ENERGY SYSTEMS TO POWER THE ATHLETE

GATORADE SPORTS SCIENCE INSTITUTE

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OVERVIEW

- Muscle contraction energetics
- Rest to Exercise transition
- Metabolic responses during recovery
- Influence of intensity and duration
- Estimation of fuel utilization

ENERGY FOR MUSCLE CONTRACTION

Adenosine Triphosphate (ATP)
Molecule which provides energy
for muscle fibers to contract.

The amount stored in the muscle
is limited.

Hargreaves, M & Spriet, L. *Nat Metab*. 2020; https://doi.org/10.1038/s42255-020-0251-4.

ENERGY FOR MUSCLE CONTRACTION

Fuel Sources to Generate **ATP** for Muscle Contraction

PCr (phosphocreatine)	**Anaerobic Glycolysis**	**Aerobic Metabolism**
High intensity ~5 s or less	High intensity ~30 s – 3 min	Lower intensity Long duration
Regenerated during recovery	Glucose	Glucose Fatty Acids

Notes:

- ✓ Creatine is made in the body and consumed from meat. The PCr system is also the mechanism through which creatine supplements provide energy for high intensity muscle contraction.
- ✓ Glucose is supplied mainly from the breakdown of **GLYCOGEN**, the storage form of glucose in the muscle and liver.
- ✓ Amino acids can enter the aerobic glycolysis system, but their contribution to ATP generation is very small.

Hargreaves, M & Spriet, L. *Nat Metab*. 2020; https://doi.org/10.1038/s42255-020-0251-4.

