- Can I qualify for Boston Marathon?

Men 18-34: 3hrs 5 min	Women: 3hrs 35 min
Men 35-39: 3hrs 10 min	Women: 3hrs 40 min
Men 40-44: 3hrs 15 min	Women: 3hrs 45 min
Men 45-49: 3hrs 25 min	Women: 3hrs 55 min
Men 50-54: 3hrs 30 min	Women: 4hrs 00 min
Men 55-59: 3hrs 40 min	Women: 4hrs 10 min
Men 60-64: 3hrs 55 min	Women: 4hrs 25 min
Men 65-69 4hrs 10 min	Women: 4hrs 40 min
Men 70-74 4hrs 25 min	Women: 4hrs 55 min
Men 75-79 4hrs 40 min	Women: 5hrs 10 min
Men 80 and over 4hrs 55 min	Women: 5hrs 25 min

- What should my training program look like to do a sub 10 hour Ironman?
- Should I shorten my stride length?
- What intensity should I train at?

Lore of Running

Chapter 2

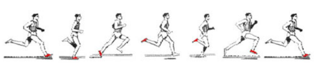
Oxygen Transport and Running Economy

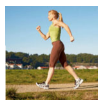
Chapter 2

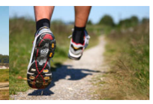
- Part 1a: VO_{2max}
- Part 1b: What does VO_{2max} mean?
- Part 2: Running Economy
- Part 3: Predicting Performance
- Part 4: Physiological changes with aging

Lore of Running

- Lore
  - Something that is taught/learned; knowledge gained through study or experience; traditional knowledge or belief; a particular body of knowledge.
- Running
  - A form of locomotion
    - Jogging
    - Sprinting
  - Gait pattern in which there is a point where both feet are off the ground.
    - vs. walking in which there is a period of double support.
  - Stride
    - A complete gait cycle
      - Consecutive discrete events
      - E.g., right heel contact to right heel contact
    - Step
      - Right - Left

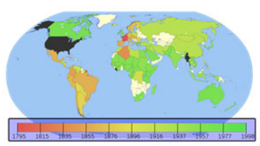






Conversions

- Kg to lbs
  - 2.2 lbs per kg
    - 70 kg x 2.2 lbs/kg = 154 lbs
    - 154 lbs x 1 kg/2.2lbs = 70 kg
- Kph to mph
  - 0.62 mph per 1 kph
    - 10 kph x 0.62 mph/kph = 6.2 mph
- m/s to mph
  - 2.2 mph per m/s
    - 4 m/s * 2.2 = 8.8 mph
- Race pace (time per distance)
  - Kph to min per kilometer
    - min/k = 60 / kph
      - 60 / 10 kph = 6 min/k
  - Mph to min/mi
    - min/mi = 60 / mph
      - 60 / 10 mph = 6 min/mi
- Celsius to Fahrenheit
  - F = 9/5 x C + 32
    - 36ºC x 9 / 5 + 32 = 96.8º F



Part 1a: VO_{2max}

- Oxygen Transport
- Air
  - 21% Oxygen
  - 78% Nitrogen
  - 1% Other (CO2, Argon, …)

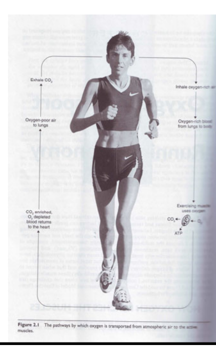
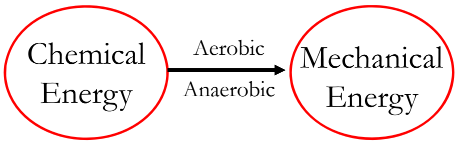


Figure 2.1 The pathways by which oxygen is transported from atmospheric air to the active muscles.

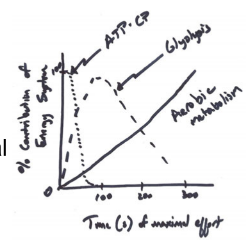
Running Performance



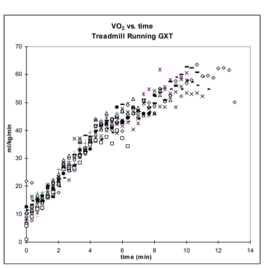
- Development of useful Mechanical Energy
  - Neuromuscular coordination
    - Generation of appropriate forces (direction, magnitude)
  - Transforming energy
    - Rate
    - Efficiency

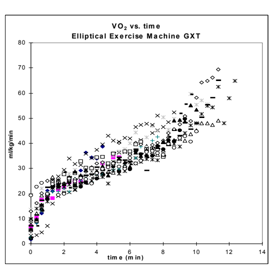
Exercise Intensity

- Exercise intensity during running increases …
  - With running speed
  - Running uphill
- The amount of energy transformed from chemical to mechanical increases
  - Aerobically: ATP HOH CO_2
    - VO_2
  - Anaerobically: ATP [La]

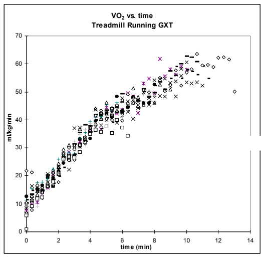


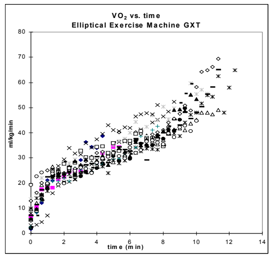
Measuring VO_{2max} Exercise Tests





Measuring VO_{2max} Exercise Tests





$\dot{V}O_{2max}$

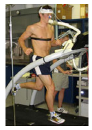
- V Volume
- O_2 Oxygen
- Max Maximum
- 'dot' Rate
- VO_{2max} Maximal rate of oxygen consumption
  - » ml/kg/min
  - » L/min
  - » aka $\dot{V}O_{2peak}$

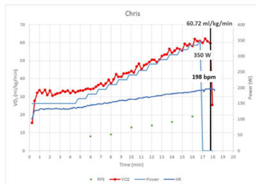
$\dot{V}O_2$

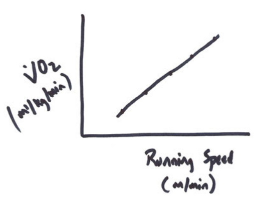
- V Volume
- O_2 Oxygen
- Max Maximum
- 'dot' Rate
- VO_2 Rate of oxygen consumption
  - » ml/kg/min
  - » L/min

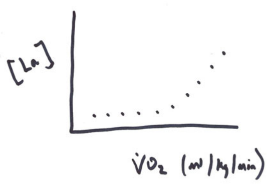
Measuring VO_{2max}
Graded Exercise Test

- vs. Stress test
- Guidelines
  - Mode
    - Specificity
      - Running vs. biking
      - Walking vs. running
  - Time
    - 8-12 min
  - Intensity
    - Graded
      - 2-3 METS per 2-3 min stage







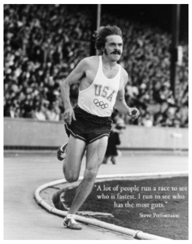


VO_{2max} alone does not predict performance.

