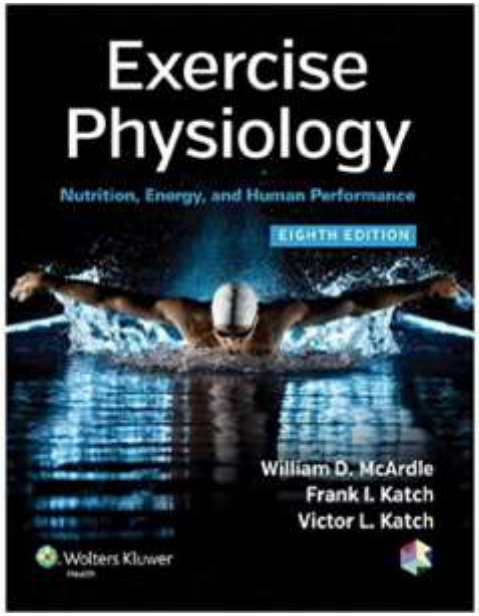
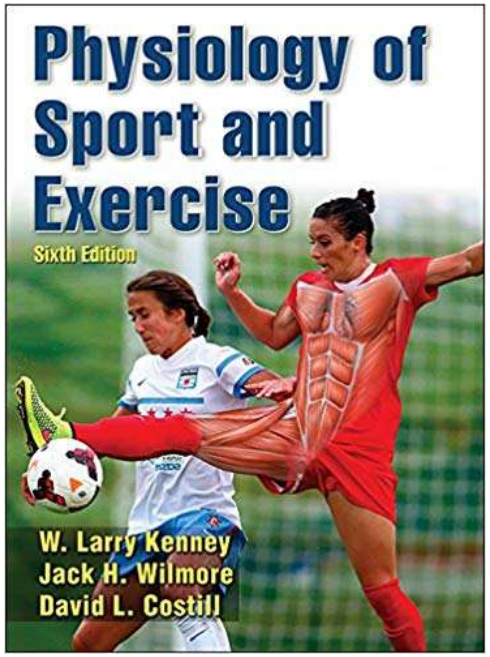
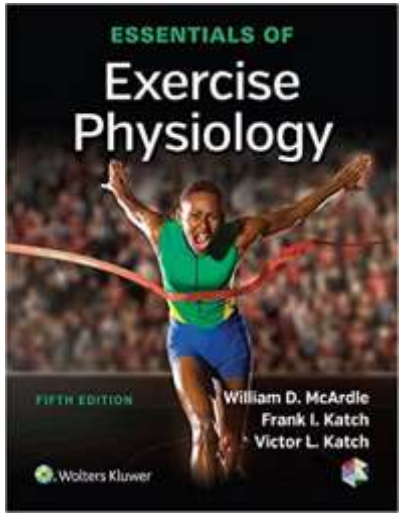
Unit 4: PHYSIOLOGY OF EXERCISE

Lecture# 01







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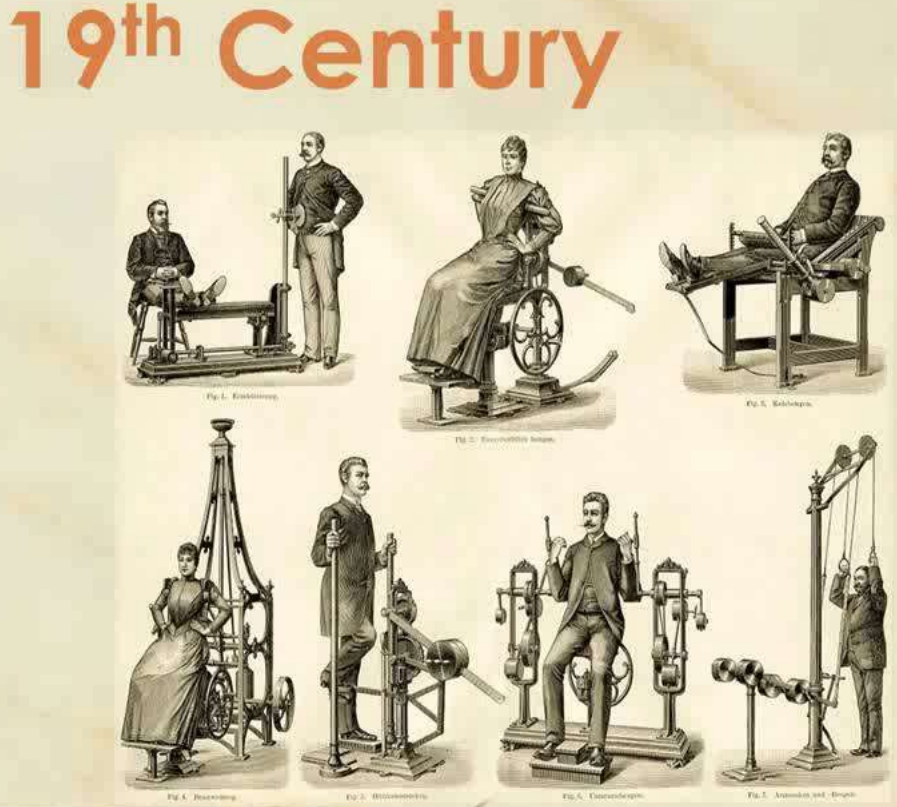
INTRODUCTION

Origins of exercise and Sports Physiology:

Historical Development & Background of Physiology and Sports Physiology.



The very, very beginning?

Cornelius Drebbel
1572-1633

Dutchman who built a submarine that rowed up the Thames in 1621 and stayed underwater for up to 3 hours. Probably used oxygen generated by burning potassium nitrate to keep rowers from becoming hypoxic during exercise.

Development of Exercise Physiology

Beginnings ..... ? - 1960

Era of Sports and Athletics..... 1960 - 1980

Era of Medical Awakening ..... 1970 - present

Present Status of Exercise Physiology
Research and Knowledge ..... 1990 - present

Brief History of Exercise Physiology

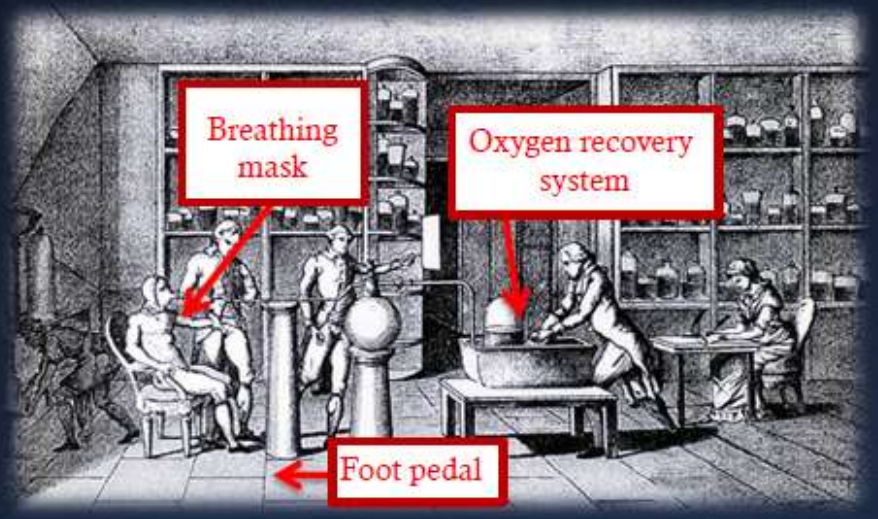
The history of exercise physiology represents a global perspective involving scientists from many different countries.

The development begin with the impact European scientists have had on the development of exercise physiology.

Numerous European scientists have had a major impact on the field of exercise physiology.

- Galen, one of the first “sports medicine” physicians
- Austin Flint, Jr., MD (1836–1915),
- Edward Hitchcock, Jr., (1828–1911),
- George Wells Fitz, MD (1860–1934,
- A.V. Hill
- Danis physiologist August Krogh (1874–1949)

First "laboratory exercise test"?



