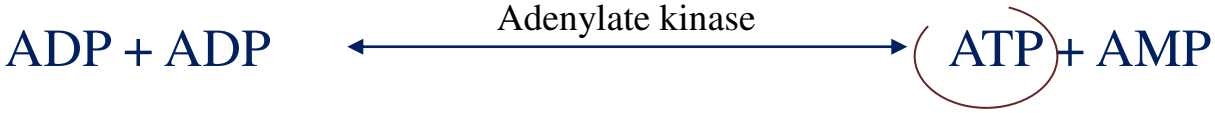
The First Energy System: Phosphagen System – What is ATP?

Adenosine Triphosphate (ATP) = body's energy currency.



Second Quick ATP Pathway (myokinase reaction)

- Increased ADP triggers 2°pathway:

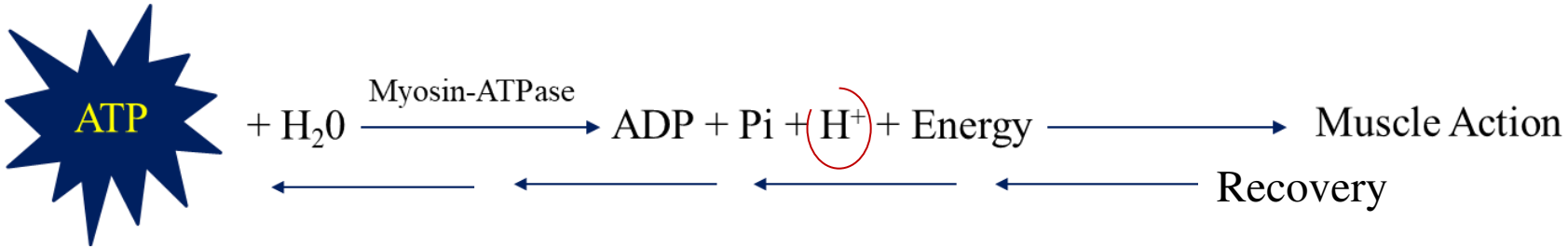


- 2° ATP pathway = beneficial initially – produces additional ATP + stimulates glycolytic enzymes.
  - Phosphorylase (glycogenolysis) and phosphofructokinase (glycolysis).
  - AMP accumulation becomes detrimental (inhibits ATP production) – AMP cannot accumulate – balance between production and breakdown.

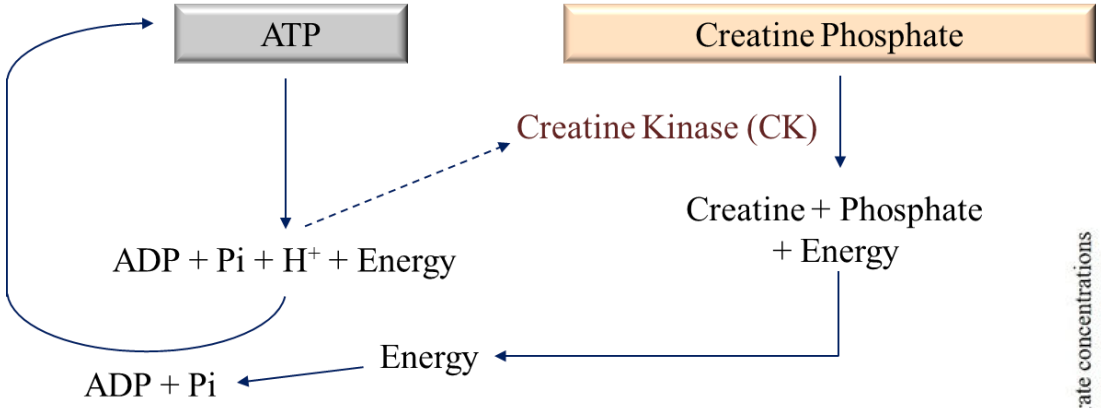
Reference: Kenney WH, Wilmore JH, and Costill DL, (2021). *Physiology of Sport and Exercise (8th edition).* Champaign, IL. Human Kinetics.

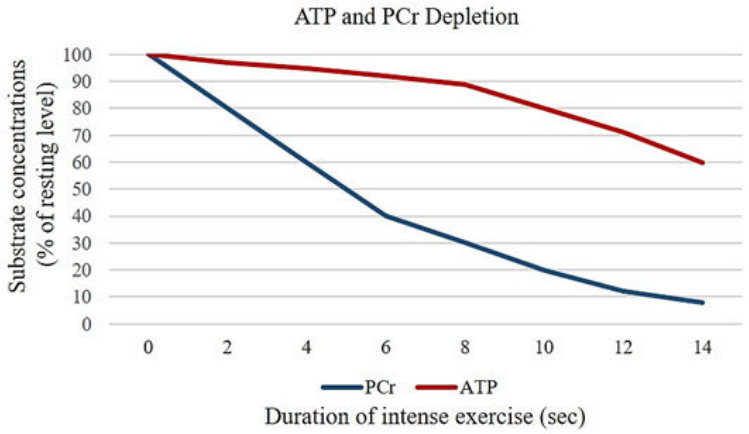
Overview of Anaerobic Systems …

The First Energy System: Phosphagen System



- Energy Release:
  - Increases ADP, P_i , and H^+ ion concentrations – move to sarcoplasm.





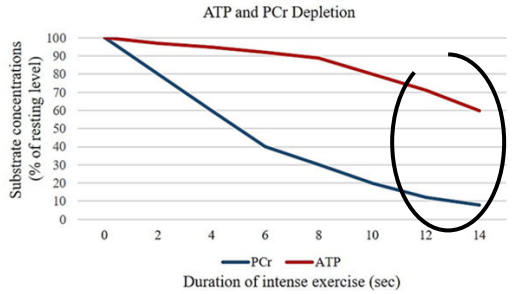
Reference: McArdle WD, Katch FI, and Katch VL, (2015). *Essentials of Exercise Physiology (5th edition).* Philadelphia, PA. Wolters Kluwer

Overview of Anaerobic Systems …

The First Energy System: Phosphagen System

Fatigue Theories:

- P_i accumulation – PCr depletion reduces ATP re-phosphorylation rates.