Table 2.1 Maximum oxygen consumption ($\dot{V}O_2$ max) values in elite endurance athletes

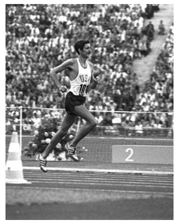
Athlete	$\dot{V}O_2$ max value ($ml \cdot kg^{-1} \cdot min^{-1}$)	Major performance	Reference
John Ngugi	85.0	5 times World X-C Champ	Saltin, Larsen, et al. (1995)
Dave Bedford	85.0	10 km WR 1973	Bergh (1982)
Steven Prefontaine	84.4	1 mile 03:54.6	Pollock (1977)
Henry Rono	84.3	10 km WR 1978	Saltin, Larsen, et al. (1995)
Said Aouita	83.0	5 km WR 1987	Zur & Hymans (1991)
Gary Tuttle	82.7	02:17:00 marathon	Pollock (1977)
Kip Keino	82.0	2 km WR 1965	Saltin & Astrand (1967)
Don Lash	81.5	2 mile WR 1937	Robinson et al. (1937)
Craig Virgin	81.1	02:10:26 marathon	Cureton et al. (1975)
Jim Ryun	81.0	1 mile WR 1967	Daniels (1974)
Steve Scott	80.1	1 mile 03:47.69	Conley et al. (1984)
Joan Benoit	78.6	02:24:52 marathon	Daniels & Daniels (1992)
Bill Rodgers	78.5	02:09:27 marathon	Rodgers & Concannon (1982)
Matthews Temane	78.0	21 km WR 1987	Coetzer et al. (1993)
Don Kardong	77.4	02:11:15 marathon	Pollock (1977)
Tom O'Reilly	77.0	927 km in 6-day race	Davies & Thompson (1979)
Sebastian Coe	77.0	1 mile WR 1981	Zur & Hymans (1991)
John Landy	76.6	1 mile WR 1954	Astrand (1955)
Alberto Salazar	76.0	02:08:13 marathon WR 1981†	Costill (1982)
Johnny Halberstadt	74.4*	02:11:44 marathon	Wyndham et al. (1969)
Amby Burfoot	74.3	02:14:28 marathon	Costill & Winrow (1970b)
Cavin Woodward	74.2	48 to 160 km WR 1975	Davies & Thompson (1979)
Kenny Moore	74.2	02:11:36 marathon	Pollock (1977)
Bruce Fordyce	73.3*	80 km WR 1983	Jooste et al. (1980)
Grete Waitz	73.0	02:25:42 marathon WR 1980	Costill & Higdon (1981)
Buddy Edelen	73.0	02:14:28 marathon WR 1963	Dill et al. (1967)
Peter Snell	72.3	1 mile WR 1964	Carter et al. (1967)
Zithulele Sinqe	72.0	02:08:05 marathon	Coetzer et al. (1993)
Frank Shorter	71.3	02:10:30 marathon	Pollock (1977)
Willie Mtolo	70.3	02:08:15 marathon	Coetzer et al. (1993)
Derek Clayton	69.7	02:08:34 marathon WR 1969	Costill et al. (1971)

NOTE: WR = world record; X-C = cross country
* Predicted sea level values from measurements recorded at medium altitude by adding 11 percent.
† Subsequently not ratified (short course).



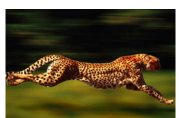
- VO_{2max} = 84.4 ml/kg/min
- 1-mile: 3:54
- 3-mile: 12:51

Difference
16%
3.4%



- VO_{2max} = 71.3 ml/kg/min
- 1-mile: 4:02
- 3-mile: 12:51

Athletic Mammals



- Cheetah
  - Can reach speeds over 60 mph
    - Only for a few hundred meters
    - Internal temperature gets too high
- Pronghorn Antelope
  - 10 K in 10 minutes
  - VO_{2max}: 300 ml/kg/min
- Thoroughbred Racehorses
  - 1 mile: 1 min 33 sec
  - VO_{2max}: 200 ml/kg/min

VO_{2max}

- Represents the maximal rate that oxygen can be used.
- It is not a good predictor of performance.
- It can be used as a marker of fitness
  - but often there are small changes in VO2max but big changes in performance.
- Used to identify relative training loads.
  - e.g., the point where lactic acid starts to accumulate in the blood at a greater rate during a GXT seems fairly consistent between subjects.

Factors that affect VO_{2max}

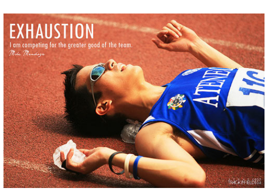
- Age
  - 9% decrease per decade (after 25 yo)
- Gender
  - Women have lower VO_{2max} than men.
    - Higher body fat content, smaller muscle mass.
- Fitness and Training
  - Training can increase VO_{2max} ~5-15%.
- Altitude
  - VO_{2max} decreases about 10% for every 1000 m (3280 feet) above 1200 m (4000 feet).
    - LV: ~2200 feet
    - Mt Charleston: ~8000-10,000 feet
    - VO_{2max} 15 ml/kg/min @ summit of Mt Everest (8848 m; 29,030')
- Ventilatory muscle action

Summary Part 1a:

- VO_{2max} background
  - Measuring
  - Performance

Part 1b: VO_{2max}

- What does VO_{2max} measure?
- What is its value to athletes?
- Why do people stop exercising at VO_{2max}?



History

– Universal 4 L/min (Hill & Lupton 1923)

vs.

– Plateau during GXT (e.g., Taylor et al., 1955)

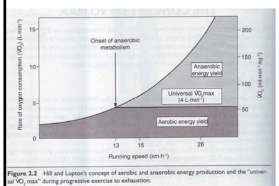
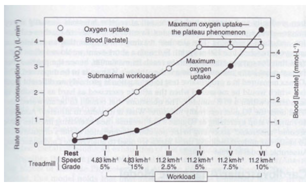
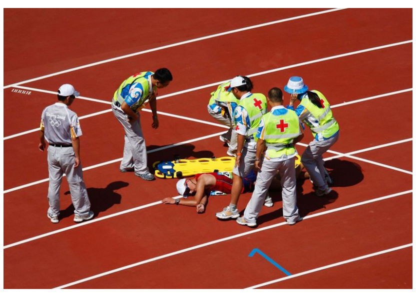


Figure 2.2 Hill and Lupton's concept of aerobic and anaerobic energy production and the "universal $\dot{V}O_2$ max" during progressive exercise to exhaustion.