Antoine Lavoisier (1743-1794)

Measured increased consumption of "vital air" during sustained exercise

Photos and labels courtesy of Prof. Frank Katch

Field has evolved through findings of several different scientists

- 1700's Antonie Lavoisier
  Discovery that oxygen uptake increased with physical exertion

- Mid to late 1800's Fernand LaGrange—1st textbook
  The Physiology of Bodily Exercise

- 1879 Dudley Sargent
  Developed a physical fitness program at Harvard University based on individual prescription

- 1891 George Fitz
  - Exercise physiology laboratory created at Harvard. Courses in exercise physiology and laboratory research were instructed. This combination is continues today.
- 20th Century
  - Finding that muscle activity is powered by carbohydrate not heat (previously believed)
- 1900's prominent researchers traced to Europe
  - Founded 1954
- 1920 August Krogh, Danish physiologist
  - Studied muscle activity and blood flow, Noble Prize

August Krogh (1879-1949) Denmark

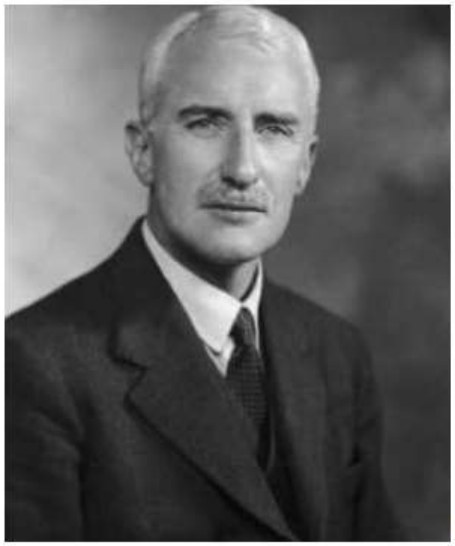
- Krogh established one of first exercise physiology laboratories
- Built accurate bicycle ergometer already by 1910
- Measured gas exchange (RER) during exercise of different intensities with great accuracy. Early forerunner to LT testing testing

In 1920's …

- Archibald Vivian Hill, British physiologist
  - Nobel Prize, studied muscle force and movement speeds
  - Pioneer in studying VO2 responses pre and post running
- John Haldane, European physiologist
  - Influential development of respiratory gas analyzer
  - Studied carbon dioxide on breathing regulation
- Otto Meyerhof, German physiologist
  - Shared Noble Prize with Hill
  - Conducted studies on energy metabolism

Early Exercise Physiologists

- **Archibald V. Hill Nobel Prize winner (1921)**
  - Studied energy metabolism in isolated frog muscle
  - Conducted first physiological studies on runners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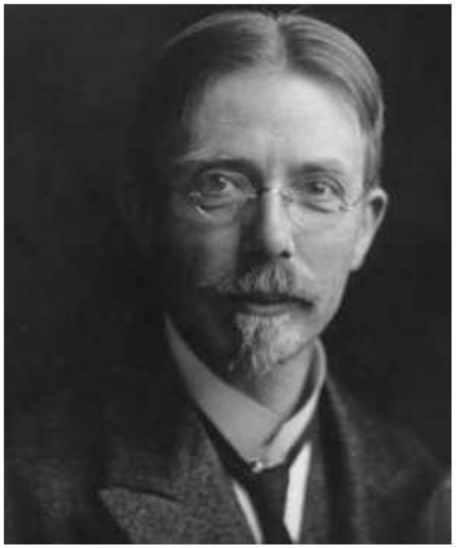

B


C

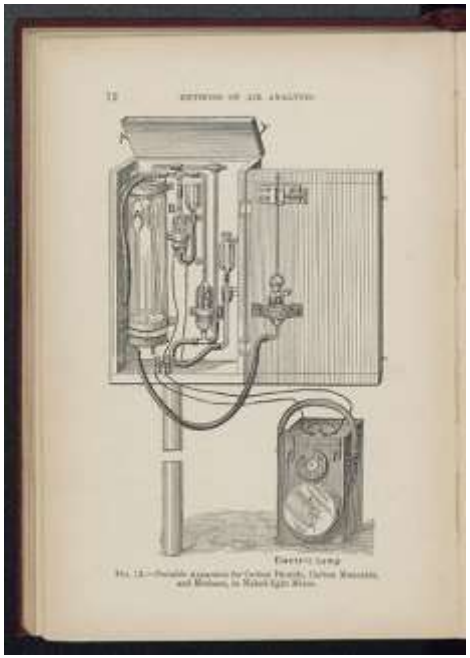
A. Archibald V. Hill, B. August Krogh, C. Otto F. Meyerhof

(A) © Lafayette/Hulton Archive/Getty Images; (B) © Underwood And Underwood/LIFE Images Collection/Getty Images; (C) © Ullstein Bild/Getty Images

■ **A. V. Hill, August Krogh, and Otto Meyerhof received the Nobel Prize for work related to muscle or muscular exercise.**

Early Exercise Physiologists

- **John S. Haldane**
  - Developed methods of measuring oxygen use during exercise
  - Known for his work in human physiology and respiration



Stroke volume comes into focus

"The stroke volume of the heart is….the most important quantitative function of the whole body…. ….for the amplitude of the heart's volume change multiplied by the pulse rate gives the total volume of arterial blood supplied to the entire body". Yandell Henderson, 1923 Yale University physiologist

$$Q = HR \times SV$$

The Harvard Fatigue Lab 1927-1947

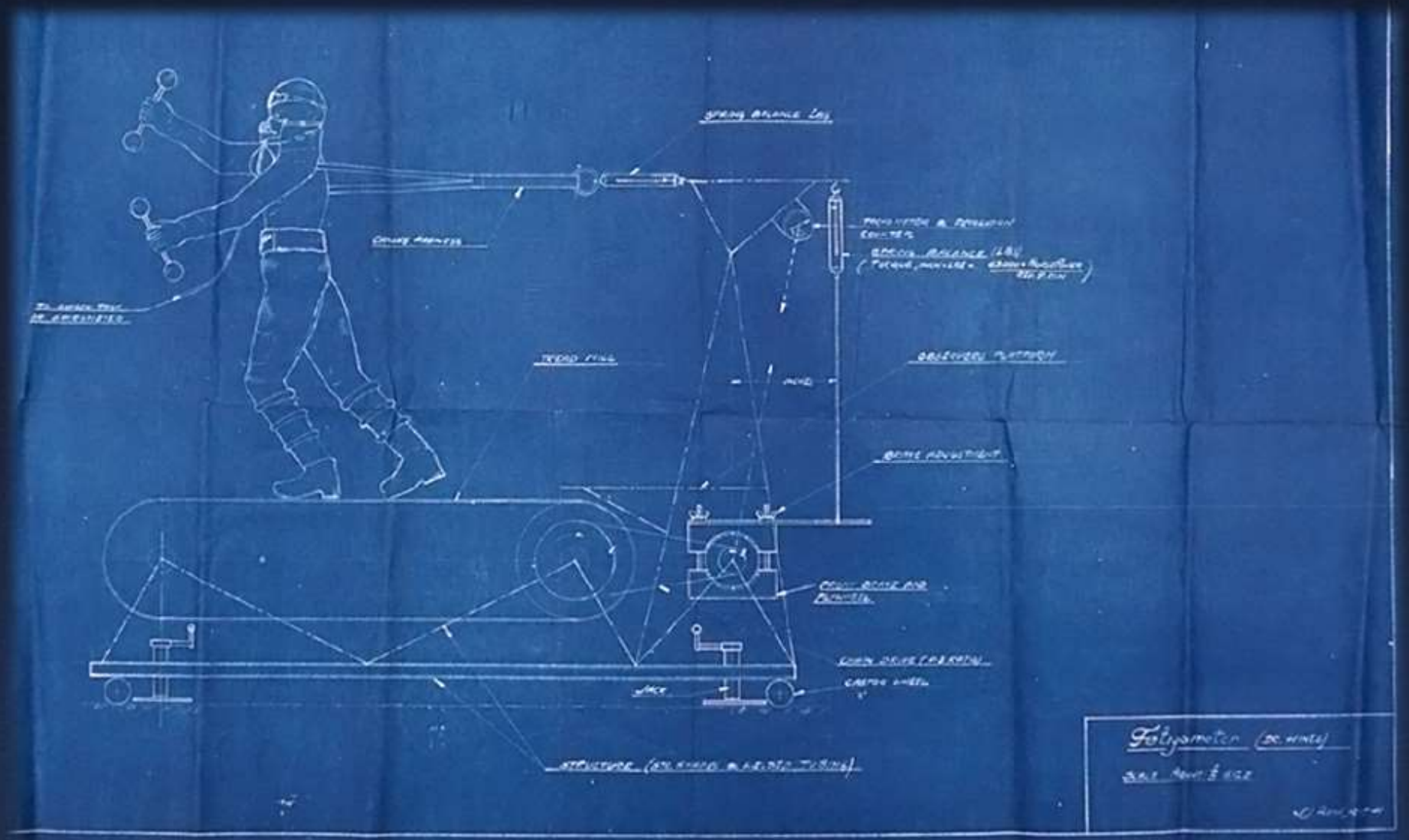
- Established by the Harvard Business School at a time when human factors in industrial factories was a major interest.
- Performed wartime research on nutrition and environmental factors.
- Exercise was one of several stresses such as heat and high altitude that were studied.
- Over 350 publications, but greatest contribution was a generation of "exercise physiologists" who built up research programs all over the United States and Europe.

