A New Perspective On Energy Systems and Performance

Joel Jamieson
Introduction

- Who am I?
- My background
- What to expect...
  - A different perspective than the traditional energy system model you see in textbooks
  - A combination of science and real world practical examples of energy systems at work
Introduction

Why Energy Systems?

Understanding energy systems – how the body produces the fuel our working muscles need while maintaining homeostasis – allows us to answer several of the most important questions about performance...
Performance Questions

- Why do we fatigue?
- What determines an athlete’s maximum speed?
- What determines an athlete’s average or maximum work rate (power)?
- What determines how long an athlete can maintain his/her speed and/or power for (endurance)?
- How are speed/power and fatigue related to one another?
Model of Physical Performance

Performance Potential

Speed of Movement
- Physical Preparation

Level of Technical Skill
- Technical Preparation

Tactics & Strategy
- Tactical Preparation
“It would be wrong to think that the aim of physical preparation is only the development of muscular strength. The strength capacities of skeletal muscles are secured from the energy produced from the corresponding biochemical processes (metabolic energy).”

“Specific physical preparation means have to develop above all the capacity of the body to provide energy for effective specific muscular work”
The role of an athlete’s strength and conditioning program IS NOT just to improve strength or conditioning…it is first and foremost to increase their potential to produce energy. This increase in energy is what provides the foundation for the athlete to perform their skills faster.

To perform high speed skills faster, the athlete must increase their rate of energy production (power). To increase how long they can maintain their speed without slowing down, the athlete must be able to produce energy for longer (endurance).

MORE ENERGY = BETTER PERFORMANCE
The biggest mistake is to increase an athlete’s ability to produce force or power, without also developing the capacity for increased energy production that’s necessary to use it within the physical demands of their sport.

Energy production should be viewed as a fundamental component and objective of every athlete’s entire yearly training program. It is NOT something that just needs to be considered a few weeks before the competitive season starts.
Energy System At Work

- World Record 100m = 9.58s
  - Avg. speed 23.35 mph
  - Peak speed: 27.78 mph

- World Record 400m = 43.18
  - Avg. speed 20.71 mph

- World Record Mile = 3:43
  - Avg. speed 16.13 mph

- World Record Marathon = 2.03:59
  - Avg. speed 12.69 mph
From 10s– 43s (100m – 400m) reduction in average speed of about 11%

From 43s to 3:43 (400m – 1 mile) reduction in average speed of about 22%

From 3:43 to 2 hours (1 mile to 26 miles) reduction in average speed of 21%

From 10s to 2 hours reduction in average speed of 54%
The higher the speed, the shorter the distance. The relationship between decreases in speed and distance between 10s and 2 hours is not linear. More than half (61%) the total decrease in average speed occurs within the first 4 minutes.

Greater force and power = higher rate of fatigue, but why? What determines whether you can run 27mph for a split second, or 12 mph for 2 hours?

What determines how fast you can sprint for 6s over a 3 hour period? What determines the pace you can maintain for 15 minutes of fighting without gassing?
The Answer

ENERGY SYSTEMS
Part I: Energy Systems Overview
Biological Energy Transfer

- Rate of Energy Production (power)
- Duration of Energy Production (capacity)
- Total Potential of Energy Production (biological power)

Energy Production

- Central Governing Control (power regulation)
- Efficiency of Energy Expenditure (skill & technique)
- Neuromuscular Contractility (mechanical)

Energy Utilization

Metabolic Energy Mechanical Work
All our cells run on ATP – it is the body’s “energy currency.” The purpose of the body’s energy systems is to maintain energy homeostasis by producing the chemical energy (ATP) that our cells run on. Energy systems transform the chemical energy from food we eat into the fuel required for muscular work.
Energy homeostasis is maintained when the rate of energy production is equal to the rate of energy expenditure. In this case, the total amount of ATP within the working muscles remains constant.
As force and power increase (higher intensity) the rate of ATP expenditure increases as well. The body responds by increasing the rate of ATP production to match expenditure so that ATP is not depleted within in the muscles.
In order to best maintain energy homeostasis during periods of highly variable rates of energy expenditure, the body has three energy systems that differ in terms of how fast they can regenerate ATP and how long they can regenerate it for. These three systems can be categorized into *aerobic* and *anaerobic*.
The Energy Systems