Why do people stop?

Plateau or no plateau … people are exhausted at the end of a GXT



Cardiovascular/Anaerobic Model

- High intensity exercise is limited by the development of anaerobic conditions in the active muscles.
  - The heart cannot increase its output of oxygenated blood to muscles.
  - Oxygen delivery to the muscles plateaus forcing the muscles to rely on anaerobic metabolism for energy supply.

Does a plateau exist?

- Plateau observed in 30% of subjects
  (Noakes 1998b; Doherty et al., 2002)
- Seldom identified in children (Rowland, 1993).
- The absence of a plateau does not imply that exercise can continue indefinitely.
  - Exhaustion is real
- The lack of plateau means that sufficient oxygen is still being delivered to muscles.

Plateau

- If a plateau does exist, that means that inadequate oxygenated blood flow is being delivered to muscles.
- That means that the heart fatigues before skeletal muscles.
  - Ischemic?
  - Healthy runners do not terminate GXT due to chest pain.
  - …but, there must be some type of protective mechanism to avoid the heart from fatigue.
    - Meaning that the capacity of the heart limits VO_{2max}.

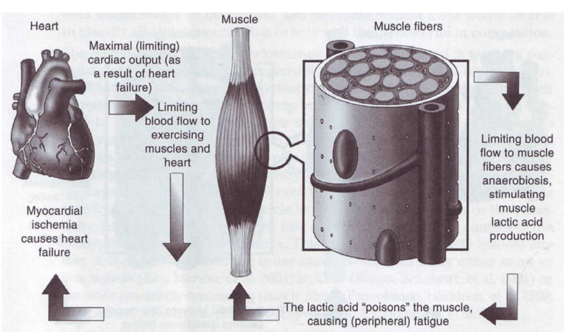


Figure 2.5 The development of an inadequate blood flow to the heart muscle (myocardial ischemia) as predicted by the Hill model.

Fatigue/exhaustion is a result of inadequate oxygen being delivered to the muscles.

Central Governor Model

(Integrated Neuromuscular Recruitment Model)

- The heart is at the greatest risk of developing oxygen deficiency during exercise.
- A 'governor' monitors the state of oxygenation of the heart (and maybe other organs such as the brain and diaphragm).
- When oxygenation approaches safe limits, the brain is informed and muscle recruitment is altered.
  - Result: Fatigue, exhaustion, pain
  - Individual exercise capacity may be a result of coronary blood flow, heart/skeletal muscle efficiency, contractility, and/or elasticity.

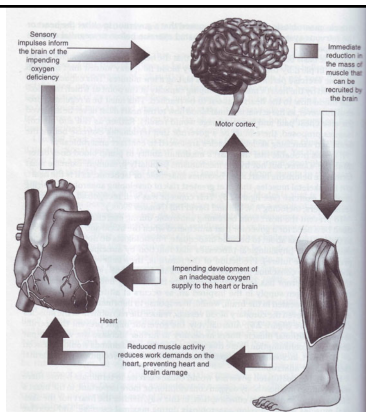
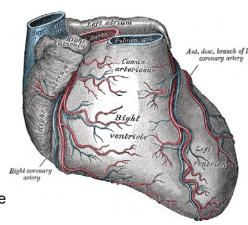


Figure 2.6 Mechanisms whereby a postulated governor in the brain terminates maximal exercise before myocardial damage resulting from ischaemia can occur.

Coronary Circulation

- Cardiac muscle has limited anaerobic ability.
- Cardiac muscle receives oxygenated blood via coronary arteries (originating in aorta) not internally through chambers.
  - Deoxygenated blood is returned via coronary veins.
  - About 70-80% of oxygen is extracted from the blood.
    - ~25% in other muscles
  - Ischemia: Inadequate blood flow.
    - Angina pectoris: Chest pain
- Cardiac Output = Heart Rate x Stroke Volume
  - SV: Amount of blood extracted from the Left Ventricle each beat.



Central Governor Model

(Integrated Neuromuscular Recruitment Model)

- VO_{2max} is a result of

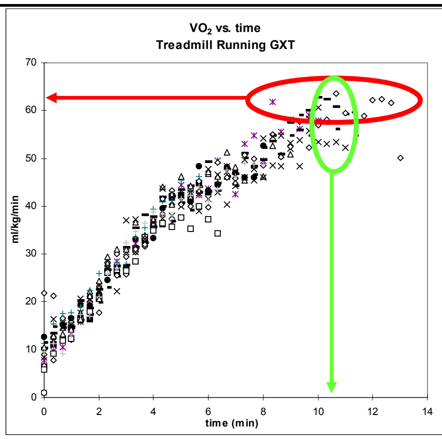
1. Maximum pumping capacity of the heart.
   - Determines the peak rate that oxygenated blood can be delivered to the muscle.
   - The 'governor' is activated to prevent anaerobic condition in the cardiac muscle.
   - Muscles recruitment is influenced.
2. The ability of muscles to generate effective force efficiently.
   - Elastic properties of muscle
   - Level of contractility
   - Fatigue resistance

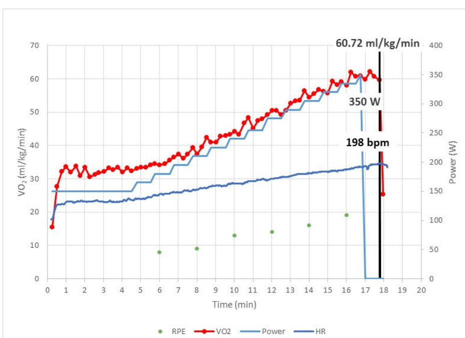
Muscle Power Model

- Muscle contractility (i.e., force generating capability) is not the same in the muscles of all humans.
  - Connective tissue
  - Titan
- Athletes of differing abilities may differ in contractility performance of individual muscle fibers (regardless of type).

What does VO_{2max} mean?

- It is not known what causes people to stop exercising during a GXT.
  - Physiological end point?
  - Psychological end point?
- A specific VO_{2max} does not predict running performance.