David Bruce Dill

The Harvard Fatigue Laboratory

- Founded by biochemist Lawrence J. Henderson
- The Harvard Fatigue Laboratory was a focal point in the development of exercise physiology in the United States.
- Dr. D. B. Dill directed the laboratory from its opening in 1927 until its closing in 1947.
- Focused on the physiology of human movement and the effects of environmental stress on exercise
- Most contemporary exercise physiologists can trace their roots back to the Harvard Fatigue Laboratory.

"Fatigometer"
Harvard Fatigue Lab



The Harvard Fatigue Laboratory: Early Measurements

- **Collected expired air in a sealed bag known as a Douglas bag**
- **A sample of the gas from the Douglas bag was then measured for oxygen and carbon dioxide using a chemical gas analyzer.**

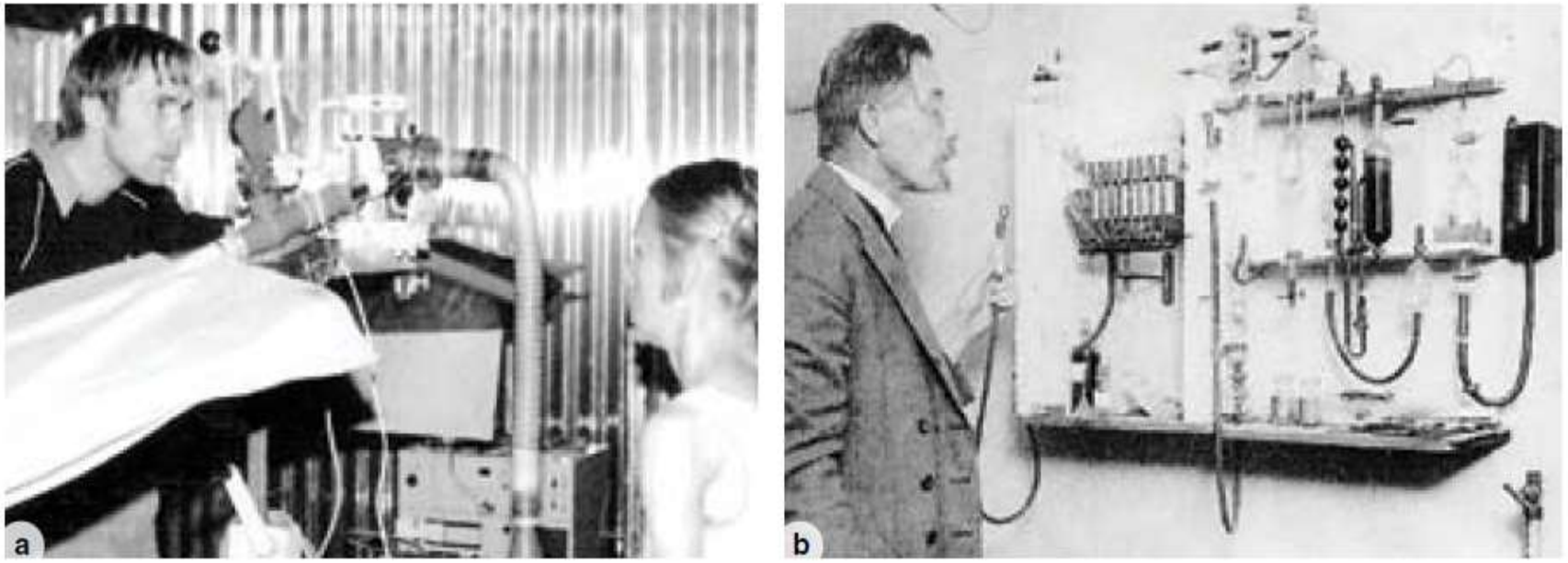


FIGURE 0.2 (*a*) Early measurements of metabolic responses to exercise required the collection of expired air in a sealed bag known as a Douglas bag. (*b*) A sample of that gas then was measured for oxygen and carbon dioxide using a chemical gas analyzer, as illustrated by this photo of Nobel laureate August Krogh.

1927 David B. Dill, biochemist from Stanford Founded

- Harvard Fatigue Laboratory, legendary accomplishments in exercise physiology.
- Studied the physiological, psychological, sociological factors with manual work.
- Research in metabolic responses to exercise, environmental stress, aging induced changes, blood-gas and acid-base chemistry
- Remained open for 20 years
- Fundamental in the spread of the field along with many European researchers

Dr. David Bruce (D.B.) Dill (*a*) at the beginning of his career; (*b*) as director of the Harvard Fatigue Laboratory at age 42; and (*c*) at age 92 just prior to his fourth retirement.

Same timeline as Harvard Fatigue Laboratory European researchers:

- Erik Howhu-Christensen
  - One of 1st researchers to study fuel patterns during exercise
  - Became faculty at Gymnastik-och Idrottshogskolan in Stockholm and mentor to many great researchers
- Per-Olof Astrand,
  - The Textbook of Work Physiology
  - Astrand-Rhyming Submaximal Exercise Test
- Ehrling Asmussen and Marius Nielsen
  - Joined faculty University of Copenhagen
  - Asmussen focus was exercise and muscle function
  - Nielsen studied temperature regulation with exercise in hot and cold environments
- Bengt Saltin
  - Leading contemporary exercise physiologists