- H^+ accumulation.
  - Ordinarily pass to oxidative pathway.
  - Excesses accumulate – lead to acidosis.
    - Lowered pH = decreases Myosin-ATP-ase activity (slows ATP splitting).
  - Cells possess capacity for intracellular H^+ buffering – carnosine manufactured from beta-alanine + histidine.
    - Carnosine buffering = only 7% of total muscle buffering (minimal effect).
    - Most H^+ passes to adjacent cells or to blood.

Reference:

1. Kendrick I, Harris R, Kim JJ, et al., (2008). The effects of 10-weeks of resistance training combined with beta-alanine supplementation on whole body strength, force production, muscular endurance and body composition. *Amino Acids*, 34:546–554.
2. Kenney WH, Wilmore JH, and Costill DL, (2021). Physiology of Sport and Exercise (8th edition). Champaign, IL. Human Kinetics.

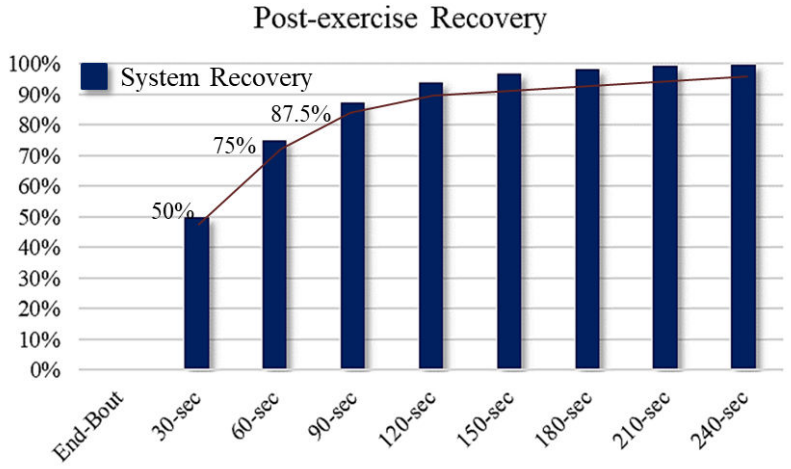
Overview of Anaerobic Systems …

The First Energy System: Phosphagen System

Recovery:

- Time to replenish 2 constituents completely (i.e., ATP, PCr) = 'doubling time'
- System re-synthesis is biphasic (not at same rates).
  - Fast recovery component (PCr) takes ~20-sec.
  - Slow recovery component (ATP) takes up to ~60-sec.

Because most of ATP-PCr system lies within PCr, average doubling time is closer to 30-sec.



Example: 10-sec of depletion:

@ 30-sec recovery = 50% replenished.

@ 60-sec recovery = 75% replenished.

@ 90-sec recovery = 87.5% replenished.

Reference: Pocari J, Bryant, CX, and Comana, F (2015). *Exercise Physiology*. Philadelphia, PA. The FA Davis Company.

Overview of Anaerobic Systems …

The Phosphagen System In Training

Primarily within type-2 muscle fibers:

% of Maximal Performance	Energy System	Bout Duration	Work-to-Recovery Ratio	Type of Recovery	Recovery Time between Sessions
90-to-100%	Phosphagen	< 10-sec	1:12-to-1:20	Passive / Active	48-hours minimum

- *Example:* Training an athlete with 5-sec 40-yard sprints:
  - 1-to-12 work-to-recovery (WTR) ratio = 60-sec recovery.
  - 1-to-20 work-to-recovery (WTR) ratio = 100-sec recovery.

Recovery Occurs Primarily within the Muscle !!!

Recoveries (target type-1 fibers to expedite type-2 fiber):

- Passive = motionless to expedite ATP-PCr re-synthesis.
- Active = light movement of trained muscles to expedite H^+ removal from cell.

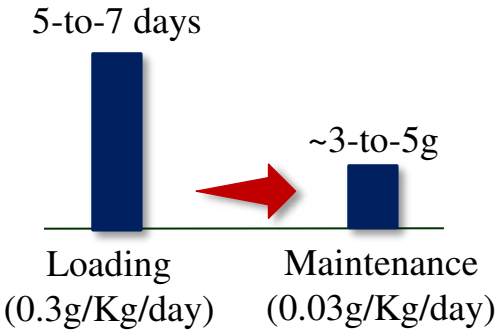
Reference: Haff GG, and Triplett NT, (2016). *Essentials of Strength Training and Conditioning (4th edition).* Champaign, IL., Human Kinetics.

Overview of Anaerobic Systems …

The Phosphagen System In Training

Can this system expand?

- Genetic predisposition – most significant effect upon:
  - Type-2 muscle fiber concentration.
  - Creatine saturation levels in muscle cells.
- Creatine supplementation:
  - Respondents v. non-respondents:
  - 20% total Cr increase – 10% increase in PCr.



Cell volumizing effect

Increased muscle CrP levels

Well-established safety reviews – short-/long-term supplementation (up to 30g/day over 5-years).

- Muscle hypertrophy:
  - Increases total PCr in body, but little change within individual muscle cell.
- Training effect:
  - Training can increase H^+ ion buffering capacity and muscle mass – little-to-no effect on PCr concentration in muscles.

References:

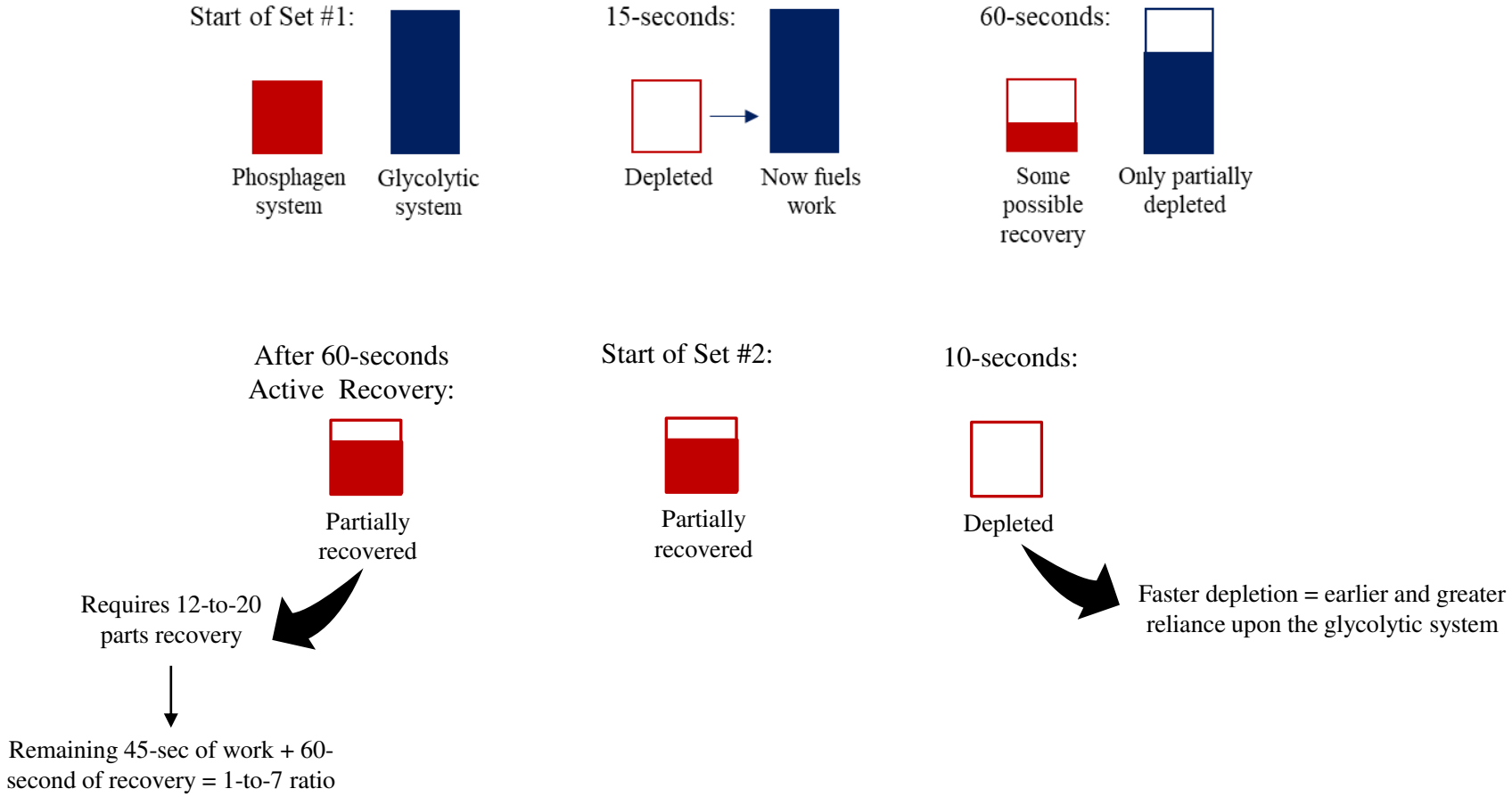
1. Sahlin K, (2014). Muscle energetics during explosive activities and potential effects of nutrition and training. *Sports Medicine,* 44(Suppl 2):S167-73.
2. de Souza E Silva A, Pertille A, Gabriela Reis Barbosa, C, et al., (2019). Effects of creatine supplementation on renal function: A systematic review and meta-analysis. *Journal of Renal Nutrition, 29(6):480-489.*

Overview of Anaerobic Systems …

The Phosphagen System In Training

What Does this Mean?

- *Example*: A 60-sec work interval + 60-sec recovery bout.



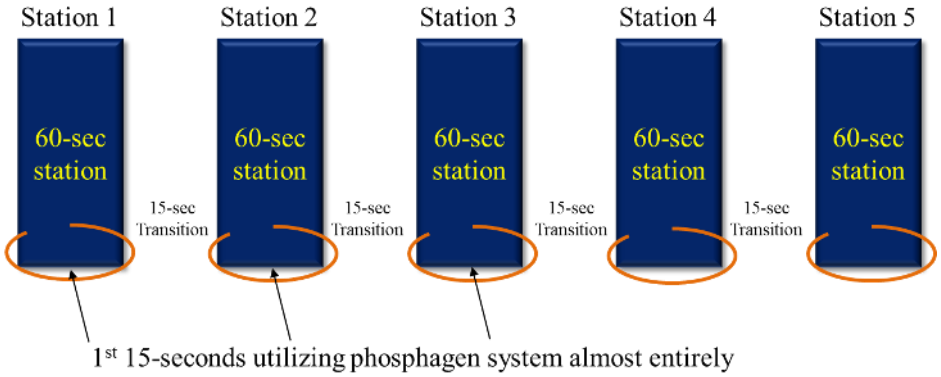
Takeaway: Subsequent sets = greater reliance upon 2nd energy system.

Overview of Anaerobic Systems …

The Phosphagen System In Training

What Does this Mean?

- *Example*: Multi-station circuit – 60-sec work intervals + minimal recovery bouts (e.g., 15-sec transitions) – pushing near maximal performance – 'burn kcal!!!'



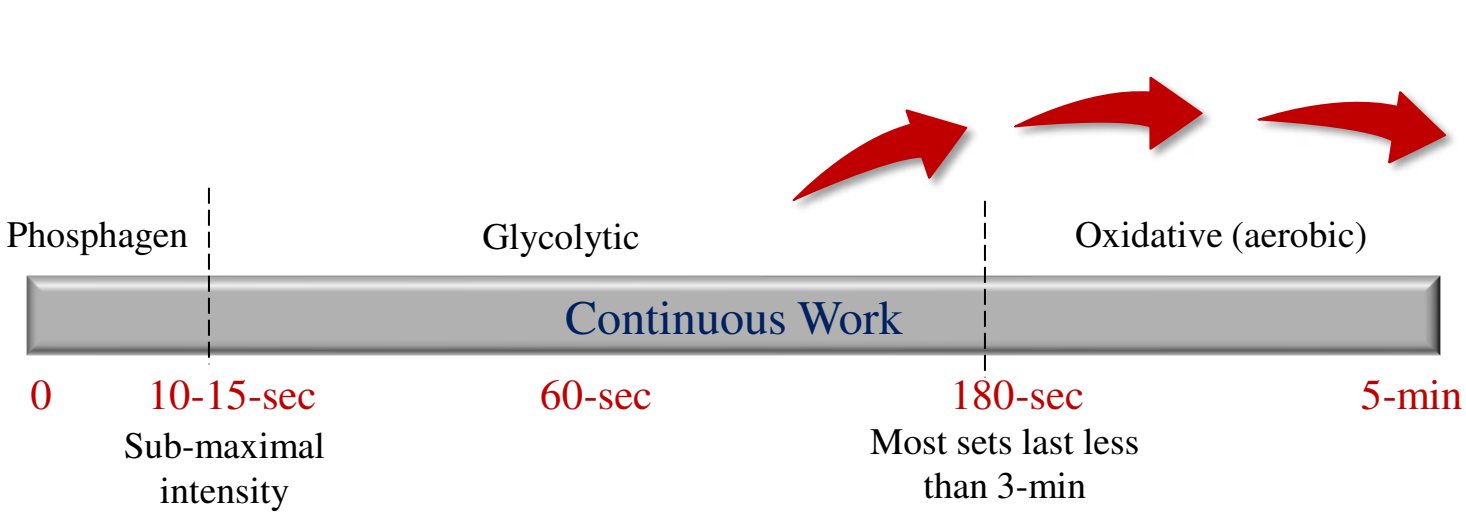
Takeaways for this Example:

- Different muscle groups – phosphagen system fuels 1st 15-sec at each station.
  - Remainder of each station (set) fueled by glycolytic system.
- Recovery:
  - Phosphagen system – recovery within specific muscle (mitochondrial ATP).
  - 15-sec of work + 360-sec recovery = 1-to-24 work-to-recovery ratio.
  - Work performance on subsequent circuit for 1st 15-sec is good !!

Overview of Anaerobic Systems …

Examine the Work Interval

Work intervals > 10-to-15 sec.



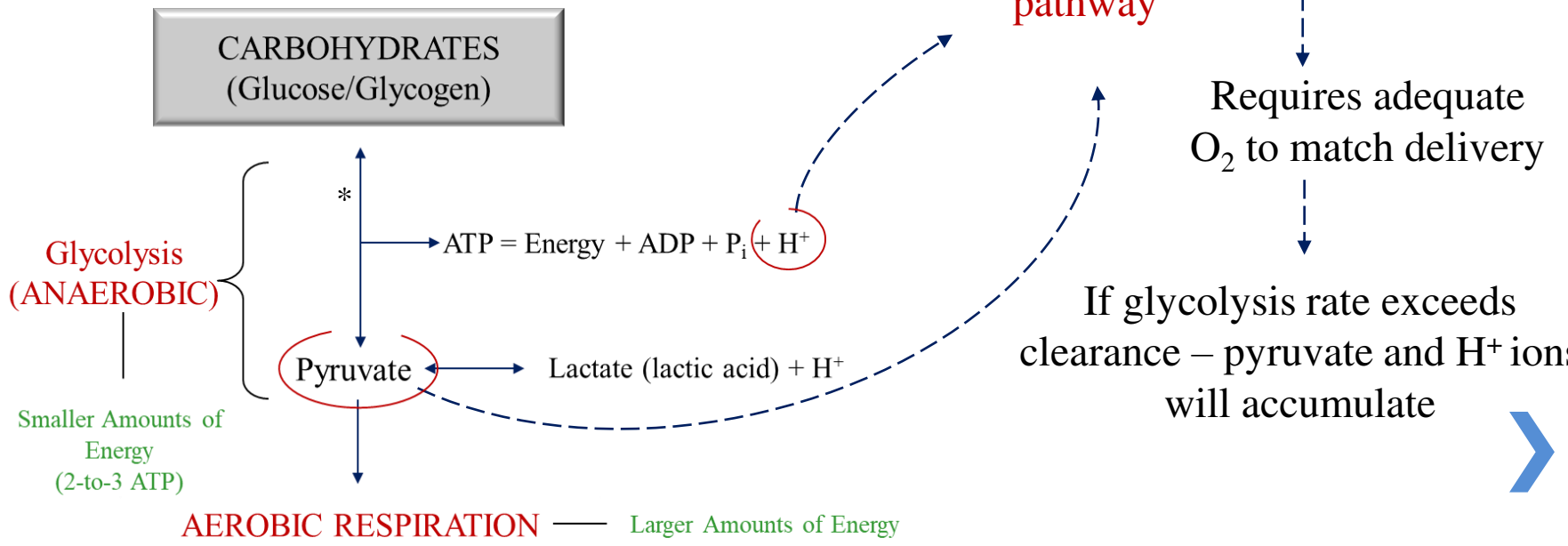
The Glycolytic System

Overview of Anaerobic Systems …

The Second Energy System: Glycolytic System

Key traits:

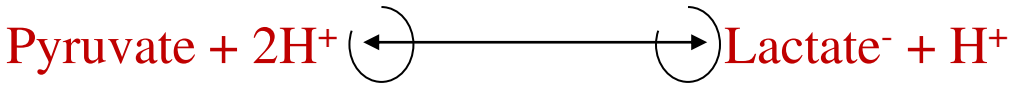
- Dominates as phosphagen system depletes and anerobic work continues (i.e., ATP demand > current aerobic capacity).
- Limited – relies upon capacity to:
  - Glycogenolysis and glycolysis rates
  - Tolerate H^+ ion accumulation.



* Not a reversible reaction in muscle tissue

Overview of Anaerobic Systems …

Removing Lactate and Hydrogen Ions



Reversible reaction

- Lactate can convert to pyruvate – fuel or waste?

Concerns with H^+ Accumulation

- H^+ lowers tissue/blood pH (more acidic) – consequences:
  - Decreases glycolytic enzyme activity.
  - Decreases Myosin-ATP-ase activity (slows ATP splitting).
  - Increases pain receptor sensitivity in muscles.
  - Decreases ability to release and re-absorb Ca^{2+} – needed for muscle contraction.
  - Interferes with Ca^{2+} ability to initiate contraction.