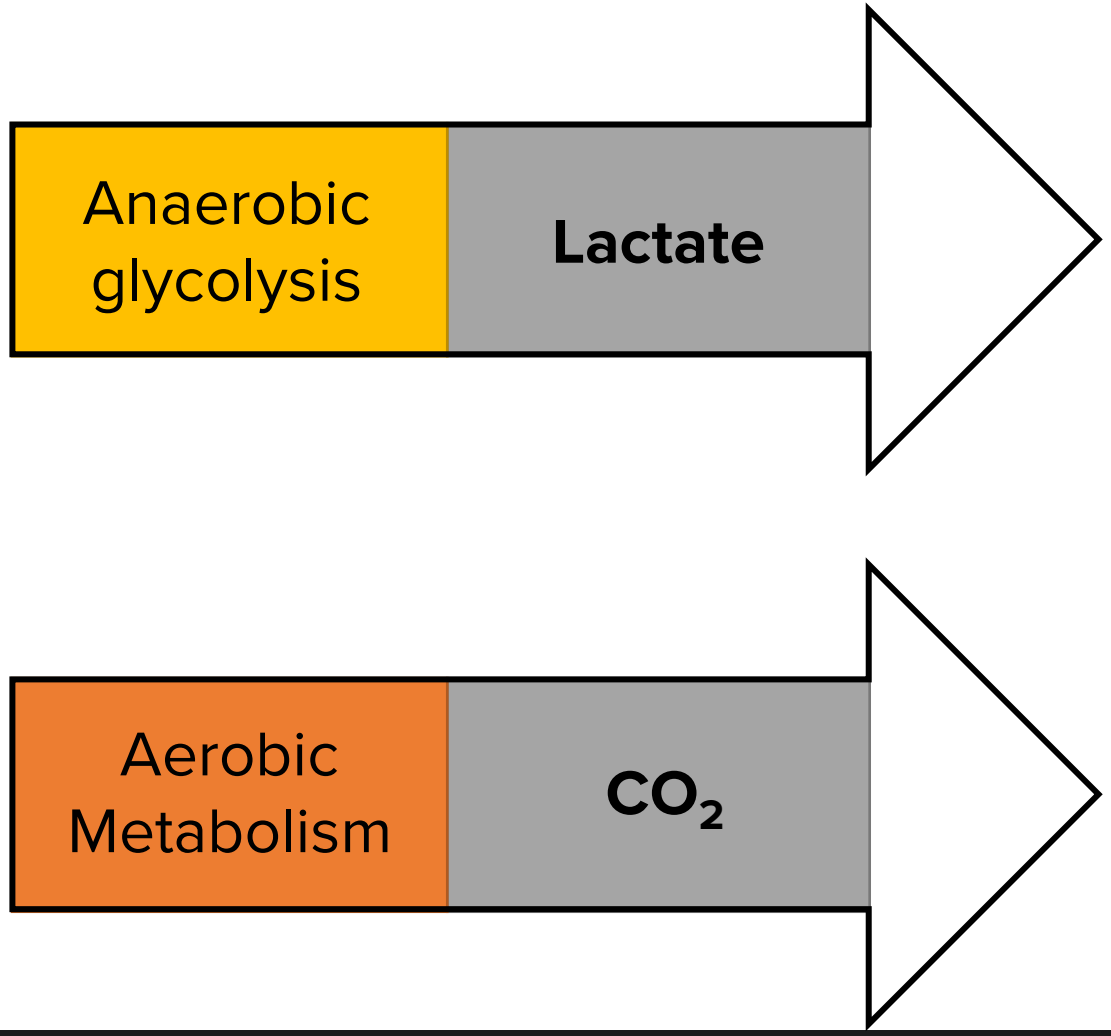
HUMAN ENGINE

- FAT = ENDURANCE FUEL
- CARB = HIGH INTENSITY FUEL
- PCr = FAST ACCELERATIONS

CAR ENGINE

- ONE KIND OF FUEL

BYPRODUCTS OF METABOLISM



Previously thought to cause fatigue and muscle soreness.

No longer believed to be the case, may provide an additional fuel source.

As oxygen is used in the process to convert fuels to ATP, carbon dioxide is produced.

Respiration increases to remove the excess CO2 from the body.

Hargreaves, M & Spriet, L. *Nat Metab*. 2020; https://doi.org/10.1038/s42255-020-0251-4.

TRANSITIONS

REST TO EXERCISE TRANSITION

Imagine a football player is standing on the sideline. On coach's whistle, he is to begin sprinting.

What is happening in the body to ensure the muscle has the fuel to go from rest to quick contractions?

REST TO EXERCISE TRANSITION

Within the first step muscles must increase their rate of ATP production

Anaerobic energy sources (PCr + anaerobic glycolysis) are used first, giving time for the aerobic system to contribute

Take Home Message: several energy systems are involved in rest-to-work transitions.

Measurement of O_2 consumption can be used as an index of aerobic ATP production

Provides information about aerobic metabolism during exercise

VO_2 max = maximal oxygen consumption, often used as an indicator of fitness

Oxygen deficit = lag in O_2 update at the beginning of exercise, indicating the reliance on anaerobic systems

Hargreaves, M & Spriet, L. *Nat Metab*. 2020; https://doi.org/10.1038/s42255-020-0251-4.

RECOVERY FROM EXERCISE

Recovery from Exercise: Metabolic Responses

Metabolism (indicated by oxygen uptake) remains elevated for several minutes after exercise.

The magnitude of elevation depends on the intensity of exercise.

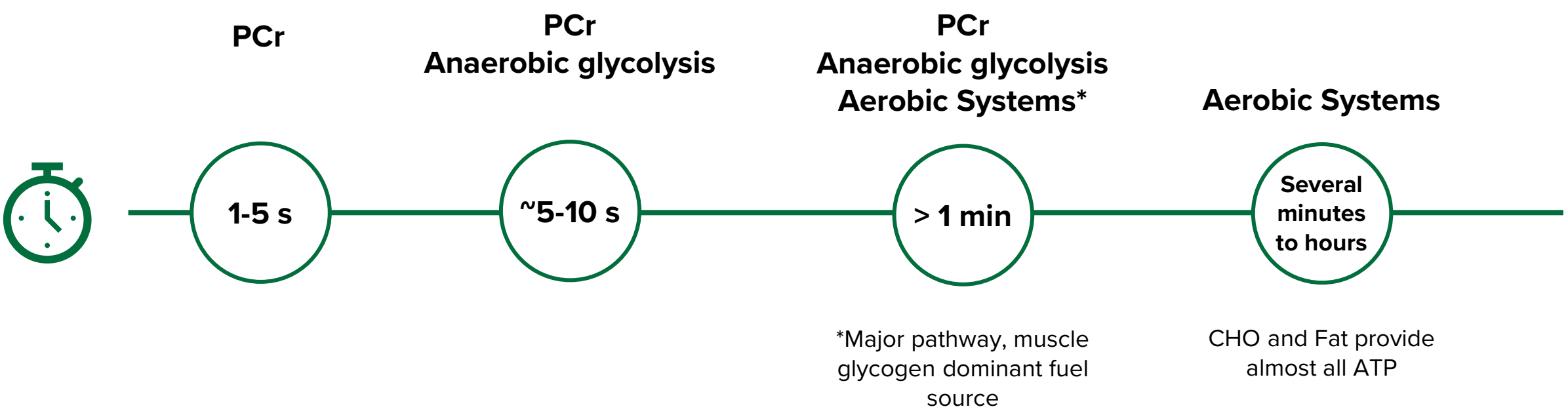
EPOC = **E**xcess **P**ost-**E**xercise **O**xygen **C**onsumption

Why does EPOC occur?