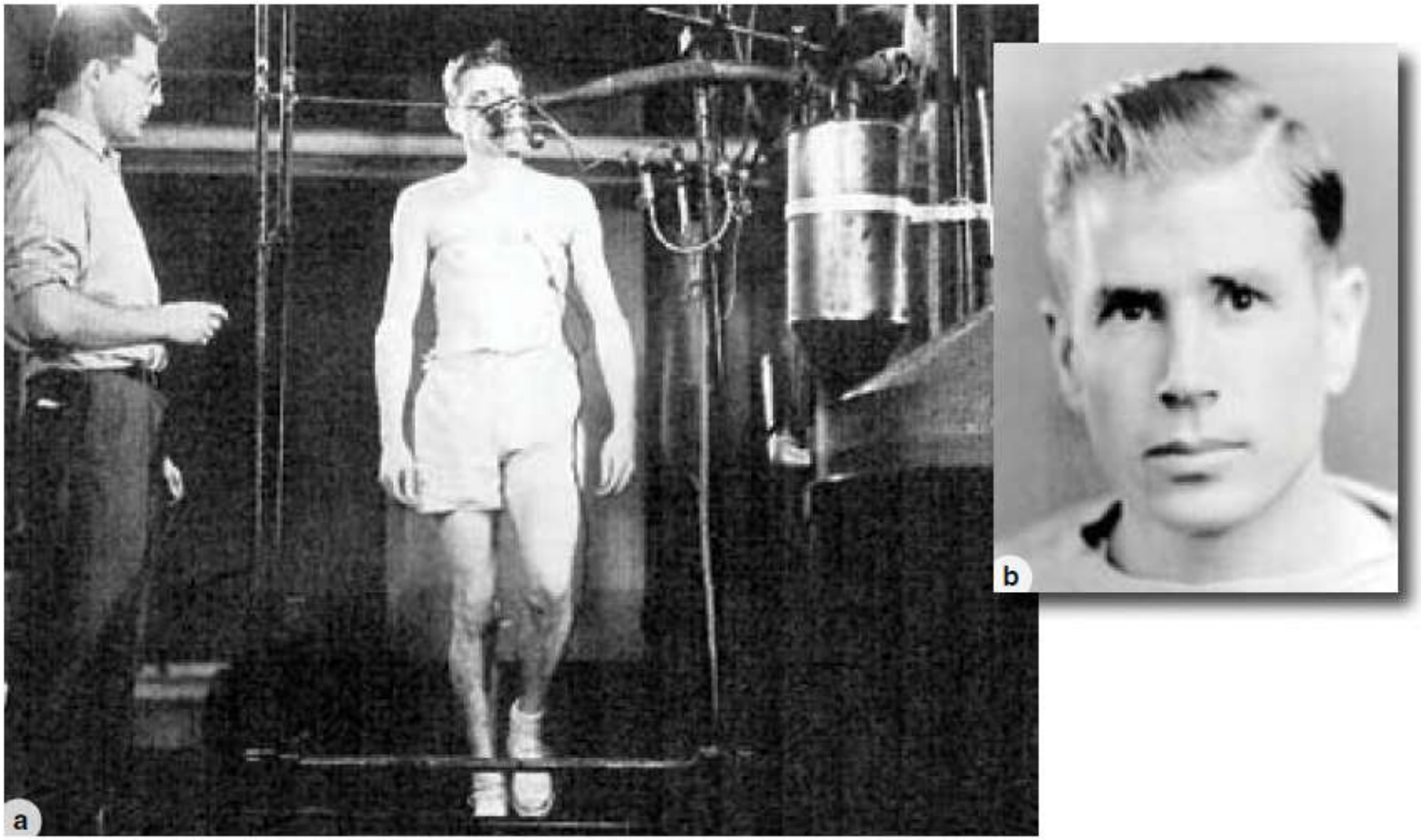


FIGURE 0.1 (*a*) Sid Robinson being tested by R.E. Johnson on the treadmill in the Harvard Fatigue Laboratory and (*b*) as a Harvard student and athlete in 1938.

”The VO2max” is born (1923-25)

Archibald Vivian (AV) Hill
1886-1977

Demonstrated that oxygen uptake increased linearly with running speed, but eventually….”*reaches a maximum beyond which no effort can drive it.*”

Connecting cardio-pulmonary function to muscular work

"….the lungs, heart and circulation should be thought of as a single apparatus for the transfer of oxygen and carbon dioxide between the atmosphere and the working tissues."

Lawrence J. Henderson, 1929
founder of the Harvard Fatigue Laboratory

In 1950's ….

- American College of Sports Medicine
  - 1954 held first scientific meeting
  - Goal was to expand the knowledge of exercise responses in humans
- Atherosclerosis
  - Evidence from the Korean War that young male casualties showed evidence of coronary artery disease
  - CVD problems were thought linked to aging, findings revealed that disease develops early in life

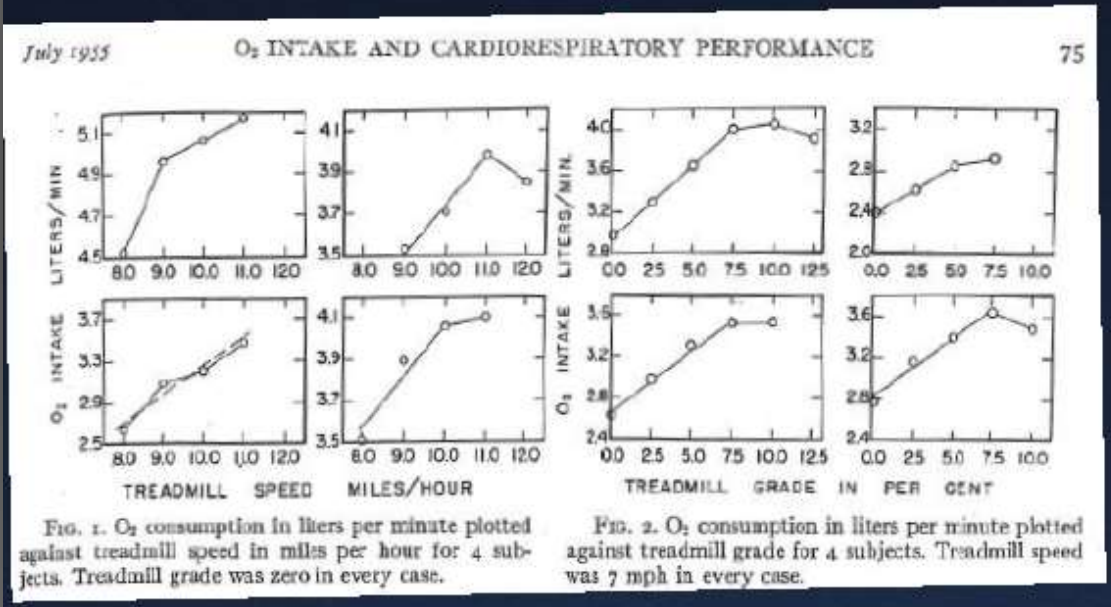
VO2max testing becomes standardized- 1955

Laboratory of Physiological Hygiene, University of Minnesota. USA

"During the Second World War, this laboratory studied the relationships between performance in its broadest sense and biological stress."

Taylor, HL, Buskirk, E. and Henschel, A. Maximal oxygen intake as an objective measure of the cardiorespiratory performance. *J. Applied Physiology* 8:73-80, 1955.

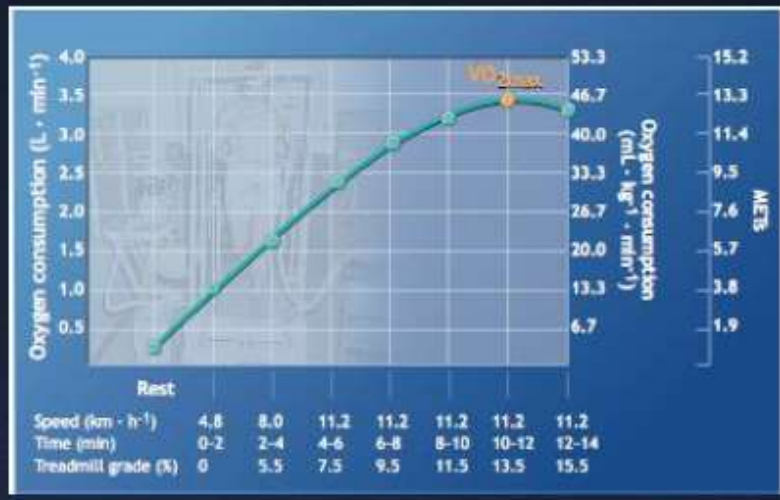
Taylor et al. findings:



July 1955 — O_2 INTAKE AND CARDIORESPIRATORY PERFORMANCE — 75

FIG. 1. O_2 consumption in liters per minute plotted against treadmill speed in miles per hour for 4 subjects. Treadmill grade was zero in every case.