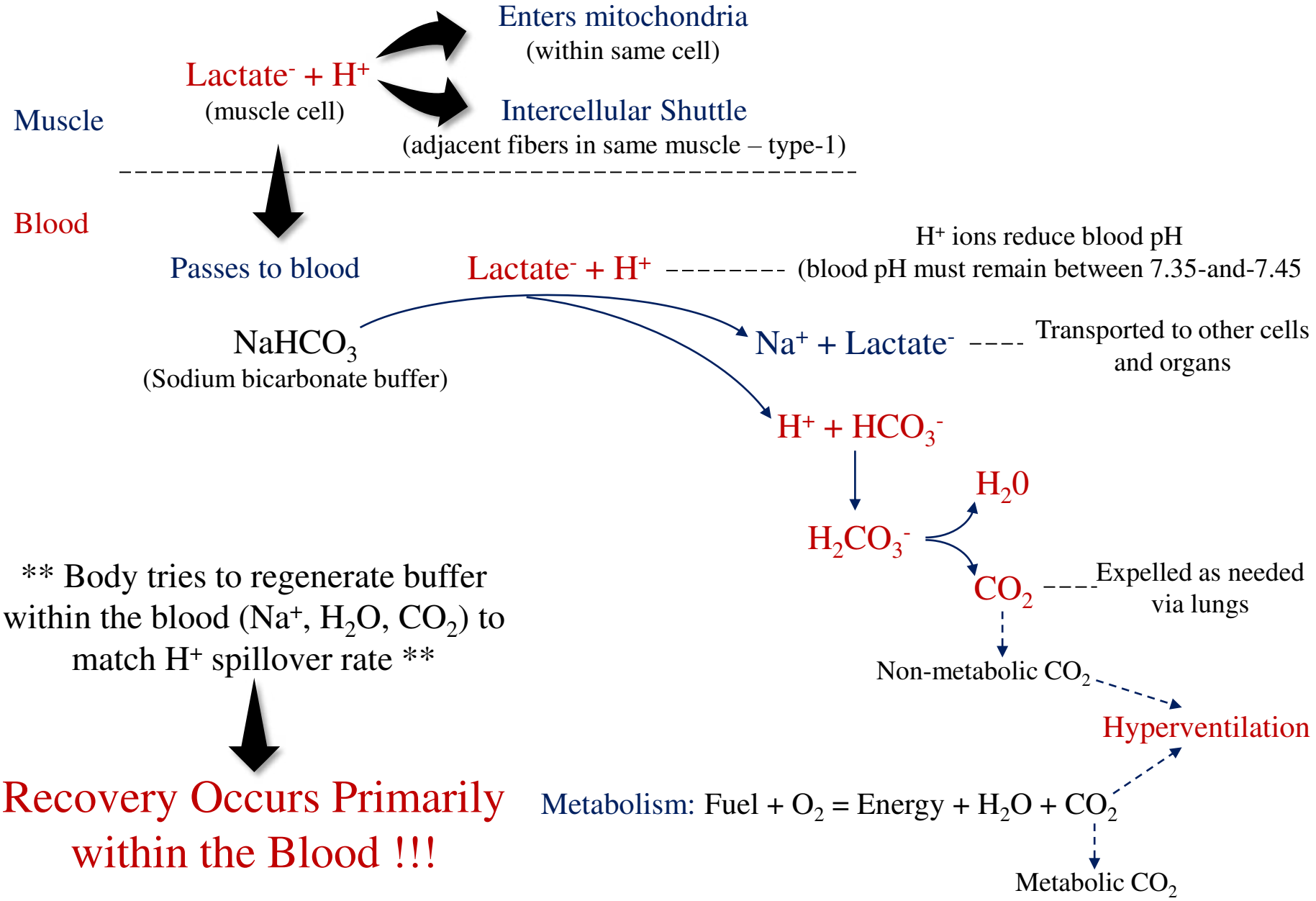
Body must buffer H^+ → Intracellular buffer (e.g., carnosine) and shuttle

→ Extracellular buffer (e.g., $NaHCO_3$) and shuttles

References:

1. Pocari J, Bryant, CX, and Comana, F (2015). *Exercise Physiology*. Philadelphia, PA. The FA Davis Company.
2. Kenney WH, Wilmore JH, and Costill DL, (2021). *Physiology of Sport and Exercise (8th edition).* Champaign, IL. Human Kinetics.
3. Haff GG, and Triplett NT, (2016). *Essentials of Strength Training and Conditioning (4th edition).* Champaign, IL., Human Kinetics.

Overview of Anaerobic Systems …



Overview of Anaerobic Systems …

Genesis Wellness Group

Glycolytic System: Key Gender Differences

Phosphagen system demonstrates small gender differences v. glycolytic system = larger differences.

Physiological Trait	Males	Females
Muscle Fibers	More anaerobic, type 2 muscle fibers	More aerobic, type 1 muscle fibers
Muscle Mass	Greater mass, greater force and rates of production = greater energy demand	Smaller = smaller energy demand per unit of time
Force Production and Recovery	Greater forces increase compression on blood vasculature and increases metabolite production = slower recovery	Better blood perfusion and capillarization for O_2 delivery, plus expedited metabolite clearance = faster recovery
Hormonal	Greater glycolytic reliance Faster glucose appearance rates in blood from liver; faster glucose disappearance rates into cells	Estrogen stimulates greater fat utilization oxidatively Estrogen may interfere with efficiency of some glycolytic enzymes
Nervous	Higher levels of SNS stimulation	Lower levels of SNS stimulation
Blood Volume	Larger volume = more lactate buffer, but more time needed to regenerate levels	Smaller amounts requires less time to replenish

Overview of Anaerobic Systems …

Genesis Wellness Group

Training the Glycolytic System

Gender: Males				
% of Maximal Performance	Bout Duration	Work-to-Recovery Ratio	Type of Recovery	Rest Between Sessions
Closer to 85-to-90%	< 45-to-60 sec	1:3-to-1:5	Active (type 1 fibers)	48-hours minimum
Closer to 75-to-80%	Up to 180 sec	1:2-to-1:4	Active (type 1 fibers)	48-hours minimum

Gender: Females				
% of Maximal Performance	Bout Duration	Work-to-Recovery Ratio	Type of Recovery	Rest Between Sessions
Closer to 85-to-90%	< 45-to-60 sec	1:2-to-1:4	Active (type 1 fibers)	48-hours minimum
Closer to 75-to-80%	Up to 120 sec	1:1½-to-1:3	Active (type 1 fibers)	48-hours minimum

Overview of Anaerobic Systems …

The Glycolytic System In Training

Can this system expand?

- Genetic predisposition – significant effect upon:
  - Gender and type-2 muscle fiber concentration.
  - Body size and corresponding blood volume (i.e., total amount of $NaHO_3$).
- Elevation??
  - 10-to-20% blood volume expansion – can hold more $NaHO_3$.
  - Altitude-associated hyperventilation reduces blood pCO_2 and $NaHO_3$.
- Supplementation:
  - Single-dose optimized at 0.3g/Kg (range = 0.2-to-0.5g/Kg) diluted in 1-liter (33.8 oz.) of water.
  - Ingest 60-to-180-min before exercise.
  - Positively impacts performance and time to fatigue between 30-sec-to-12-min.
  - Side-effects = bloating, nausea, vomiting and abdominal pain.