Aerobic Processes

- Regenerates ATP through oxidative (oxygen dependent) metabolic processes
- Can utilize fat, carbohydrate and amino acids as substrates
- Produces the most ATP per given substrate, but also requires the most chemical steps and takes much longer than the Anaerobic systems to generate ATP
- Capable of sustaining moderate power outputs for very long durations

ATP

Anaerobic Processes

- Regenerates ATP through non-oxidative processes only
- Can utilize ATP, phosphocreatine (alactic) or carbohydrate (lactic) as substrates
- Produces ATP at a much faster rate than the aerobic system, but also causes rapid changes in cellular environment, leading to large disturbances in homeostasis
- Able to support maximum power output, but only for very brief periods of time
Central factors of aerobic energy production are primarily related oxygen transport

- Stroke Volume
- Myocardial contractility
- Autonomic regulation
- Pulmonary diffusion
- Blood volume
- Hemoglobin affinity

Peripheral factors of aerobic energy production involve oxygen utilization within working muscles

- Oxidative enzymes
- Mitochondria density
- Mitochondrial enzymes
- Capillary density
- Muscle glycogen stores
- Myoglobin
Central factors of anaerobic energy production are dependent on central nervous function:

- Motor unit firing rate
- Motor unit recruitment
- Intra- and inter- muscular coordination
- Sympathetic drive

Peripheral factors of anaerobic energy production involves factors of metabolism within muscles:

- Glycolytic enzymes
- Phosphocreatine levels
- Alactic enzymes
- pH buffering capacity
All performance lies somewhere on the energy system continuum of maximum power (high speed) and maximum duration (endurance).
Energy Systems Summary

The body’s central drive is always homeostasis and in order to maintain energy homeostasis within working muscles, it has the ability to regenerate ATP at either tremendously high rates (anaerobically) for short periods of time, or at more moderate levels for incredibly long durations (aerobically).

Energy production can generally be segmented into two distinct but overlapping components: central and peripheral.
The saying that “speed kills” is generally a pretty accurate statement when it comes to performance in athletics. The higher the level of sport, the faster everything occurs. If an athlete can’t perform their skills fast enough, they can’t compete.
How the body regenerates ATP during different rates and durations of energy expenditure ultimately dictates the performance potential of the neuromuscular system.

When ATP is regenerated through aerobic processes, energy homeostasis is maintained and a given power output can be sustained for long periods of time.

When anaerobic processes are used, greater acute power output is achieved but only for very short durations before fatigue occurs and power output is reduced.

The ultimate tradeoff between maximum power and high endurance is dictated by an athlete’s ability to regenerate ATP through aerobic and anaerobic means.
### Energy Systems in 200m – 1500m

![Graph showing energy system contribution over time](image)

<table>
<thead>
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<th>Distance</th>
<th>Duration</th>
<th>Aerobic %</th>
<th>Anaerobic %</th>
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<tbody>
<tr>
<td>200m</td>
<td>22s</td>
<td>29%</td>
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<tr>
<td>400m</td>
<td>49s</td>
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<tr>
<td>800m</td>
<td>1:53</td>
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</tr>
<tr>
<td>1500m</td>
<td>3:55</td>
<td>84%</td>
<td>16%</td>
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</table>
Energy Systems in 200m – 1500m

“The crossover to predominantly aerobic processes occurs within 15–30s for the 400m, 800m and 1500m

Unlike most textbook models depicting the first 60–90s of maximum intensity exercise as being predominantly anaerobic, the aerobic system contributes heavily even in relatively short duration events
- 43% of the 400m @ <50s
Anaerobic Speed Reserve