- Resynthesize PC
- Replace O_2 in muscle & blood
- Elevated body temperature
- Convert lactic acid to glucose
- Elevated epinephrine & norepinephrine

INFLUENCE OF INTENSITY AND DURATION ON ENERGY PATHWAY SELECTION

INFLUENCE OF DURATION ON SOURCE OF ATP



Most sports use a combination of anaerobic and aerobic pathways to produce ATP

Sport Nutrition 3rd Ed. Jeukendrup & Gleeson, Human Kinetics.
Hargreaves, M & Spriet, L. *Nat Metab*. 2020; https://doi.org/10.1038/s42255-020-0251-4.

INFLUENCE OF DURATION

Contribution of Aerobic/Anaerobic Production of ATP During MAXIMAL Exercise as a Function of the Duration of the Event

Duration of **MAXIMAL** Exercise

	Seconds			Minutes					
	10	30	60	2	4	10	30	60	120
Percent Aerobic	10	20	30	40	65	85	95	98	99
Percent Anaerobic	90	80	70	60	35	15	5	2	1

Recreated from:

Powers & Howley. *McGraw-Hill Education*. 2017

INFLUENCE OF DURATION & INTENSITY

Short-Term Intense Exercise

- Energy comes primarily from anaerobic pathways
- Length of the activity determines if PCr or glycolysis is the predominant energy source
- Transition from PCr to glycolysis is a gradual shift

Example

50 m dash or single play in a football game: PCr

400 m dash (~55 s): PCr, glycolysis, and aerobic, with anaerobic glycolysis predominating

INFLUENCE OF DURATION & INTENSITY

Prolonged Exercise

- Energy comes primarily from aerobic metabolism
- Steady-state oxygen update can be maintained during prolonged low-intensity exercise
- However, a hot/humid environment or higher intensity increases oxygen consumption over time

Reminder
Oxygen consumption is an indicator of aerobic metabolism

ASSESSING METABOLISM DURING EXERCISE

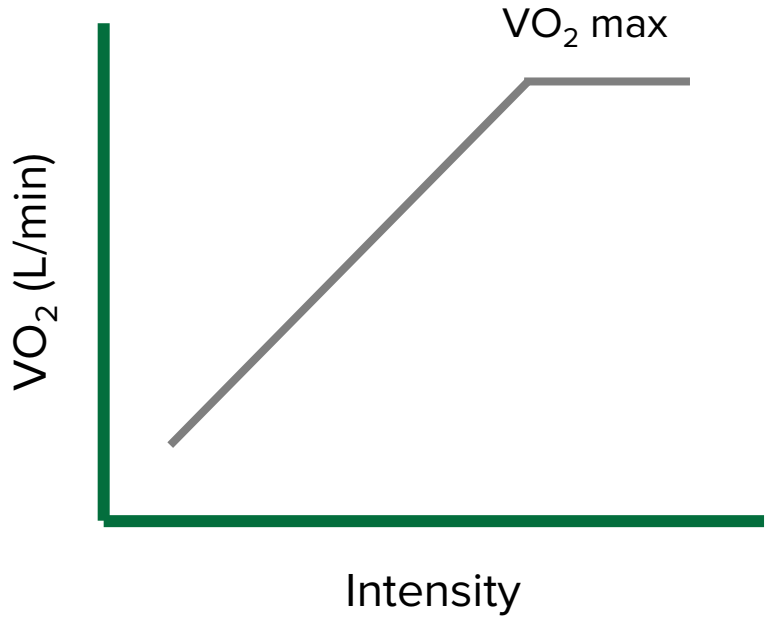
INCREMENTAL EXERCISE: VO_2 MAX

Incremental exercise = gradually increasing exercise intensity over time

As intensity increases, oxygen uptake increases in a linear fashion until VO_2 max is reached

VO_2 max is the "physiological ceiling" for the ability to deliver O_2 to contracting muscles

Training can result in an increased VO_2 max, and sometimes training intensity is set at a %VO_2 max



VO_2 MAX

VO_2 max is influenced by:

1. The maximal ability of the cardiorespiratory system to deliver oxygen to the muscle
2. The muscles ability to take up the oxygen and produce ATP aerobically
3. Genetics

"Excellent" VO_2 max values for ages 18-25 yo:

> 56 mL/kg/min

> 60 mL/kg/min

VO_2 max values of some of the best US male and female endurance athletes

Joan Benoit
Distance Runner
1984 Olympic Marathon Champion
78.6 mL/kg/min

Lance Armstrong
Cyclist
84.0 mL/kg/min

https://www.topendsports.com/testing/records/vo2max.htm

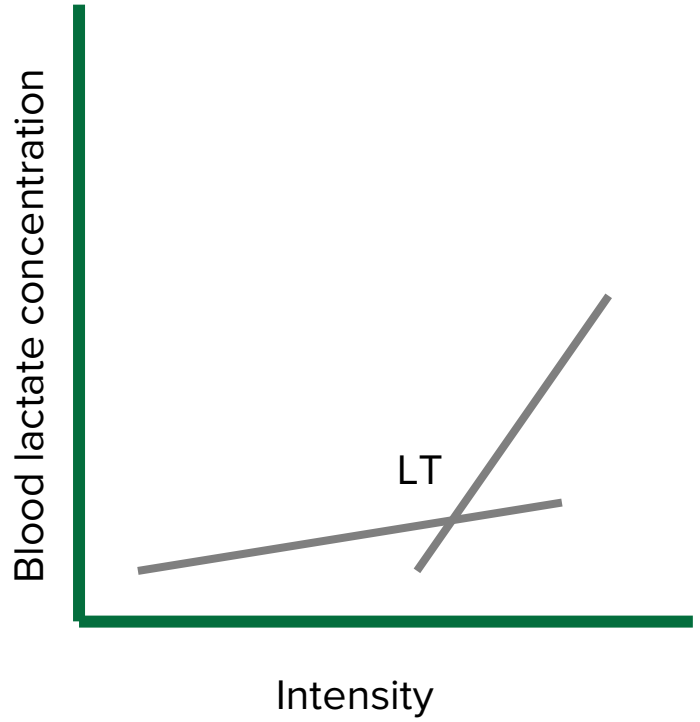
LACTATE THRESHOLD

Most of the ATP production in the early part of an incremental exercise test (lower intensities) comes from aerobic sources.

As intensity increases, blood levels of lactic acid begin to rise.

While there is debate, it is thought that the rise in lactic acid indicates an increasing reliance on anaerobic metabolism.

Lactate threshold (LT) = exercise intensity where there is an increase in lactic acid in the blood.

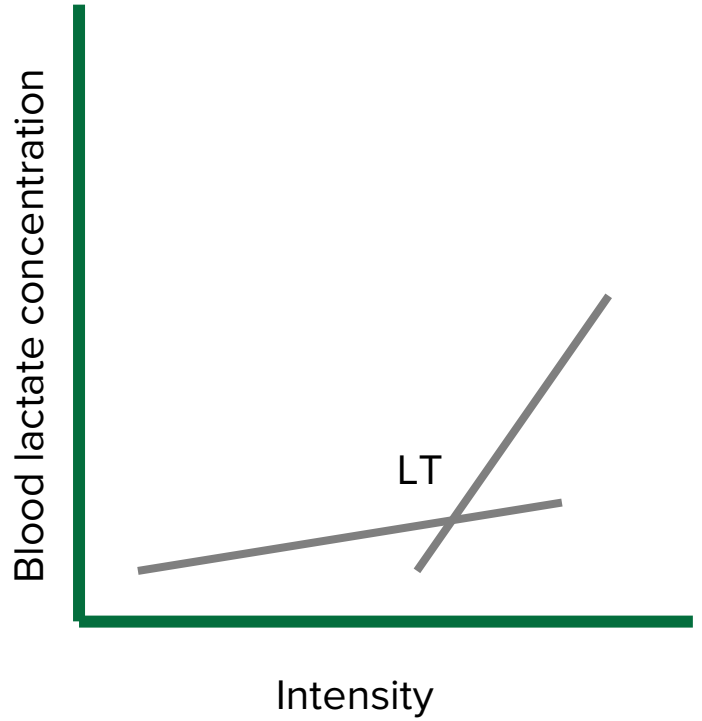


LACTATE THRESHOLD

While the exact cause of the LT is unclear, it may occur due to:

1. Low muscle oxygen
2. Accelerated glycolysis
3. Reduced rate of lactate removal

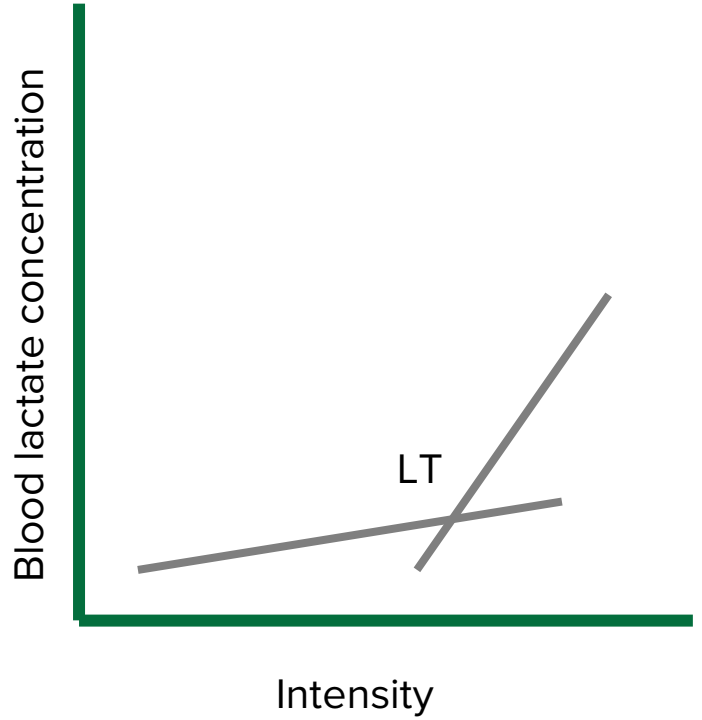
In a practical setting, lactate threshold can be used to set training intensity.