FIG. 2. O_2 consumption in liters per minute plotted against treadmill grade for 4 subjects. Treadmill speed was 7 mph in every case.



- Mouthpiece diameter- limitations on ventilation
- Speed vs grade changes for eliciting VO_2 plateau on treadmill
- Importance of warm-up
- Temperature conditions- Not too hot
- Test-retest reliability- Standard error of ~2.5%
- Criteria for identification of a plateau in VO_2

Era of Sports and Athletics. 1960 - 1980

Research progressed to applied questions that concerned exercise.

- Diet, exercise and muscle glycogen
- Metabolic demands of differing exercise intensities
- Determinants of exercise performance
- Effects of training on function and performance
- Exercise in various environmental conditions
- What strategies delay fatigue?

The Swedish Influence

nadig Intro 58. P-O. Astrand, Department of Physiology, Karolinska Institute, Stockholm. A. Measuring maximal performance of Johnny Nilsson, Olympic Gold Medal speed skater, 1964. B. Maximal oxygen consumption measured during cycle ergometer exercise, 1958. C. Laboratory experiment, 1955. D. Invited lecture, 1992 International Conference on Physical Activity, Fitness and Health, Toronto.

- GIH- Gymnastik och idrettshögskolan (founded 1813)
- Karolinska Institute (founded 1810)
- Integrated physiological and performance focus; dozens of classic studies published

Photo courtesy of Prof. Frank Katch

Scandinavian Influence

- **Eric Hohwü-Christensen**
  - In the late 1930s, published an important series of five research studies on carbohydrate and fat metabolism
- **Per-Olof Åstrand**
  - During the 1950s and 1960s, conducted studies on physical fitness and endurance capacity
- **Jonas Bergstrom**
  - Reintroduced the biopsy needle in 1966 to study human muscle biochemistry

Scandinavian Exercise Physiologists

Eric Hohwü-Christensen

Bengt Saltin

Jonas Bergstrom (left) and Eric Hultman (right)

FIGURE 0.3 (*a*) Erik Hohwü-Christensen was the first physiology professor at the College of Physical Education at Gymnastik-och Idrottshögskolan in Stockholm, Sweden. (*b*) Bengt Saltin, winner of the 2002 Olympic Prize. (*c*) Jonas Bergstrom (left) and Eric Hultman (right) were the first to use muscle biopsy to study muscle glycogen use and restoration before, during, and after exercise.

Photos courtesy of the authors.

Jack Daniels testing runner on the track at altitude in Colorado, 1967

BENGT SALTIN in Mexico City: Exercise Physiology in the early 70s:

Era of Medical Awakening, 1970 - present

Contemporary Exercise Physiologists

- **John Holloszy and Charles Tipton**
  - Introduced biochemical approach to exercise physiology research
  - First to use rats and mice to study muscle metabolism and fatigue
- **Reggie Edgerton, Phil Gollnick, and Bengt Saltin**
  - Studied individual muscle fiber characteristics and their responses to training in rats and humans

Per Åstrand & Bengt Saltin

Scientific Citations as of Nov 2011*

Åstrand: 140+ publications
>6,000 citations
H factor 35

Saltin: 340+ publications
>21,000 citations
H factor 76

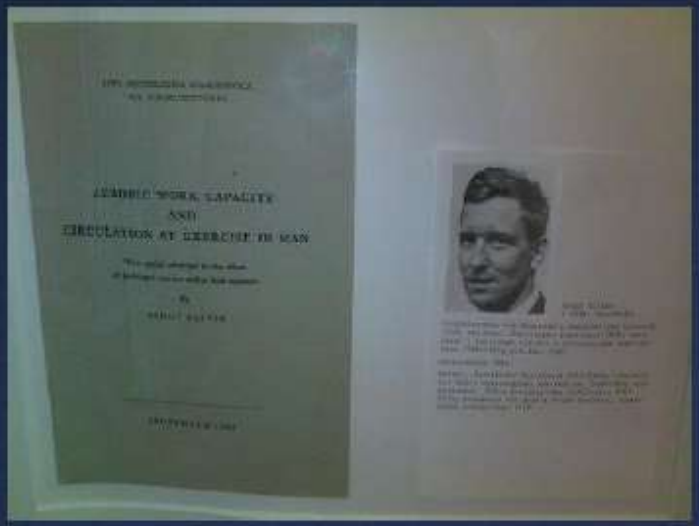
Photos provided courtesy of Prof. Frank Katch

The Åstrand laboratory

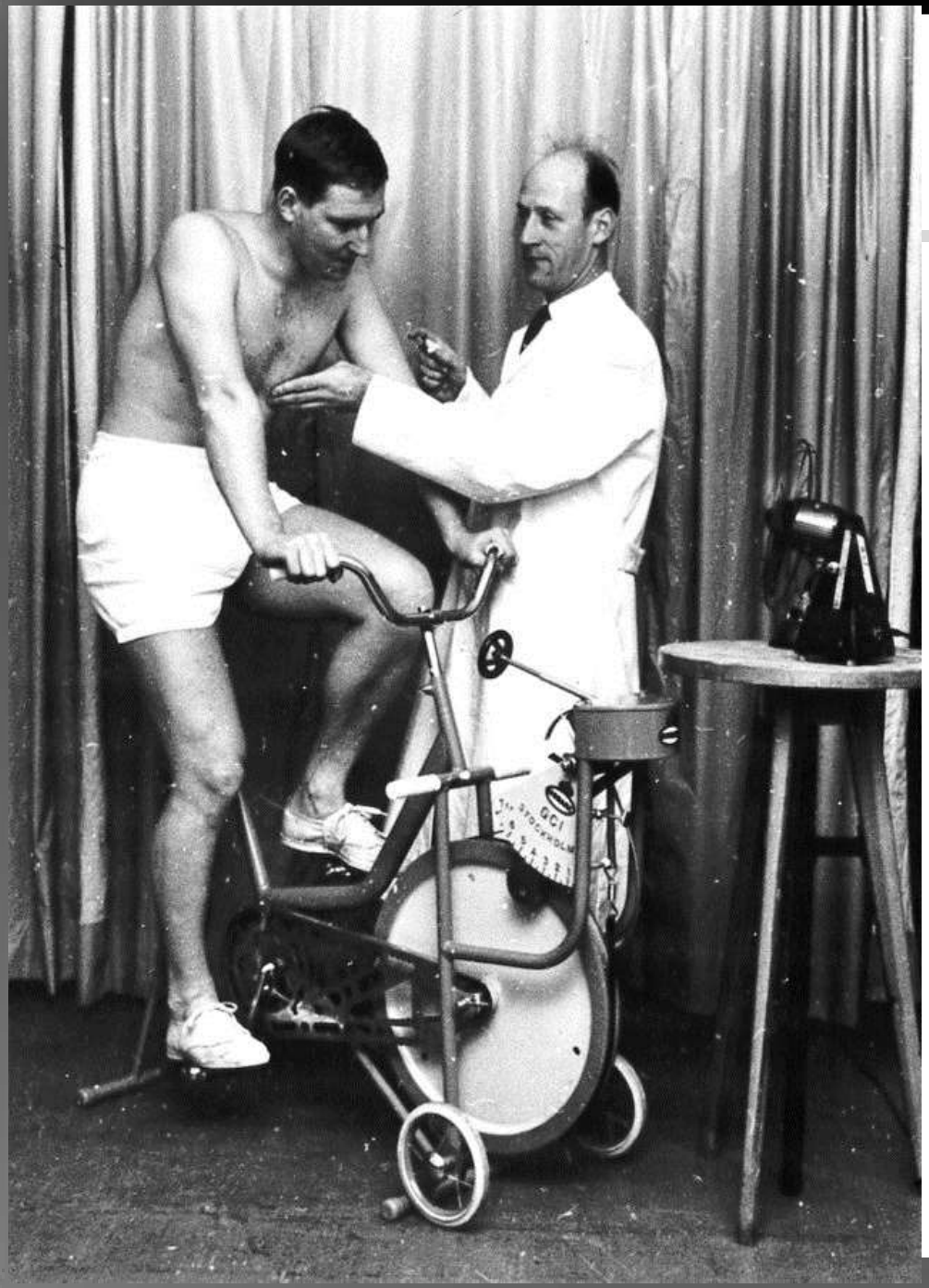
The treadmill used in early studies

The very first Monark cycle ergometer

Scholander apparatus for measuring oxygen concentration in gas samples



A picture of the front cover of Bengt Saltin's doctoral dissertation. He was Åstrand's first PhD student.