![Graph showing anaerobic speed reserve and aerobic speed range for different subjects.](image)


Journal of Applied Physiology
After recording maximum speeds that could be supported through *aerobic* and *anaerobic* energy production (3s sprint and speed at VO2 max) researchers could predict running performance from 3s – 240 to within 2.5%

This test showed that each runner's maximum and average speed, as well as the decrease in their speed, over any given duration was directly proportional to the relationship between their maximal aerobic and anaerobic energy production.
Energy Systems in Acyclic Sports

Bout 1 - 30s maximal sprint

- PCr: 21%
- Glycolysis: 50%
- Oxidative: 29%

Bout 2 - 30s maximal sprint

- PCr: 20%
- Glycolysis: 36%
- Oxidative: 44%

Energy Systems in Acyclical Sports

Sprint 1

Sprint 2

Aerobic
ATP
PCr
Glycolysis

ATP utilisation (mmol·kg⁻¹ dry muscle)

Time (s)

0 10 20 30

29%
19%
48%

43%
20%
36%

Time (s)

0 10 20 30

25%
“Despite this approximately 41% reduction in anaerobic energy, the total work done during the second 30-s sprint was reduced by only approximately 18%. This mismatch between anaerobic energy release and power output during sprint 2 was partly compensated for by an increased contribution of aerobic metabolism”

- Recovery of power output during first 10 seconds of 2nd sprint was linked directly to restoration of PCr stores

- The importance of the aerobic system for maintaining power output increases as high intensity sprints are repeated with incomplete rest
A 2009 study by Osgnach used computer video analysis of almost 400 players in game scenarios to evaluate energy demands of soccer:

- 18% of total distance covered was at high speed
- 70% of the total match time was at low intensities
- Overall ratio of high to low intensity work equates to a 2–4s sprint every 90 seconds
- Total Anaerobic energy ranged from 11–27% of total energy expenditure
Maximal aerobic and anaerobic power output was evaluated, then subjects were asked to perform 10 sprints of 6s each with 30s rest between sprints.
Subjects with higher anaerobic power reserves, implying a greater reliance on anaerobic processes to supply energy, recorded larger power decrements across the ten sprints.

Those with highest ratios of aerobic to anaerobic power showed the least fatigue over the 10 sprints.

Decrease in peak power over the 10 sprints was inversely related to peak power of 1st sprint.

Reduced EMG activity was recorded over the sprints, indicated decrease in neural drive (central fatigue).
Energy Systems & Fatigue

In order to prevent serious cellular damage, the body is designed to fatigue (slow down rate of energy expenditure) long before your muscles or heart run completely out of ATP. In fact, even at the highest intensities, total levels of ATP generally don’t fall below 60% of resting levels.

As part of this defense mechanism – designed to maintain energy homeostasis – the body has multiple different safeguards in place and controls it uses to make sure you reduce the rate of ATP expenditure (fatigue) long before you run out of it.
Central vs. Peripheral Fatigue

Central Fatigue

- Decrease in central drive of nervous system to reduce force/power
- Fewer motor units recruited, rate coding turned down to decrease force produced by working muscles
- Increased RPE for a given task alter behaviors and motor patterns
- Most of the research on central fatigue is centered around endurance events and pacing strategies (Noakes)

Peripheral Fatigue

- Decrease in contractile properties (force–velocity) in the muscles
- Likely caused by a variety of physiological mechanisms that impair force production due to large changes in the cellular environment. These factors likely depend on the nature of the muscular work
- Factors in peripheral fatigue may include:
  - change in cellular excitability due to changes in ions (K+, NA+, Ca2+, etc.)
  - Decrease in substrate availability (PCr, glucose, glycogen), hypoxia, acidosis, buildup of inorganic Pi, ROS, cytokines
At the highest rate of energy expenditure, even the anaerobic systems cannot regenerate ATP fast enough to maintain energy homeostasis and ATP levels decline. The body is designed to fatigue rapidly and reduce energy expenditure before cellular damage occurs. This is seen during periods of high anaerobic energy production because this only occurs when there is a high rate of energy expenditure.