Achieving VO_{2max}

- *High* VO_{2max}
  - Low work rates combined with inefficient hearts and muscles (poor contractile performance).
    - *Inefficient transformation of energy from chemical to mechanical*
- *Low* VO_{2max}
  - High work rates combined with efficient hearts and muscles.
    - Produce less heat

Summary Part 1b

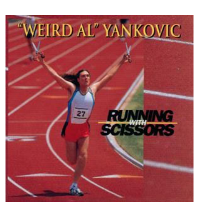
- VO_{2max}
  - Plateau or not?
  - Explained by
    - Cardiovascular Model
      - Inability of muscles to receive adequate oxygenation
    - Central Governor Model
      - Protective limit to cardiac muscle
    - Biomechanical Model
      - Differential contractility performance between humans
  - Represents the maximal rate of oxygen consumption (and use).
    - Work load achieved is important in predicting performance

Part 2: Running Economy

- VO_{2max} by itself is not a good predictor of endurance performance.
- Running Economy may be more important.
  - The amount of oxygen used when running at a constant (submaximal) running speed.
    - ml/kg/min for a given speed

Running Economy

- The amount of oxygen consumption for a given speed.



Running Economy

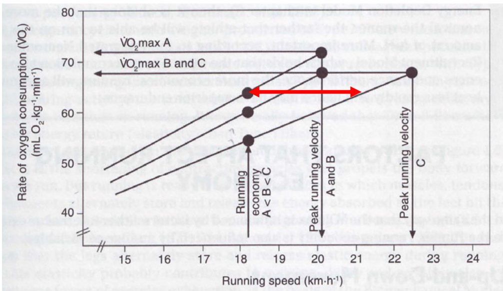


Figure 2.9 Comparison of running economy, peak treadmill running speed, and $\dot{V}O_2$max in three theoretical runners (A, B, and C) during a progressive exercise test to measure $\dot{V}O_2$max.

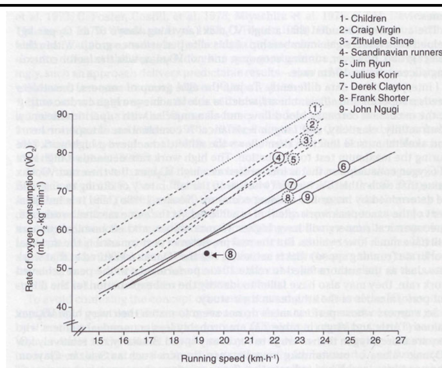


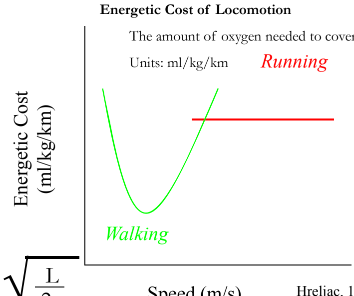
Figure 2.8 Running efficiencies of Derek Clayton, Jim Ryun, Frank Shorter, Zithulele Sinqe, Craig Virgin, John Ngugi, and Julius Korir, and Scandinavian runners compared with those of a group of children.

Running to cover a distance
aerobically

Energetic Cost of Locomotion

The amount of oxygen needed to cover a particular distance.

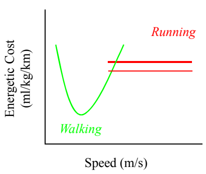
Units: ml/kg/km



$$T = 2\pi\sqrt{\frac{L}{2g}}$$

Hreljac, 1993, MSSE
Holt, Hamill, & Andres, 1991 MSSE

Running Economy



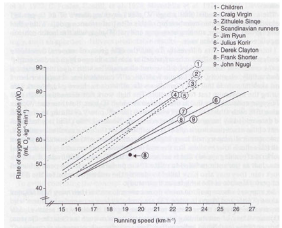
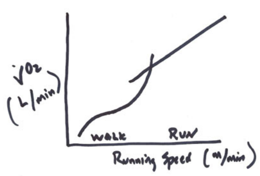
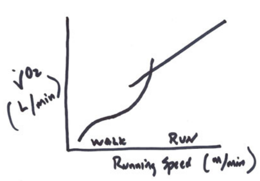


Figure 2.8 Running efficiencies of Derek Clayton, Jim Ryun, Frank Shorter, Zithulele Sinqe, Craig Virgin, John Ngugi, and Julius Korir, and Scandinavian runners compared with those of a group of children.

Improved (better, greater) Running Economy = lower VO_2 per speed.



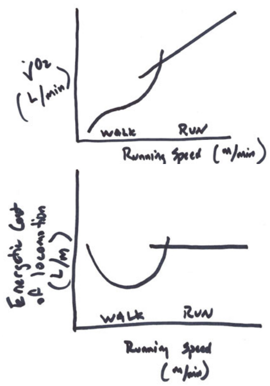
Adapted from Falls & Humphreys, 1976, MSSE, 8(9)

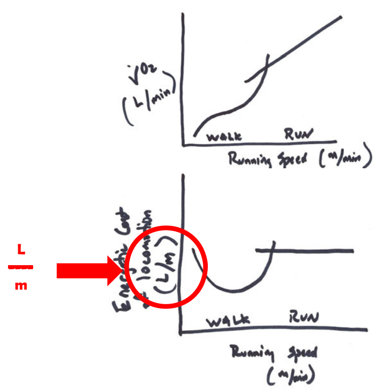


$$\text{Slope} = \frac{\text{rise}}{\text{run}} = \frac{\Delta y}{\Delta x} = \frac{\Delta\, L/\text{min}}{\Delta\, m/\text{min}}$$

$$= \frac{L}{m} \quad \left[\begin{array}{l}\text{oxygen consumed}\\ \text{over a distance}\end{array}\right]$$

Adapted from Falls & Humphreys, 1976, MSSE, 8(9)





The amount of Oxygen (L) used to cover a distance (m)

Powers & Howley

TABLE 18.8 Net Caloric Cost Per Mile for Walking, Jogging, and Running

Walking							
Mph	2	2.5	3	3.5	4	4.5	5
Meters/min	54	67	80	94	107	121	134
Net cost kcal · kg^{-1} · mile^{-1}	.77	.77	.77	.77	.96	1.15	1.38
Jogging/Running							
Mph	3	4	5	6	7	8	9
Meters/min	80	107	134	160	188	215	241
Net cost kcal · kg^{-1} · mile^{-1}	1.53	1.53	1.53	1.53	1.53	1.53	1.53

Note: Multiply by body weight in kilograms to obtain the number of kilocalories used per mile.