References:

1. Pocari J, Bryant, CX, and Comana, F (2015). Exercise Physiology. Philadelphia, PA. The FA Davis Company.
2. Grgic J, Pedisic Z, Saunders B, et al., (2021). International Society of Sports Nutrition position stand: sodium bicarbonate and exercise performance. Journal of the International Society of Sports Nutrition, 18(1):61. https://doi.org/10.1186/s12970-021-00458-

Overview of Anaerobic Systems …

The Glycolytic System In Training

Can this system expand?

- Training Effect:
  - Aerobic Training – optimal expansion of:
    - Blood volume (~20%) – allows blood to hold more $NaHCO_3$ with elevating blood pH.
    - Mitochondrial density and efficiency – allow for more aerobic work at higher intensities.
  - Anaerobic Training – expansion or improvements in:
    - Intracellular buffering.
    - Lactate clearance.
    - Hydrogen ion tolerance.
    - Lactate regeneration rates in blood.

References:

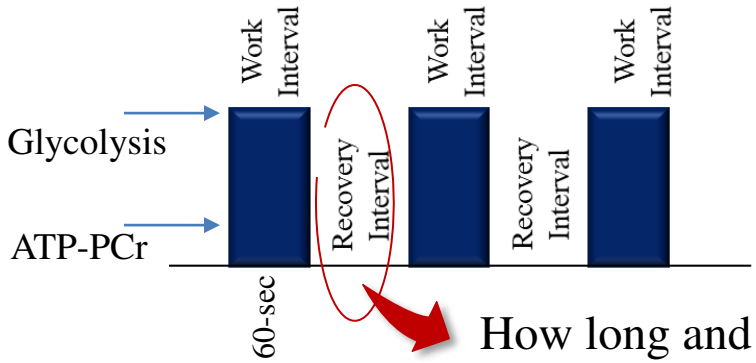
1. Pocari J, Bryant, CX, and Comana, F (2015). Exercise Physiology. Philadelphia, PA. The FA Davis Company.
2. Grgic J, Pedisic Z, Saunders B, et al., (2021). International Society of Sports Nutrition position stand: sodium bicarbonate and exercise performance. Journal of the International Society of Sports Nutrition, 18(1):61. https://doi.org/10.1186/s12970-021-00458
3. Haff GG, and Triplett NT, (2016). *Essentials of Strength Training and Conditioning (4th edition).* Champaign, IL., Human Kinetics.

Overview of Anaerobic Systems …

The Glycolytic System In Training

What Does this Mean?

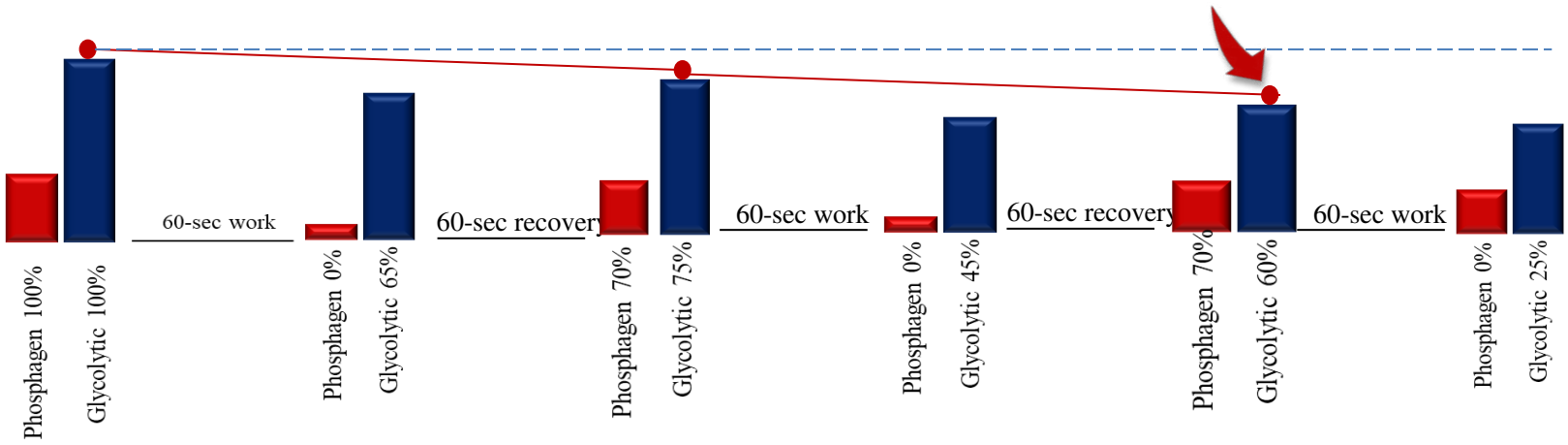
- *Example*: A multi-set format on one muscle group with short recovery bout.



How long and what kind of recovery? → Timing is critical.

Format = active.

- Advantages = improved hydrogen clearance.



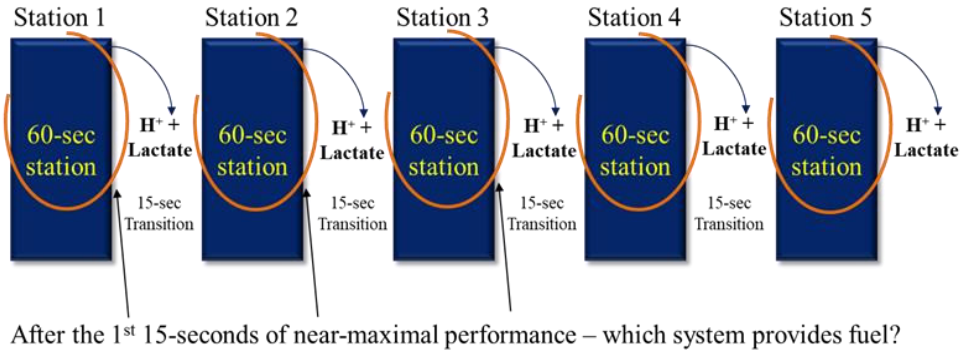
Takeaway: Is this performance or effort – we seek metabolic stress, but at what cost?

Overview of Anaerobic Systems …

The Glycolytic System In Training

What Does this Mean?

- *Example*: Multi-station circuit – 60-sec work intervals + minimal recovery bouts (e.g., 15-sec transitions) – pushing near maximal performance – 'burn kcal!!!'