Athletes with the highest levels of aerobic energy production fatigue the least but also produce less maximum power because they have lower anaerobic speed/power reserves. Athletes with highest anaerobic production produce the most power, but fatigue the fastest as well.
The aerobic system contributes a large % of total ATP even during relatively short durations.

Regardless of whether the event is cyclical or interval in nature, the aerobic system contributes a greater % of total energy as duration increases while % from anaerobic glycolysis decreases.

The intensity–duration (force/power–endurance) curve can be accurately predicted by looking at the maximum power than can be generated aerobically and anaerobically because this provides the ratio of energy production used during muscular work.
Energy system models in terms of graphs and charts in a textbook provide general insight, but looking at real world examples of energy system development between different athletes and sports provides the most practical information.
## Olympic Level Pole Vaulter

### Parameters

<table>
<thead>
<tr>
<th>Correlative Parameters of the Energy Metabolism System</th>
<th>Value</th>
<th>Norm</th>
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<tr>
<td>Relative VO2 max index *</td>
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<td>58 - 85</td>
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<td>HR at anaerobic threshold</td>
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<td>150 - 183</td>
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* Weight= 89 kg

Resting HR = 48
## Olympic Level Pole Vaulter

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### Jumps

![Graph showing jumps](image)
### NFL Fullback – Off Season

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* Weight = 114 kg

Resting HR = 61
NFL Fullback – Off Season

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Jumps
### NFL Tailback – Pre Season

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<td>HR at anaerobic threshold</td>
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<td>150 - 183</td>
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* Weight= 91 kg

**Resting HR = 54**
NFL Tailback – Pre Season

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### UFC Fighter – Pre Camp

#### Parameters

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* Weight = 93 kg

Resting HR = 56
# UFC Fighter – Post Camp

## Parameters

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<tr>
<td>HR at anaerobic threshold</td>
<td>172</td>
<td>148 - 180</td>
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*Weight = 95 kg*

Resting HR = 48
## UFC Fighter – Post Camp

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### Jumps

![Jumps graph]
Aerobic Energy Production

Fighter

Pole Vaulter

Tailback

Fullback

124
113
111
127
Anaerobic Energy Production

Fighter

Pole Vaulter

Tailback

Fullback
Alactic Energy Production

Fighter

Pole Vaulter

19

15

Tailback

20

15

Fullback
Alactic Power Output

Pole Vaulter 6.14
Tailback 5.57
Fighter 4.66
Fullback 5.03
Energy Systems Profile Summary

- Every sport requires a different balance of aerobic to anaerobic energy production depending on the intensity-duration demands of the sport. Sports with shorter work intervals and longer rest intervals can utilize a greater % of total energy from the anaerobic systems.

- Even in sports with high anaerobic contributions, the most successful athletes show strong central aerobic development, i.e. low resting heart rate, good ANS regulation.
ENERGY SYSTEMS
Part IV: Training & Performance
The goal of every strength and conditioning program is to improve athletic performance through increased physical preparation. This increase provides the foundation for higher speed of movements and allows the athlete to perform their skills faster.
An increase in physical preparation requires increased energy production. There is no way to increase work rate (power) over any given time without supplying more ATP to the working muscles to fuel the additional work being done.

The goal of training to improve performance is to:

A) maximize total energy production

B) correctly balance total energy production between aerobic and anaerobic processes given the specific demands of the sport and the nature of the intensity-duration curve required for high level performance
Training & Performance

Power Output

Before Training

After Training

Anaerobic Power Reserve

Aerobic Power
## The Great Tradeoff

### Force/Power – Anaerobic
- High proportion of anaerobic muscle tissue (fast twitch) with maximum amount of glycolytic and alactic enzymes and substrates suited towards anaerobic energy production
- Large fast twitch CSA for maximum force, leading to low mitochondrial and capillary density
- Optimal CNS activation to fire as many motor units at once in high rate of synchronization. High contractility of fast twitch fibers
- Strong sympathetic drive to increase acute hormonal production of adrenaline/noradrenaline, etc.