Summary – Running Economy (1)

- Running economy
- Energetic cost of locomotion

Factors that Affect Running Economy

- Running style
  - Stride Rate
    - aka Stride Frequency
    - Units
      - Strides/s
      - Hz
  - Stride Length
    - Units
      - m/stride

Factors that Affect Running Economy

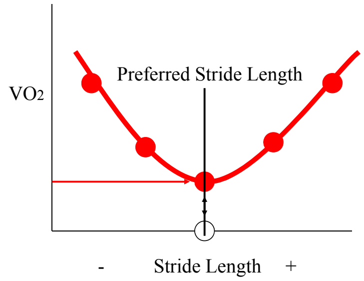
- Running style
  - Stride Rate
    - aka Stride Frequency
    - Units
      - Strides/s
      - Hz
  - Stride Length
    - Units
      - m/stride

Velocity = SR x SL

m/s = strides/s x m/stride

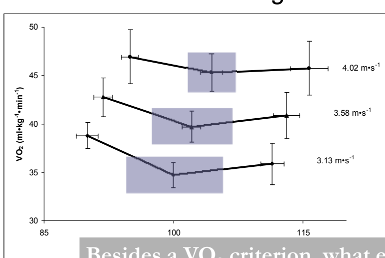
Rate of Oxygen Consumption

at a set speed with different stride lengths



Rate of Oxygen Consumption

at different speeds with different stride lengths

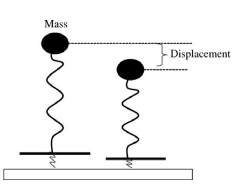


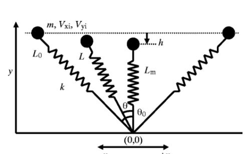
- SF changes slightly
- 'U-shaped' curve
- Little change in VO_2 near PSF.
- PSF important as velocity increases.

Besides a VO_2 criterion, what else could influence running style?

Factors that Affect Running Economy

- Muscle capacity to store energy
  - Elastic energy (i.e., springs)
    - Tendon, titan, …





Factors that Affect Running Economy

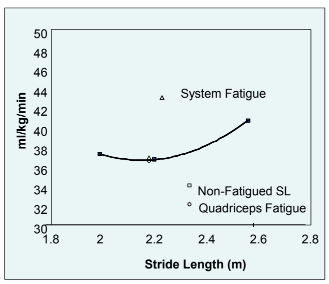
- Fitness and training
  - People become more economical with training.
    - ~1-4% improvement without changes in VO_{2max}
- Age
  - Children are less economical runners than adults.
    - But become more economical with age.
      - Training, weight gain, running mechanics, elastic

Factors that Affect Running Economy

- Fatigue

Running economy is worse with fatigue (e.g., end of a long run).

- Maybe due to damage to elastic material.
  - Stretch-shortening cycle



Factors that Affect Running Economy

- Gender
  - Gender does not influence running economy.
    - …but because body composition varies between gender, maybe women would be more economical if this was controlled.
- Ethnicity
  - May be a factor … but not clear if ethnicity or culture effect.
    - African pygmies were about 10% more economical than Caucasians when running but not when walking.

Factors that Affect Running Economy

- Added weight (clothing and shoes)
  - Running economy is influenced by what is worn.
  - Adding weight distally vs. proximally has a greater negative effect on running economy.
    - 0.5 kg added to the thigh increased RE 3.5%
    - 0.5 kg added to the foot increased RE 7.2%
    - ~1% increase in RE for every 100 g added to th
      - Shoes weigh about 160 g (racing flats) to 310 g (trainer)
      - Orthotics weigh about 80 g



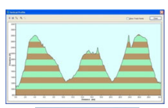
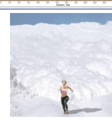
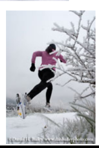


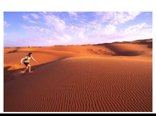




Factors that Affect Running Economy

- Environmental conditions
  - Running uphill
    - 2.6 ml/kg/min per 1% inc in gradient *(=~0.4 mph slower)*
  - Running Downhill
    - 1.5 ml/kg/min per 1%
  - Running surface
    - Sand, snow, soft surfaces
      - worse RE
    - “tuned” track?



Factors that Affect Running Economy

Environmental conditions:
- Wind
  - $D = \frac{1}{2}(\rho C_d A V^2)$
    - ρ Air density
    - C_d: Coef. Of drag
    - A: Frontal area
    - V: velocity
  - ~8% of energy is used to overcome air resistance
    - 6 m/s or 4 min 30 s min/mi
    - Drafting reduces energy cost
    - Greatest effect at speeds 18 kph (11.2 mph)
    - Follow within 1 m (i.e., as close as possible!)
      - When head wind is 18 kph
    - On TM, set grade to 1-2 %
- Grade
  - $VO_2 = v(0.2 + \text{grade} \times 1.8) + 3.5$

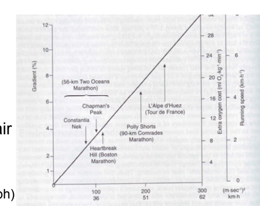


Figure 2.10 The additional oxygen cost of running up differing gradients or running into headwind speeds (facing wind speeds) of different velocities.
Based on the data of C.T.M. Davies (1980b; 1981).

Pacing

- Velocity is not constant during marathons
  - Training programs target a set pace
  - Pace varies
    - Elevation changes, aid stations, change in weather, …
    - Nutrition, fatigue, …
- Haney & Mercer, 2011
  - 285 GPS data sets
    - 116 Las Vegas
    - 169 San Diego

Suggestions to Improve Running Economy

- Focus should be on improving RE vs. VO_{2max}.
  - Training can improve RE more so than VO_{2max}
  - Training increases the running speed at the LT
    - The %VO2max that can be sustained increases
  - Noakes hypothesizes that rate of heat accumulation is reduced with training
  - It is not clear what training program is best for improving RE
  - Practical suggestions:
    - Minimize shoe and clothing weight
    - Aerodynamics (e.g., tight fitting clothing)

Summary: Part 2

- Running Economy
  - vs. VO_{2max}
- Factors that influence RE
  - Running style
  - Fitness/training
  - Age
  - Fatigue
  - Gender
  - Ethnicity
  - Added weight
  - Environmental conditions
    - Grade, surface, wind

Part 3: Predicting Running Performance

- VO_{2max} is an indirect measure of athletic performance
  - It is a measure of VO_2 at the peak work rate (i.e., speed, grade)
  - It is not possible to run at VO_{2max} for more than a few minutes
  - Trained runners can sustain a speed that elicits 80-95% of VO_{2max}
- The maximum work rate at VO_{2max}
- The work rate at the lactate turnpoint
- 10 K run time
  - Use this to test how prepared you are for a marathon