The tutor, Per-Olof Åstrand, and the doctoral student, Bengt Saltin, sitting on the Monark ergometer cycle, an invention by Wilhelm von Döbeln, who worked at the department.

TABLE 2. *Maximal values for oxygen uptake, heart rate, pulmonary ventilation, and lactic acid in 100 ml of blood obtained in various types of muscular activity*

	Cycling, Legs	Cycling, Arms + Legs	Running	Skiing*	Cycling in Supine Position, Legs	Swimming*	Cycling, Arms
Subject 1, ♂							
Max. $\dot{V}O_2$, l.	4.19	4.20	4.23	4.12	3.73	3.94	2.87
Max. HR	192	188	194	194	185	182	188
Max. $\dot{V}_E$, l.	157.1	136.8	141.5	133.5	117.5	132.4	109.8
Max. HLa	175	160	195	140	140	130	130
Subject 2, ♂							
Max. $\dot{V}O_2$, l.	4.49	4.51	4.82	4.78†	3.99	4.26	3.16
Max. HR	192	185	189	192†	179	182	169
Max. $\dot{V}_E$, l.	181.6	150.0	153.4	133.8†	126.6	138.7	125.2
Max. HLa	175	150	195	100†	160	125	130
Subject 3, ♂							
Max. $\dot{V}O_2$, l.	4.24	4.24	4.59	4.33	3.52	3.73	
Max. HR	190	190	192	194	179		
Max. $\dot{V}_E$, l.	154.7	134.6	156.4	135.8	110.9	134.7	
Max. HLa	160	120	170	125	115	95	
Subject 4, ♂							
Max. $\dot{V}O_2$, l.	5.30	5.39	5.63	5.43	4.56	4.65	3.78
Max. HR	185	188	180	183	174	182	174
Max. $\dot{V}_E$, l.	183.4	173.0	170.0	170.4	145.5	130.0	132.9
Max. HLa	170	150	170	140	130	95	125
Subject 5, ♀							
Max. $\dot{V}O_2$, l.	3.01	3.05					
Max. HR	185	185					
Max. $\dot{V}_E$, l.	104.6	93					
Max. HLa	135	115					
Subject 6, ♂							
Max. $\dot{V}O_2$, l.	4.15	4.06	4.19	4.10	3.46	3.01	
Max. HR	194	197	192	200	190	182	
Max. $\dot{V}_E$, l.	117.7	122.7	134.8	137.1	99.3	80.4	
Max. HLa	165	145	175	165	125	86	
Subject 7, ♂							
Max. $\dot{V}O_2$, l.	3.81			4.14		3.17	
Max. HR	192					182	
Max. $\dot{V}_E$, l.	144.3			147.5		102.4	
Max. HLa	145			115		135	

PO Åstrand & Bengt Saltin
Maximal oxygen uptake and heart rate
In various types of muscular activity
J. Appl. Physiol. 16(6):977-981, 1961

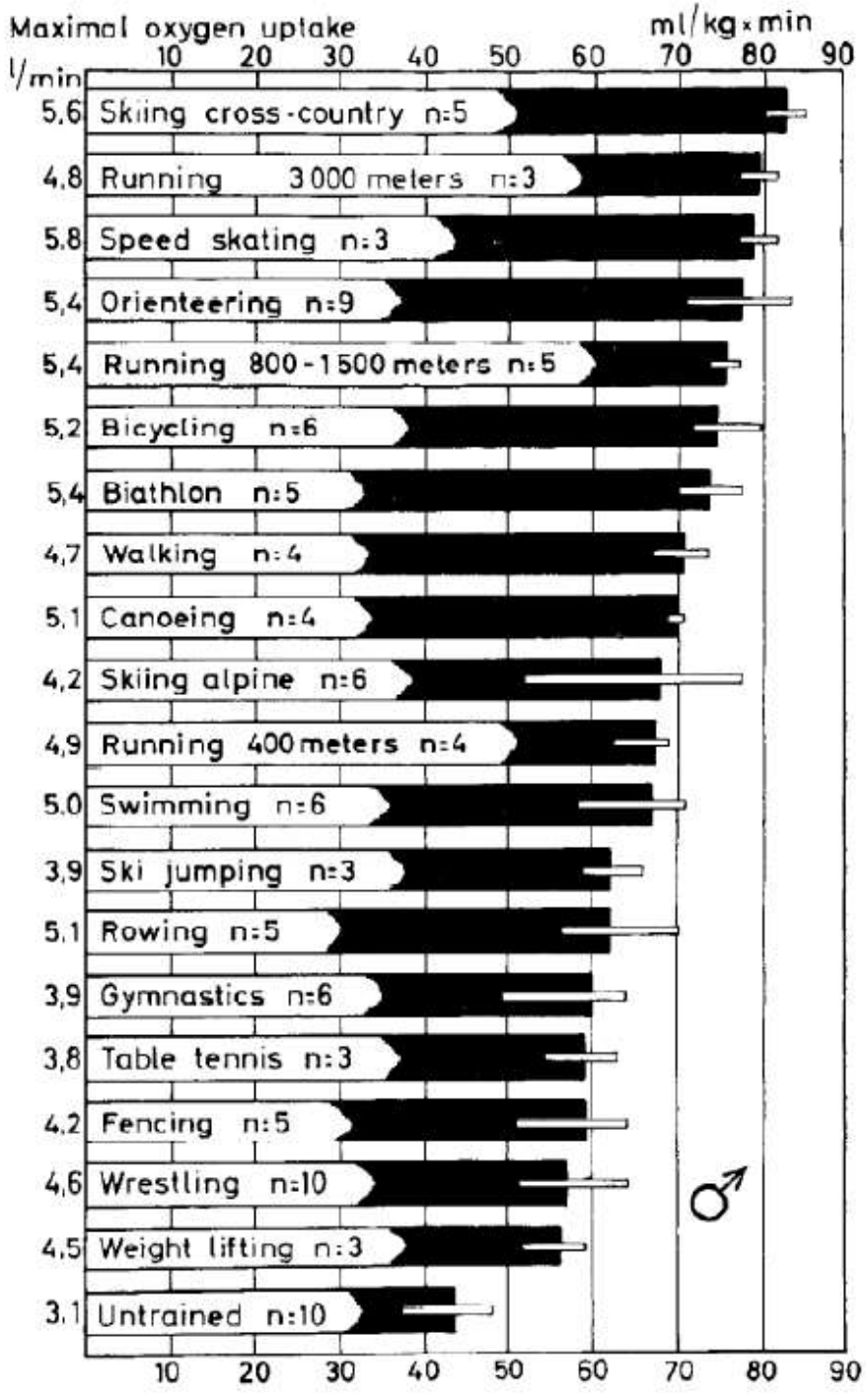
Demonstrated that running was sufficient to elicit the maximal oxygen consumption