### Endurance – Aerobic
- High proportion of fatigue resistance slow twitch fibers capable of producing as much force as possible (size and contractility)
- Maximum development of oxygen transport system (VO2 max) to supply working muscles with as much oxygen as possible
- High mitochondrial density along with peripheral vascular network to provide for high rate of oxygen utilization
- Oxidative enzymes and substrates used in aerobic metabolism
- Parasympathetic dominant to conserve energy expenditure and improve overall economy
Peak Developmental Phase: Aerobic or anaerobic energy production can only be increased at the expense of the other

Mid Developmental Phase: Aerobic or anaerobic energy production can be increased while the other is maintained

Early Developmental Phase: Both aerobic and anaerobic energy production can be increased simultaneously
Develop optimal energy system profile for performance

Test athlete(s) and compare against the model

Determine overall level of overall energy production and profile of aerobic/anaerobic balance

Develop program based on necessary changes in energy production required to improve performance
Developing the Model

- **Aerobic Tests**
  - Resting HR
  - 1.5 mile or 12 minute run (coopers test)
    - Can be correlated to VO2
  - HR recovery after exercise – 1 min after run
  - Lactate threshold/power at lactate threshold
  - VO2 max/Speed at VO2

- **Anaerobic Tests**
  - 3–10 second maximal sprint or other explosive movement
  - 30s maximal effort test (Wingate)
  - Maximum strength
    - 1–5RM on major lifts
  - Power tests
    - Vertical jump
    - Broad jump/bounds
    - Olympic lifts
    - Tendo/Myotest
  - Muscular endurance
    - Pull-ups
    - 225lb bench press
Sample Performance Profile

A radar chart showing performance in various fitness areas:
- Anaerobic Fitness
- Strength
- Explosive Power
- Muscular Endurance
- Aerobic Fitness

The Bioforce Performance Index is 6.5.
Sample Performance Profile

![Image of a radar chart showing performance in various categories such as explosive power, strength, muscular endurance, aerobic fitness, and anaerobic fitness. The chart indicates a bioforce performance index of 4.0.](Image)
The best improvements in performance are the result of targeted training designed to raise total energy production and create the right balance between the aerobic and anaerobic systems.

Only in relatively low level athletes can both aerobic and anaerobic energy production be improved simultaneously. At the highest levels, the development of one will always compromise the other because of the conflicting peripheral adaptations.

Creating a “Performance Profile” gives coaches a tool to objectively see the big picture of an athlete’s energy production and measure progress.

In large group or team settings, athletes can be organized into groups based on results of their performance profile. This offers the advantage of individualization of training while allowing for practical application in a group/team environment.
Energy systems are an integral part of sports performance because they provide the foundation for all motor work. Energy system development dictates both maximal power and the ability to maintain it over a given duration.

The aerobic energy systems contributes far more than reported in previous research and becomes the dominant energy source within 15–30 seconds at maximum intensity.

During intermittent work, the aerobic contribution to total energy production increases over time and glycolytic contribution goes down.

Maximal aerobic and anaerobic energy cannot be developed simultaneously as there are tradeoffs in peripheral adaptations that take place in the muscles.
Different sports require different relative contributions from the aerobic and anaerobic systems for optimal performance.

When the proper ratio between the two is not developed, the athlete either lacks power or endurance and performance is compromised.

Specific training is required to improve energy production and both central and peripheral factors need to be developed for maximal increases in energy production.

Creating a profile of energy production provides an effective tool for the assessment and programming to improve performance.
Thanks for listening

For more info on training register for FREE membership at my site

8WeeksOut.com