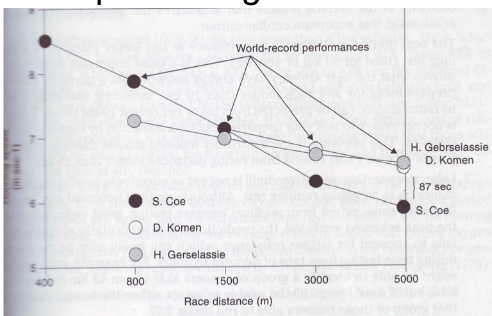
Limits to Performance

- No one knows what limits performance
- Sprint vs. Endurance performance
  - Mechanisms are different
  - Sprinters can transform energy from chemical to mechanical at high rates but are not fatigue resistant
  - Endurance runners are fatigue resistance but do not transform chemical energy to mechanical at high rates

Limits to Endurance Performance

- Muscle and neural factors contribute to running performance
  - Superior heart and skeletal muscle function
    - Allows fastest athletes to maximize muscle power output
  - Ability to resist fatigue during prolonged exercise
    - Endurance performance limited by prevention of fatigue of cardiac muscle
      - Response to heat?
      - Glycogen stores?
      - Blood glucose levels?
      - Skeletal muscle damage?

Example of fatigue resistance



2.12 Comparative fatigue resistances of Sebastian Coe, Daniel Komen, and Haile

Part 3: Predicting of Performance

- Prediction tables
- Based upon
  - past performances
  - Knowledge of VO_{2max} and running economy (i.e., the percent VO_2 that can be sustained)
- Do not account for
  - Environmental conditions
    - Grade, wind, temperature
  - Differences in subjects

Davies-Thompson

- Must know
  - VO_{2max}
  - Percent that can be sustained
- Example
  - VO_{2max} = 60 ml/kg/min
  - $\%VO_{2max}$: 50% (i.e., 30 ml/kg/min)
  - Running speed (km/h) = ($\%VO_2$ + 7.736) / 3.966
    - 9.5 km/h could be sustained

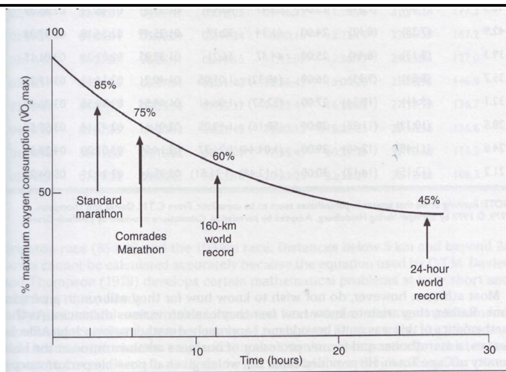


Figure 2.13 The sustainable exercise intensity (expressed as a percentage of $\dot{V}O_2$max) falls progressively with increasing exercise duration.
From C.T.M. Davies and Thompson (1979, p. 239). © 1979 by Springer-Verlag, Heidelberg. Adapted by permission.

Table 2.3 Predicted equivalent running times (h:min:sec) for different racing distances related to predicted $\dot{V}O_2$ max

Predicted $\dot{V}O_2$max (ml·kg·min)	Distance 1500 m	1 mile	5 km	8 km	10 km	16 km	21 km	30 km
93.6	(3:50)	(4:07)	10:00	(20:43)	(25:59)	42:16	55:52	01:20:41
89.9	(3:59)	(4:16)	11:00	(21:29)	(26:57)	43:51	57:59	01:23:48
82.7	(4:18)	(4:36)	13:00	(23:12)	29:07	47:26	01:02:46	01:30:49
79.1	(4:28)	(4:48)	14:00	24:11	30:21	49:27	01:05:27	01:34:46
75.5	(4:40)	(5:00)	15:00	25:14	31:43	51:38	01:08:23	01:39:05
71.9	(4:43)	(5:14)	16:00	26:23	33:08	54:02	01:11:55	01:43:49
68.2	(5:06)	(5:29)	17:00	27:39	34:43	64:40	01:15:06	01:49:01
64.6	(5:22)	(5:45)	18:00	29:03	36:28	59:33	01:18:59	01:51:45
61.0	(5:38)	(6:03)	19:00	30:55	38:25	01:02:46	01:23:17	02:01:08
57.4	(5:57)	(6:23)	20:00	32:17	40:34	01:06:20	01:28:04	02:08:15
53.7	(6:18)	(6:46)	21:00	34:12	42:59	01:10:20	01:33:27	02:16:15
50.2	(6:41)	(7:11)	22:00	36:21	45:37	01:14:50	01:39:30	02:25:18
46.5	(7:08)	(7:39)	23:00	38:47	48:44	01:19:57	01:46:24	02:35:37
42.9	(7:38)	(8:12)	24:00	41:34	52:17	01:25:49	01:54:18	02:47:28

Daniels-Gilbert

- Assumption
  - $\%VO_{2max}$ that can be sustained falls with running time.

Table 2.4 Predicted equivalent running times (h:min:sec) for different racing distances related to a reference $\dot{V}O_2$max

Reference $\dot{V}O_2$max (ml·kg·min)	Distance 1500 m	1 mile	5 km	8 km	10 km	16 km
112.1	2:40	2:53	10:00	16:29	20:52	34:25
100.2	2:56	3:10	11:00	18:07	22:55	37:47
90.5	3:12	3:27	12:00	19:44	24:57	41:10
82.4	3:28	3:45	13:00	21:22	27:01	44:35
75.5	3:44	4:02	14:00	23:00	29:04	48:01
69.7	4:01	4:20	15:00	24:38	31:08	51:28
64.6	4:17	4:38	16:00	26:16	33:12	54:56
60.2	4:34	4:56	17:00	27:54	35:17	58:25
56.3	4:51	5:14	18:00	29:33	37:21	01:01:54
52.8	5:08	5:33	19:00	31:11	39:26	01:05:23
49.7	5:25	5:51	20:00	32:49	41:31	01:08:53
47.0	5:42	6:09	21:00	34:28	43:36	01:12:22
44.5	5:59	6:28	22:00	36:06	45:41	01:15:52
42.2	6:16	6:46	23:00	37:44	47:46	01:19:21
40.1	6:33	7:05	24:00	39:22	49:51	01:23:50
38.3	6:51	7:24	25:00	41:00	51:56	01:26:18
36.5	7:08	7:42	26:00	42:38	54:00	01:29:46
35.0	7:25	8:01	27:00	44:16	56:04	01:33:12
33.5	7:42	8:19	28:00	45:53	58:08	01:36:38
32.2	7:59	8:37	29:00	47:30	01:00:12	01:40:14
30.9	8:16	8:56	30:00	49:07	01:02:15	01:43:28

NOTE: Based on equations derived from data in J. Daniels and Gilbert, (1979), © 1979 by J. Daniels and J.R. Gilbert. The exact data can be derived from *Oxygen Power*. The book can be purchased by writing to Jack Daniels, SUNY Cortland, Box 2000 Park Center, Cortland, NY 13045.