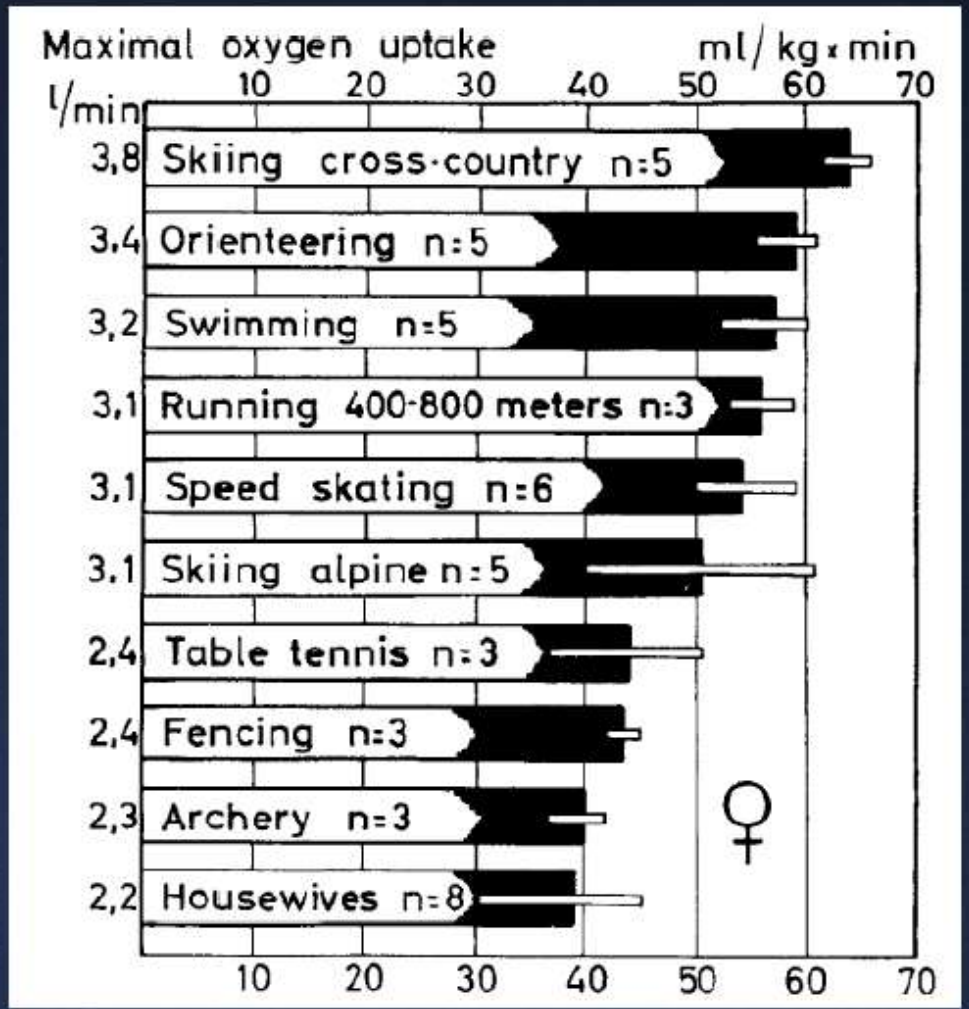
Arms + legs did not further increase VO_2

Swimming or arms-only activity was insufficient to elicit VO2max

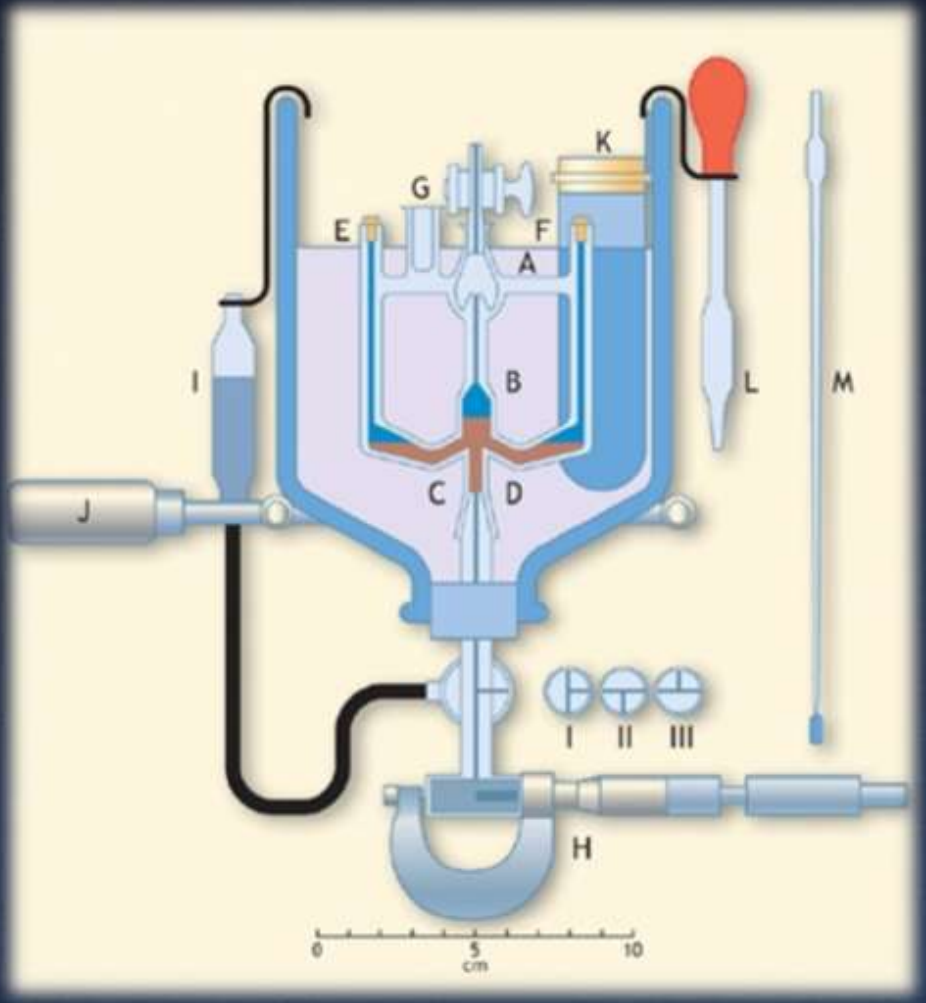
VO_2 peak concept born?

Saltin B & Åstrand PO. Maximal oxygen uptake in athletes. J. Appl. Physiol. 23(3), 1967.





Most important Norwegian contribution to endurance testing?



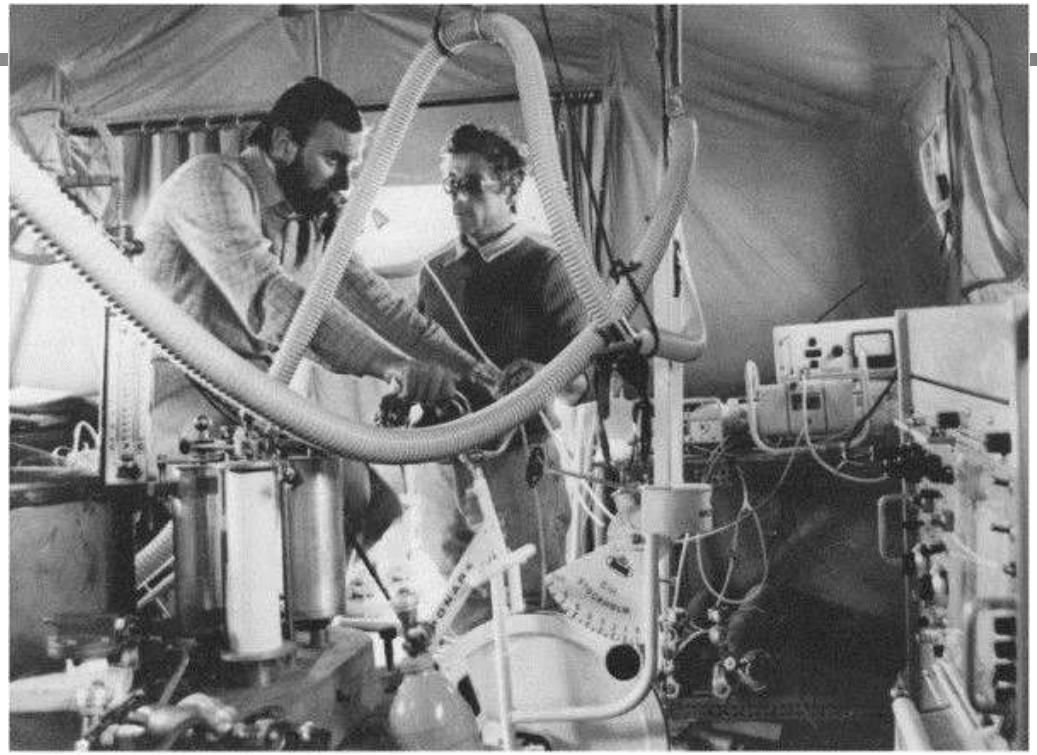
PF Scholander. Analyzer for accurate estimating of respiratory gasses in one-half cubic centimeter samples. *J. Biol. Chem.* 167:235-2359, 1947.