LACTATE THRESHOLD

Lactate is now known NOT to cause fatigue, however, the LT test is still utilized.

Click here to watch a YouTube video by Dr. Laurent Bannock explaining lactate and the utility of VO_2 max vs LT testing.



Video Link https://www.youtube.com/watch?v=lgUMcal5TgM

ESTIMATION OF FUEL UTILIZATION

Respiratory Exchange Ratio (RER)	=	VCO_2/VO_2	=	Ratio of carbon dioxide produced to oxygen consumed

Based on their chemical structures, fat and carbohydrate differ in the amount of O_2 used and CO_2 produced during oxidation.

Fat oxidation requires more O_2 than carbohydrate.

Ignores protein, since protein contributes little as a fuel source.

Determined using a metabolic cart during steady state exercise.

ESTIMATION OF FUEL UTILIZATION

Percentage of Carbohydrate and Fat Utilization by RER value (R)

R	% Fat	% CHO
0.70	100	0
0.85	50	50
1.0	0	100

AEROBIC METABOLISM: INFLUENCE OF INTENSITY & DURATION ON FUEL SELECTION

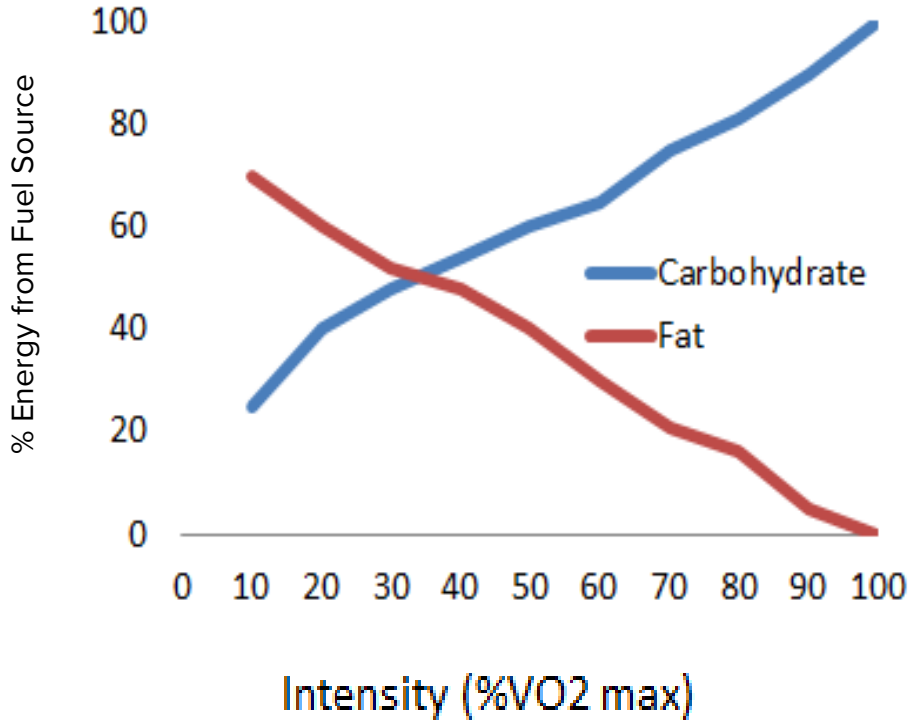
INTENSITY & FUEL SELECTION

Fat is the primary energy source for low-intensity exercise (< ~30% VO_2 max).