Typical circuit format works for Phosphagen System, but …..

- Glycolytic:
  - Alternating muscle groups generates same issue – where does H^+ + lactate go?
  - Blood spillover rate v. lactate buffer regeneration.
  - 45-sec of work + 30-sec recovery before more blood lactate + H^+ spillover = 3-to-2 work-to-recovery ratio.

This is where 'intensity' now shifts to 'effort' – what is the purpose?

Fad, science-based, or irrelevant?

Interval-Training Options …

What is HIIT?

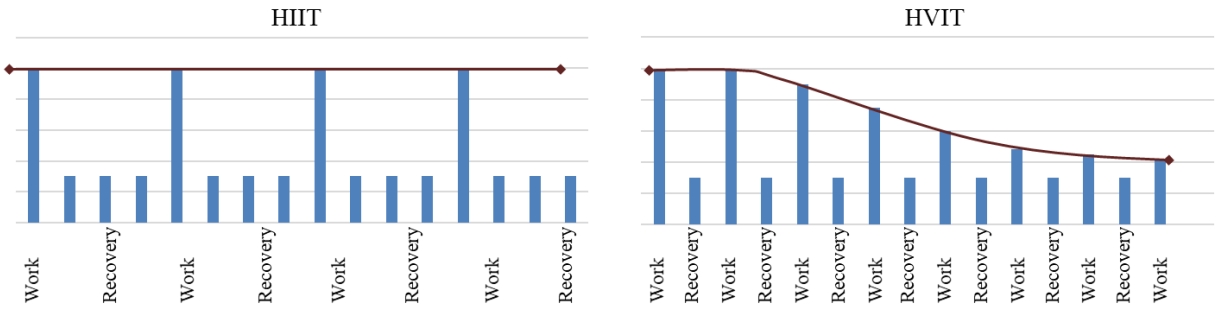
Traits:

- No universal consensus exists on defining the intensity of HIIT.
  - Repeated sessions of brief, intermittent work @ intensities that elicit ≥85% (VO_2peak) or >90% of true MHR, interspersed by recovery bouts.
  - Training intensities @ near-maximal levels nearing 100% MHR or 'sprint interval training' (SIT) that involves supramaximal efforts (workloads > VO_2max/VO_2peak).
- No universal definition defines HIIT training volume.
  - Consensus = total volume of HIIT work in a session ≤ 10-minutes, excluding recovery, warm-ups or cool-downs.
- Relies predominantly upon the anaerobic systems given the interval-nature of the work.

Interval-Training Options …

HIIT v. Fitness Industry Version of HIIT

HIIT (true HIIT)	HVIT (pseudo-HIIT)
Defined by maximal or near maximal performance (movement quality)	Defined by some measure of effort (movement quantity)
Objectively measured (intensity)	Subjectively measured (effort)
Example: best 40-yard sprint time (e.g., 5-seconds)	*Example:* Pushing as hard possible under fatigue, but 40-yard dash = 7-seconds
Work interval shorter than recovery interval	**Work interval longer or equal to the recovery interval**
Goal = improve performance (bigger, stronger, faster)	Goal = questionable? Some additional calories, but at what cost? (as intensity drops, so does kcal burn rate)



Interval-Training Options …

HIIT v. Fitness Industry Version of HIIT

	Workout A (HIIT)	Workout B (HVIT)
Maximal 60-sec Performance (N=8)	Mean: 320 watts	Mean: 320 watts
Work Interval	5 Intervals (1-to-3 ratio) ▪ 60-sec @ 288 watts (90%)	10 Intervals (1-to-1 ratio) ▪ Interval 1-and-2 @ 288 watts (90%) ▪ Interval 3-and-4 @ 233 watts (73%) ▪ Interval 5-and-6 @ 192 watts (60%) ▪ Interval 7-and-8 @ 160 watts (50%) ▪ Interval 9-and-10 @ 135 watts (42%)
Recovery	180-sec recovery @ 75 watts	60-sec recovery @ 75 watts
Total Duration	20-min	20-min
Calories – work	18.7 kcal/min	Range of 10.3-to-18.7 kcal/min
Calories – recovery	7.0 kcal/min	7.0 kcal/min
Total Kcal	198.5 kcal	211.6 kcal
EPOC	Not measured	Not measured
Experience	7.8 (subjective)	5.8 (subjective)
Injury Risk	?	?

Think to:

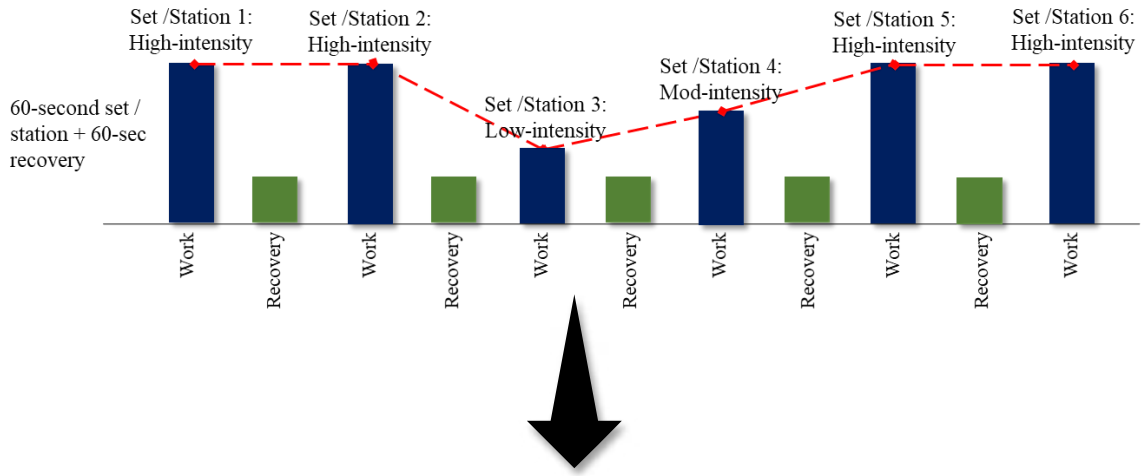
- Experiences, attrition, risk of injury and even EPOC (derived from intensity, NOT effort)!

Interval-Training Options …

Interval Training Solutions

Option One: VIIT – Variable-intensity Interval Training.