Osler and 2. Gardner-Purdy

- Prediction tables that include ‘quality’ of performance
  - Quality is not on a linear scale with time

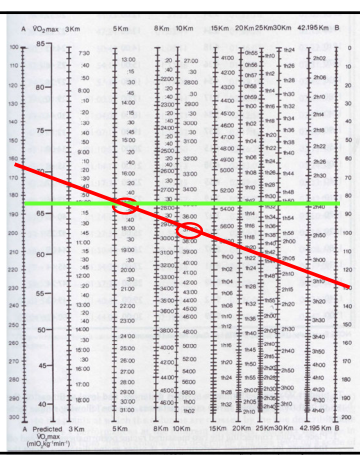
Table 2.7

Mercier-Leger-Desjardins

- Nomogram
  - Must know two race times

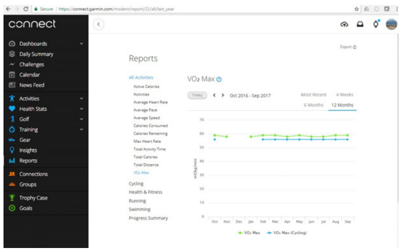
  - Connect two race times with a straight line
  - Estimate VO_{2max}
  - Estimate other times
  - Determine ‘quality’ of performances

A value closer to 100 means more fatigue resistant

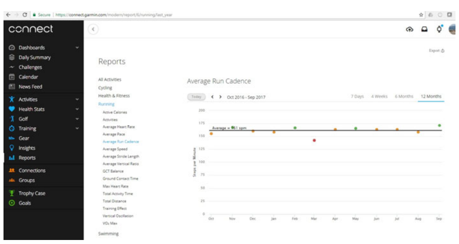


164-128 = 36

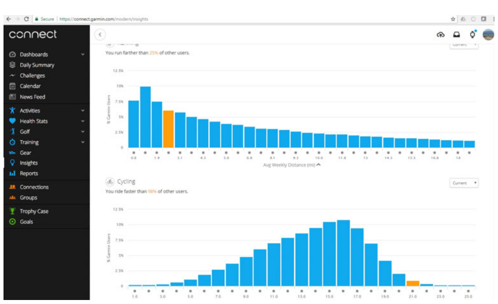
Wearable Technology



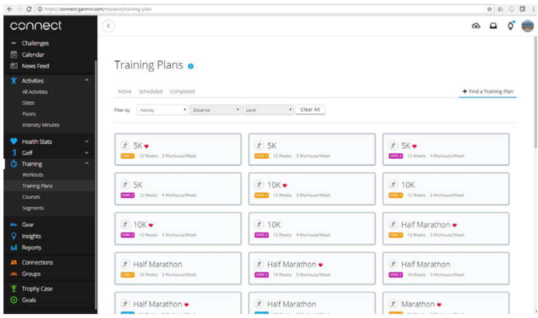
Wearable Technology



Wearable Technology



Wearable Technology



ACSM Equation

- Running

$$VO_2 = (0.2\ Spd) + (0.9\ Spd\ Grd) + 3.5$$

VO_2 = ml/kg/min
Spd = m/min (1 mph = 26.8224 m/min)
Grd = fraction

ACSM Equation

- Running

$$VO_2 = (0.2\ Spd) + (0.9\ Spd\ Grd) + 3.5$$

- Use equation
  - To predict VO_2 for a given speed.
  - To predict speed for a given VO_2.

ACSM Equation

- Running

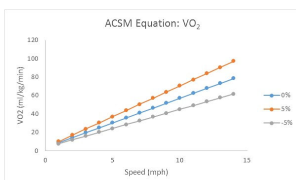
$$VO_2 = (0.2\ Spd) + (0.9\ Spd\ Grd) + 3.5$$

- For 0% grade …
  - VO_2 = 30 ml/kg/min
  - Spd = (VO_2 – 3.5)/0.2
  - Spd = 132.5 m/min = 4.9 mph

ACSM Equation

- Running

$$VO_2 = (0.2\ Spd) + (0.9\ Spd\ Grd) + 3.5$$



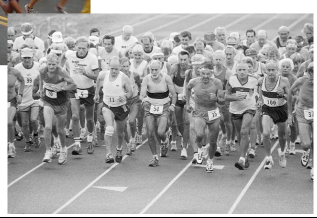
Summary of Prediction

- VO_{2max} is not necessarily a great predictor of endurance performance
  - This might be because VO_{2max} is a result of performance vs. a determinant of performance.
- Past performances are the best predictor of endurance performance.
  - 10 K
  - Time for 42 km = 5.48 x (10K in min) – 28 (min)
    - 10 K = 40 min
    - 5.48 x 40 – 28
      - 191.2 min or 3.2 hrs or 3 hours and 12 mins

Summary of Prediction

- The ability to predict endurance performance is dependent on identifying the fatigue resistance an athlete has.
  - The % VO_{2max} is important
    - Or, the % of max work rate
  - An athlete can use the prediction tables to determine his/her level of fatigue resistance.
    - Monitor training progress
    - Identify overtraining, detraining

Part 4: Physiological Changes with Aging



Changes with Aging

- Reduction in VO_{2max}
  - 10% reduction per decade
    - Maybe 5% per decade for trained
  - Why?
    - Central Governor Model
      - Reduced blood flow to the heart
      - Reduced cardiac output
      - Decreased permissible mass of skeletal muscle that can e recruited
      - Reduction in skeletal muscle contractility

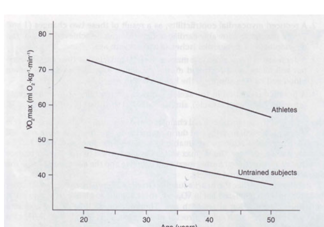


Figure 2.15 Reductions in $\dot{V}O_2max$ with age in athletes and in those who do no training.