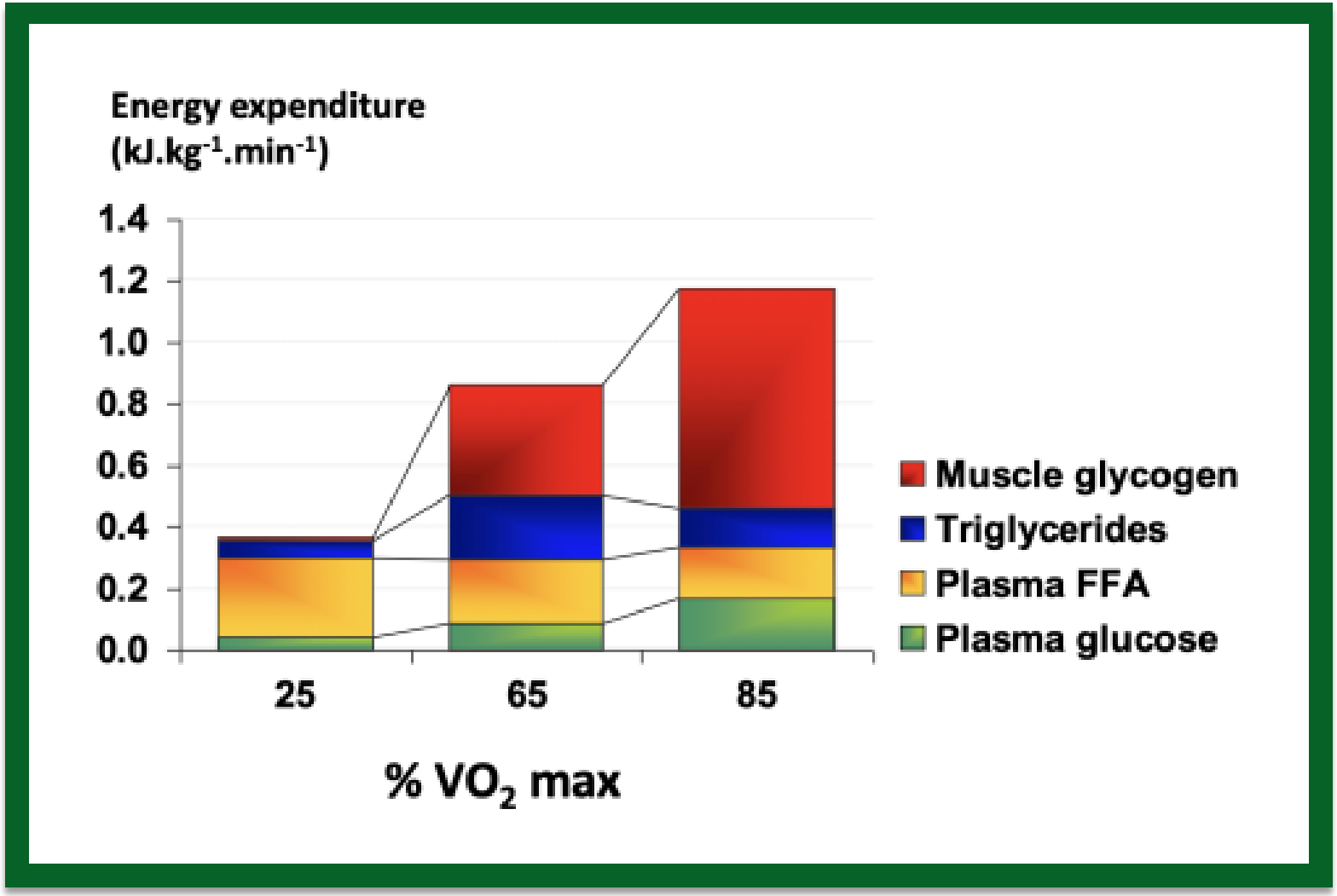
Carbohydrate is the primary energy source for high intensity exercise (> 70% VO_2 max).

Athletes are almost always using a mixture of carbohydrate and fat.

Schematic of Energy Sources Based on Exercise Intensity



INTENSITY & FUEL SELECTION



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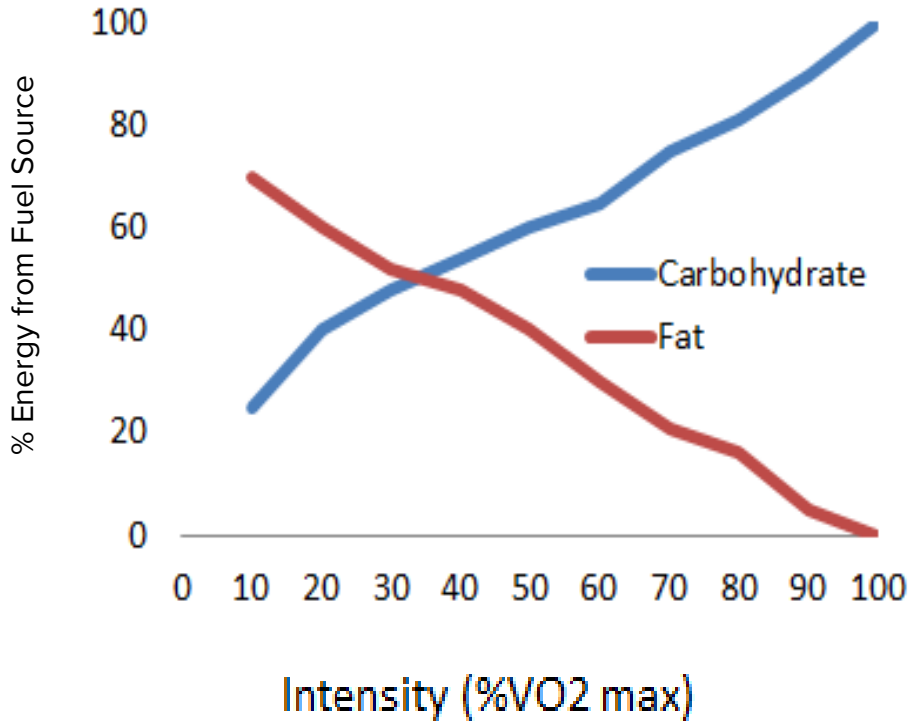
INTENSITY & FUEL SELECTION