- Mixed pursuit of:
  - High-intensity intervals = more calories + EPOC.
  - Overall improved technique = reduced injury potential.
  - Positive experiences.

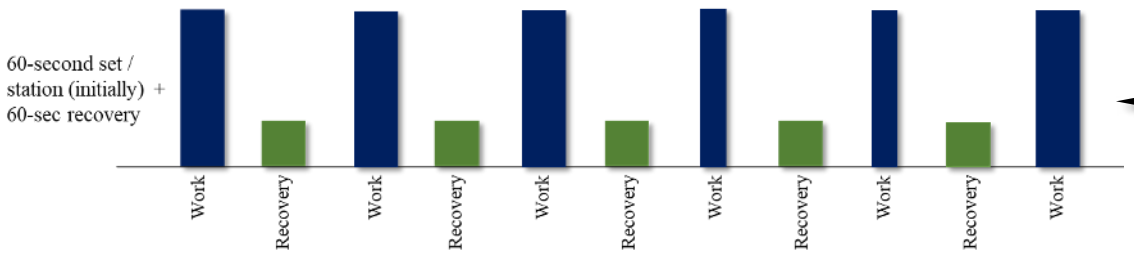


Decision to undulate intensity is fluid and adaptable – based upon the end-performance of the previous set.

Interval-Training Options …

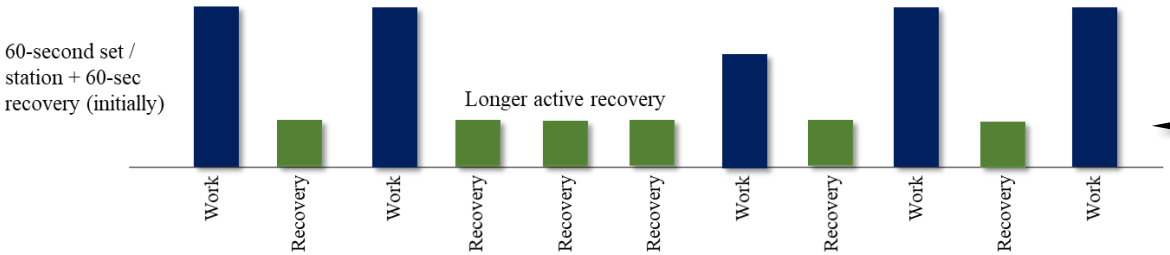
Interval Training Solutions

Option Two: VIT – Variable Interval Training.



Decision to undulate interval time is fluid and adaptable – based upon the end-performance of the previous set.

Option Three: VRT – Variable Recovery Intervals.

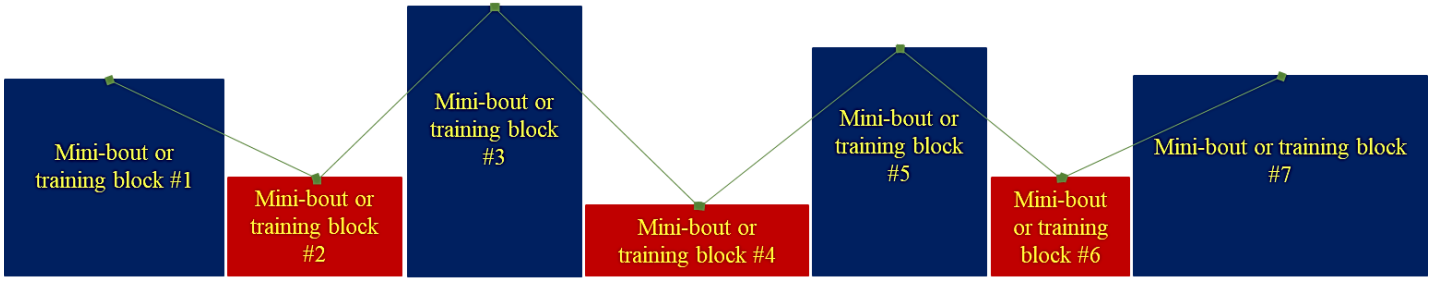


Decision to undulate recovery time is fluid and adaptable – based upon the end-performance of the previous set.

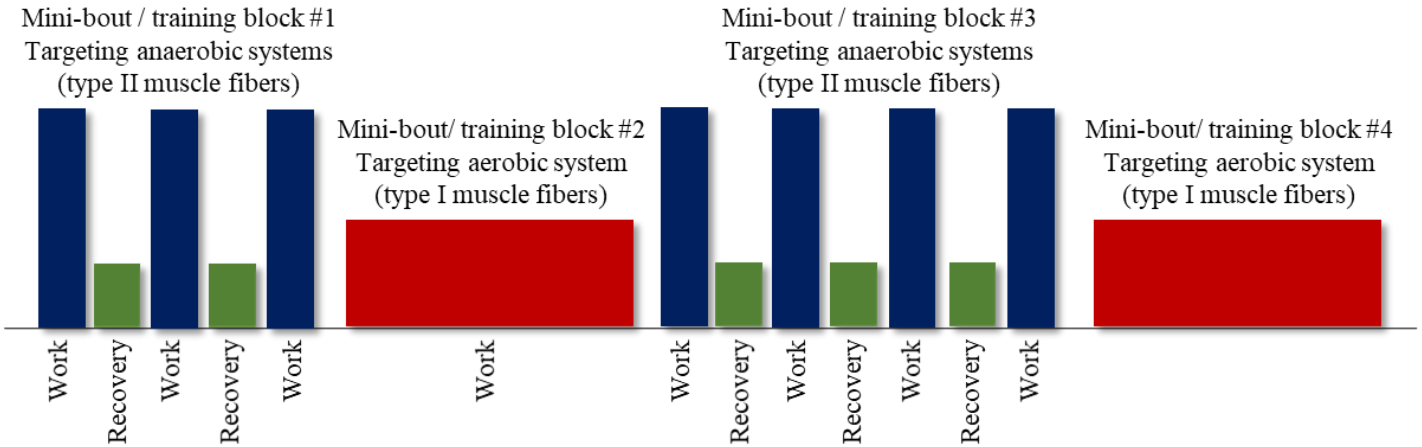
Interval-Training Options …

Interval Training Solutions

Option Four: VMT – Variable Modality Training.



Decision to shift to a Type I (more aerobic block) is based upon the end-performance of the last set of the current (anaerobic) training block.



Thank You..!!

For Your Commitment to Excellence

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