Changes with Aging

- Muscular components
  - Muscle mass declines with aging
    - Especially at ages greater than 50/60 yo
      - Muscle strength is somewhat maintained up to about 50.
        - » 15% loss per decade up to 70, then a 30% loss per decade
      - Muscle mass peaks about 24 yo and falls by about 10% at 50 yo
      - Type I and II fibers both lost
        - » Type I retain normal size; Type II are smaller
        - » Oxidative capacity decreases with age but is reversible with training
      - The number of motor neurons decreases after 60, about 10% per decade

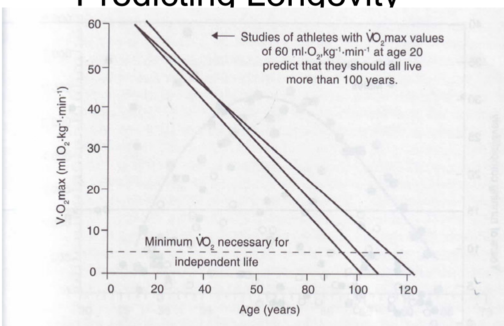
Changes with Aging

- Body composition
  - Increased body fat with aging has a negative impact on VO_{2max}
    - Training helps reduce increase in body fat
    - …remember, muscle mass is decreasing

Changes with Aging

- Training changes
  - General reduction in training volume and intensity accounted for 28% and 35%, respectively, in variance of VO_{2max} (Marti and Howald, 1990).
    - Which comes first?
      - Reduced training leads to reduced VO_{2max}
      - Reduced VO_{2max} leads to reduced training
    - Athletes who are genetically better endurance athletes may have a reduced decrement of VO_2 (and reduced training)

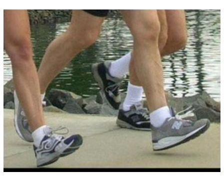
Predicting Longevity



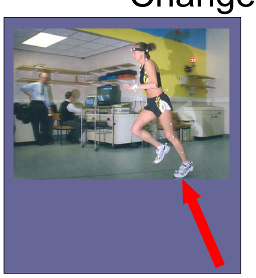
- Longevity predicted based upon decrease of VO_{2max} (Booth, 1989).

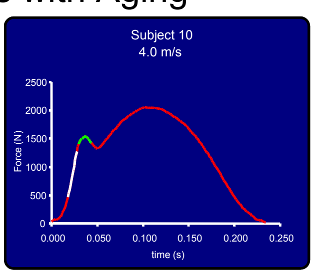
Changes with Aging

- Capacity to absorb landing forces
- Capacity to attenuate landing forces
- Capacity to absorb impact energy



Changes with Aging





- The body has to manage the impact while also generating the right amount of force to generate the next stride.

Changes with Aging

- Capacity to absorb impact energy
  - Do elite runners damage skeletal muscle in such a way that they cannot be competitive at an older age?
  - Noakes hypothesizes that high volume and intensity can only be sustained for about 15 years.

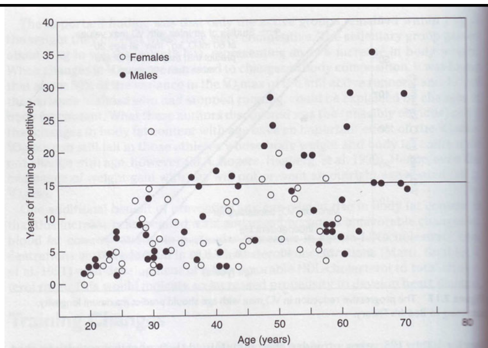
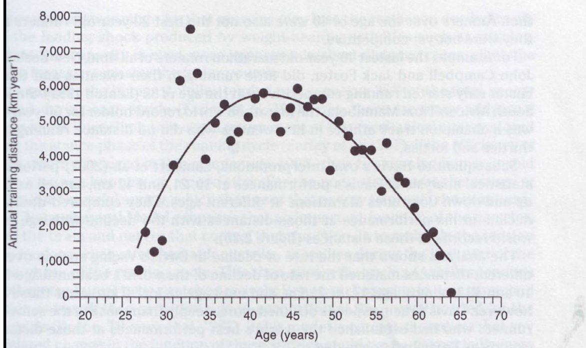


Figure 2.18 Number of years running for age-group record holders in a 56-km ultramarathon. Note that, with the exception of some runners older than 45 years, the majority of records are held by runners who have trained and raced for fewer than 15 years (horizontal line).
From M.I. Lambert and Keytel (2000, p. 30).

Changes with Aging

- Case study: Basil Davis
  - Completed 122 marathons
  - 34 Comrades marathons
  - 56 ultramarathons
- Training log
  - After age 45, his marathon performance deteriorated at a fast rate.
  - After age 50, he recorded he always “seems to be stiff.”
  - In later years, he could not predict his marathon time based on his 10K time.



e 2.19 Annual training distance (km per year) for Basil Davis between ages 27 and 64.
M.I. Lambert, Bryer, et al. (2002).

Changes with Aging

- Does "wear and tear" accumulate over time?
- Is there a breakdown of the elastic behavior of the lower extremity?
- Biomechanical Model (Muscle Power Model):
  - Muscle contraction is important to maintain the tension on the connective tissue.
  - Is exhaustion (at any age) a simulation of aging?
  - Is "hitting the wall" a function of the breakdown of elastic tissue?
- Noakes hypothesizes that when the shock absorbing mechanisms are damaged the central governor will force the body to run at a slower pace to protect the muscles and joints.

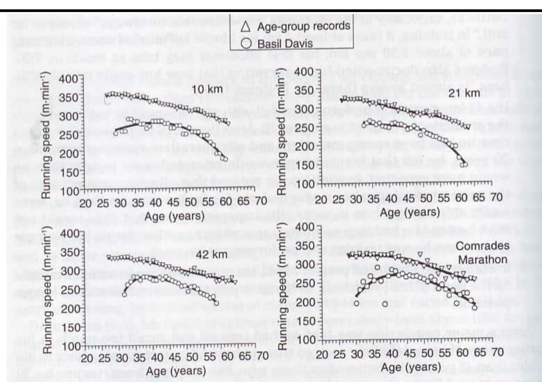


Figure 2.20 The average running speeds at 10, 21, and 42 km and at the Comrades Marathon (90 km) at different ages for Basil Davis (lower curves) compared to United States national age-group records for the shorter distances and the Comrades Marathon age-group records (upper curves).

Changes with Aging

- Decline in performance with aging may be due to accumulated miles.
- Evidence:
  - Sharwood et al. (2000)
    - 20 marathon and ultramarathon performers
    - Runners who accumulated more than 5000 km in racing used a different muscle recruitment strategy than those who raced less.

Changes with Aging

- Recovery
  - The ability to recover from intense exercise is impaired with aging.
- Chronic Orthopedic Disabilities
  - Runners get injured
  - Are older runners more susceptible to injuries?
- Ability to Adapt to Training
  - Aging does not seem to negatively influence adaptation to training
  - Volume and Intensity may be reduced with aging

Summary of Changes With Aging

- Reduction in VO_{2max}
- Muscular components
- Body composition
- Training changes
- Capacity to absorb landing forces
- Recovery
- Chronic orthopedic disabilities
- Ability to adapt to training