MYTH: Individuals exercising to lose weight should work out at a lower intensity, in the “fat burning zone.

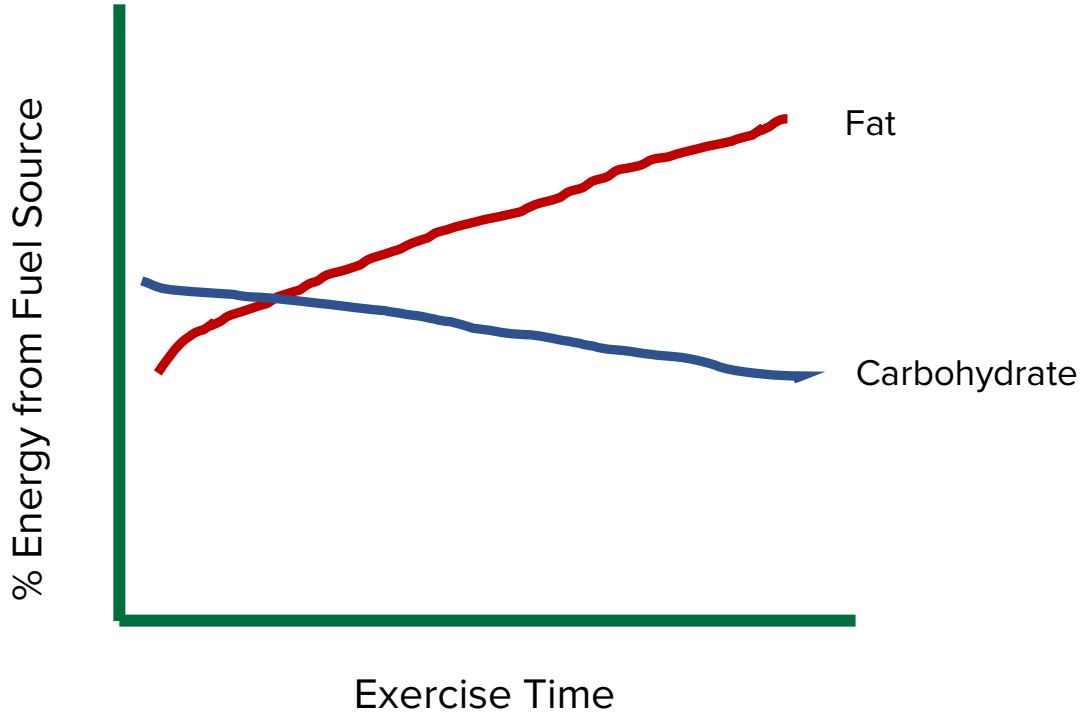
TRUTH: Weight loss depends on overall calories expended. Exercising at a lower intensity results in lower calorie burn (given the same duration). It is more beneficial to work out at a higher intensity, to get a greater EPOC and use more fat for energy during recovery.

Schematic of Energy Sources Based on Exercise Intensity



DURATION & FUEL SELECTION

At a given **intensity**, as exercise duration increases there is a gradual shift from carbohydrate utilization to a greater reliance on fat as a fuel source.



Powers & Howley. *McGraw-Hill Education*. 2017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TRAINING

IMPACT OF TRAINING ON METABOLISM

Regular training can improve fatigue resistance and performance, partly through changes in muscle metabolism.

High Intensity Interval Training (HIIT)

Increases capacity for anaerobic energy production.

Enhances tolerance to metabolic acidosis (increased buffering capacity).

Endurance Training

Increased VO2 max, leading to greater fatigue resistance.

Increased skeletal muscle mitochondrial density.

Increased fat oxidation.

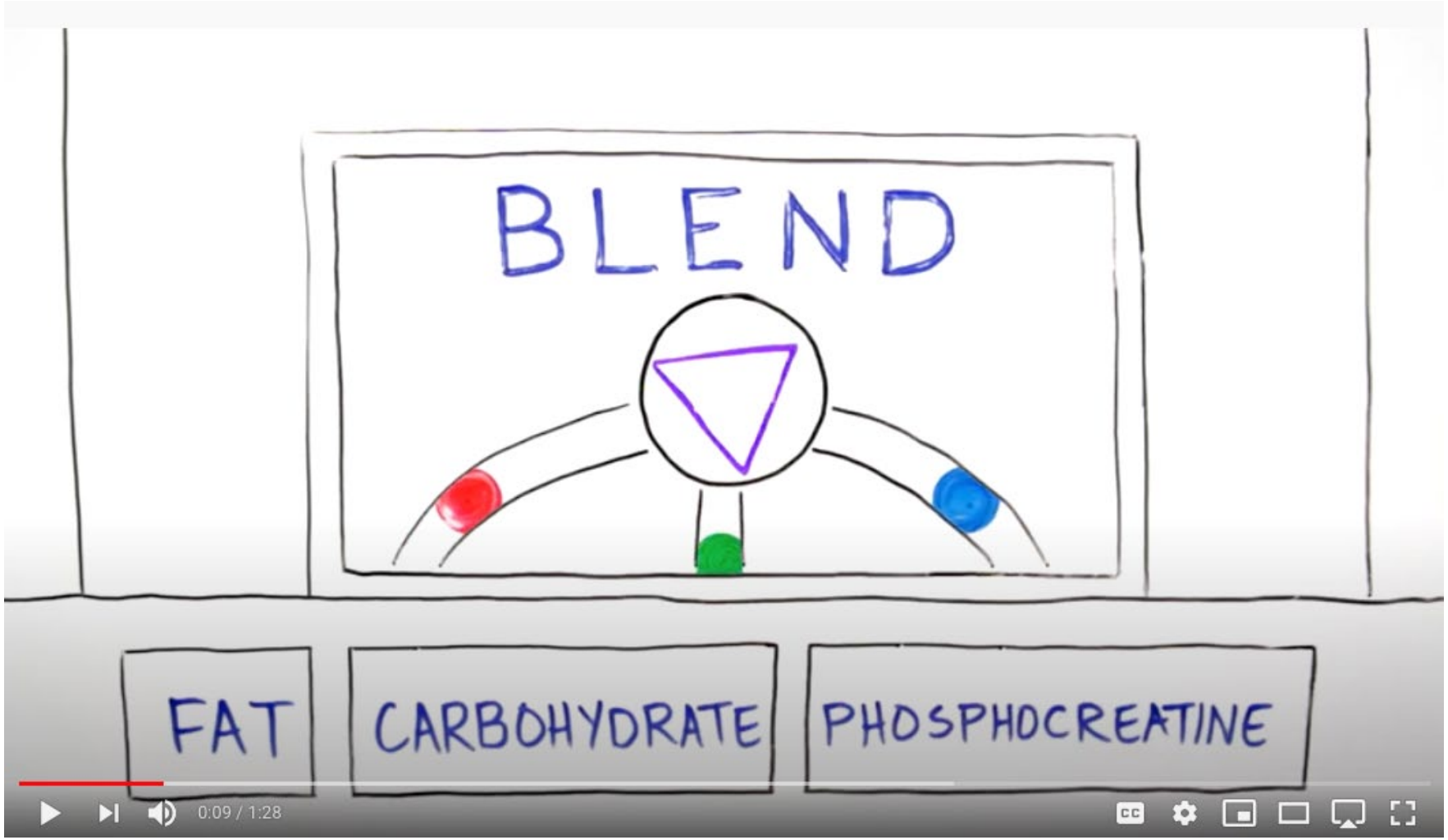
Increased capacity for carbohydrate oxidation, allowing for maintenance of higher power output.

Hargreaves, M & Spriet, L. *Nat Metab*. 2020; https://doi.org/10.1038/s42255-020-0251-4.

KEY TAKEAWAYS

- ✓ Most exercise uses a blend of PCr, anaerobic glycolysis and aerobic metabolism
- ✓ Fuel sources shift during the rest to exercise transition and transition to recovery
- ✓ VO_2 max, Lactate Threshold and RER are tests to estimate fuel utilization
- ✓ Intensity and duration dictate fuel utilization
- ✓ Training can alter fuel metabolism

SUMMARY VIDEO



Link to video

Video Link https://www.youtube.com/watch?v=YI95mrBt1a0

www.GSSIweb.org