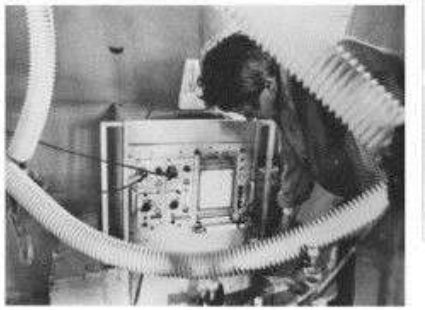
Figure above from McArdle, Katch, & Katch, Exercise Physiology. 7th ed.

Contemporary Exercise Physiologists

FIGURE 0.4 (*a*) John Holloszy was the winner of the 2000 Olympic Prize for scientific contributions in the field of exercise science. (*b*) Charles Tipton was a professor at the University of Iowa and the University of Arizona, and a mentor to many students who have become the leaders in molecular biology and genomics. (*c*) Phil Gollnick conducted muscle and biochemical research at Washington State University.

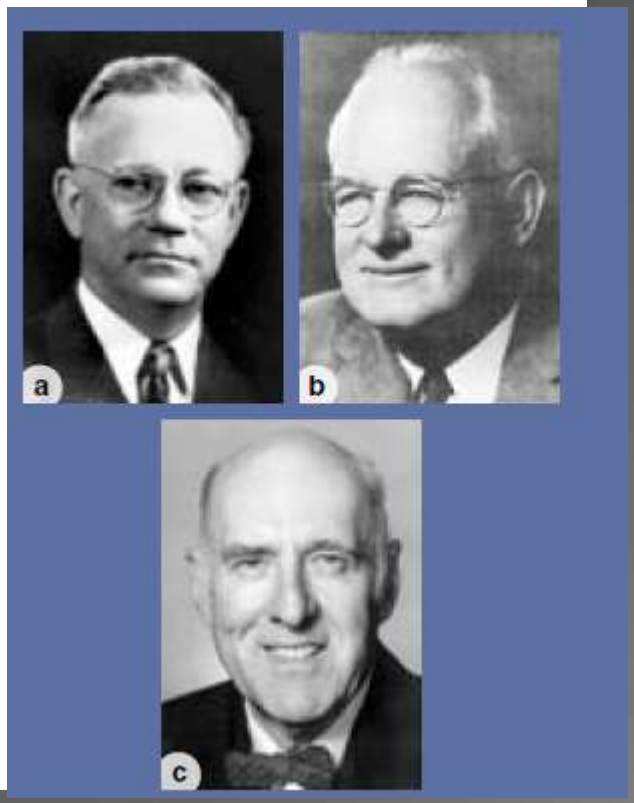
Exercise laboratory at the base camp. A bicycle ergometer, spirometers, gas analyzers, and electronic recorders are visible.





Exercise Physiology Milestones

- **Peter Karpovich,** Springfield College
  - Helped introduce exercise physiology to physical education
- **Thomas K. Cureton,** University of Illinois
  - Helped support a rationale for using exercise to promote a healthy lifestyle
  - Directed the exercise physiology laboratory at university of Illlnols at Urbana-Champaign from 1941to 1971.
- **Elsworth Buskirk,** Penn State University
  - Founded an intercollege graduate program focusing on applied physiology in 1966.
  - Established The Laboratory for Human Performance Research in 1974.



Women in Exercise Physiology

- **Birgitta Essen**
  - In 1954, Irma Rhyming collaborated with her future husband, P.-O. Åstrand, to publish a classic study that provided a means to predict aerobic capacity from submaximal heart rate
  - Collaborated with Bengt Saltin and Phil Gollnick in publishing the earliest studies on human muscle fiber types
- **Karen Piehl**
  - In the 1970s, two Swedish women, Birgitta Essen and Karen Piehl, gained international attention for their research on human muscle fiber composition and function
  - Among the first to demonstrate that the nervous system selectively recruits type I and type II fibers

- **Barbara Drinkwater**
  - In the 1970s and 1980s, a third Scandinavian female physiologist, Bodil Nielsen, daughter of Marius Nielsen, actively conducted studies on human responses to environmental heat stress and dehydration.
  - Among the first to address issues specifically related to the female athlete

(*a*) Birgitta Essen collaborated with Bengt Saltin and Phil Gollnick in publishing the earliest studies on muscle fiber types in human muscle. (*b*) Karen Piehl was among the first physiologists to demonstrate that the nervous system selectively recruits type I (slow-twitch) and type II (fast-twitch) fibers during exercise of differing intensities. (*c*) Barbara Drinkwater was among the first to conduct studies on female athletes and to address issues specifically related to the female athlete.

Exercise Physiology Beyond Earth's Boundaries

An important segment of exercise physiology concerns the response and adaptation of people to extremes of heat, cold, depth, and altitude. Understanding and controlling the physiological stresses and adaptations that occur at these environmental limits have contributed directly to notable societal achievements such as construction of the Brooklyn Bridge, the Hoover Dam, pressurized aircraft, and underwater habitats for the commercial diving industry.

The next generation of environmental challenges will also require such physiological expertise. In January 2004, President George Bush announced the Vision for Space Exploration, a strategy to first return humans to the moon, then send explorers to the planet Mars, over the next 30 years. This ambitious plan to construct permanent human outposts on the moon beginning in 2017, followed by 2.5- year missions to the planet Mars, will require effective countermeasures to minimize the physiological changes that put space explorers at risk.

Dr. James A. Pawelczyk.

NASA & Exercise Physiology

Present Status of Exercise Research and Knowledge …….. 1990 - present

- Role of exercise in supporting body functions in microgravity

- Exercise in special populations: disabled, elderly, children, pregnant women, etc.

- Development of new equipment, technologies and techniques: stable isotopes (substrate use and cellular metabolism); magnetic resonance imaging and spectroscopy (muscle metabolism and blood flow)

Early connections between exercise and lactic acid

- Swedish chemist Berzelius detected blood lactate in "exercised" deer (1808).
- Englishman AV Hill connected lactic acid production to muscle contraction (1922).
- German Otto Meyerhoff associated increase in lactate concentration with muscle fatigue in frog muscle (1922).
- Margaria and Dill – Formulated oxygen debt hypothesis (1933).
- O. Bang- Showed that lactate production and removal were continuous (1936).
- Norwegian Lars Hermansen (1972). Explained lactate appearance and removal responses.

THE POSSIBLE MECHANISMS OF CONTRACTING AND PAYING THE OXYGEN DEBT AND THE RÔLE OF LACTIC ACID IN MUSCULAR CONTRACTION[1]

R. MARGARIA,[2] H. T. EDWARDS AND D. B. DILL

From the Fatigue Laboratory, Morgan Hall, Harvard University, Boston

1933

R. Margaria

David Dill and Harry Edwards in Panama

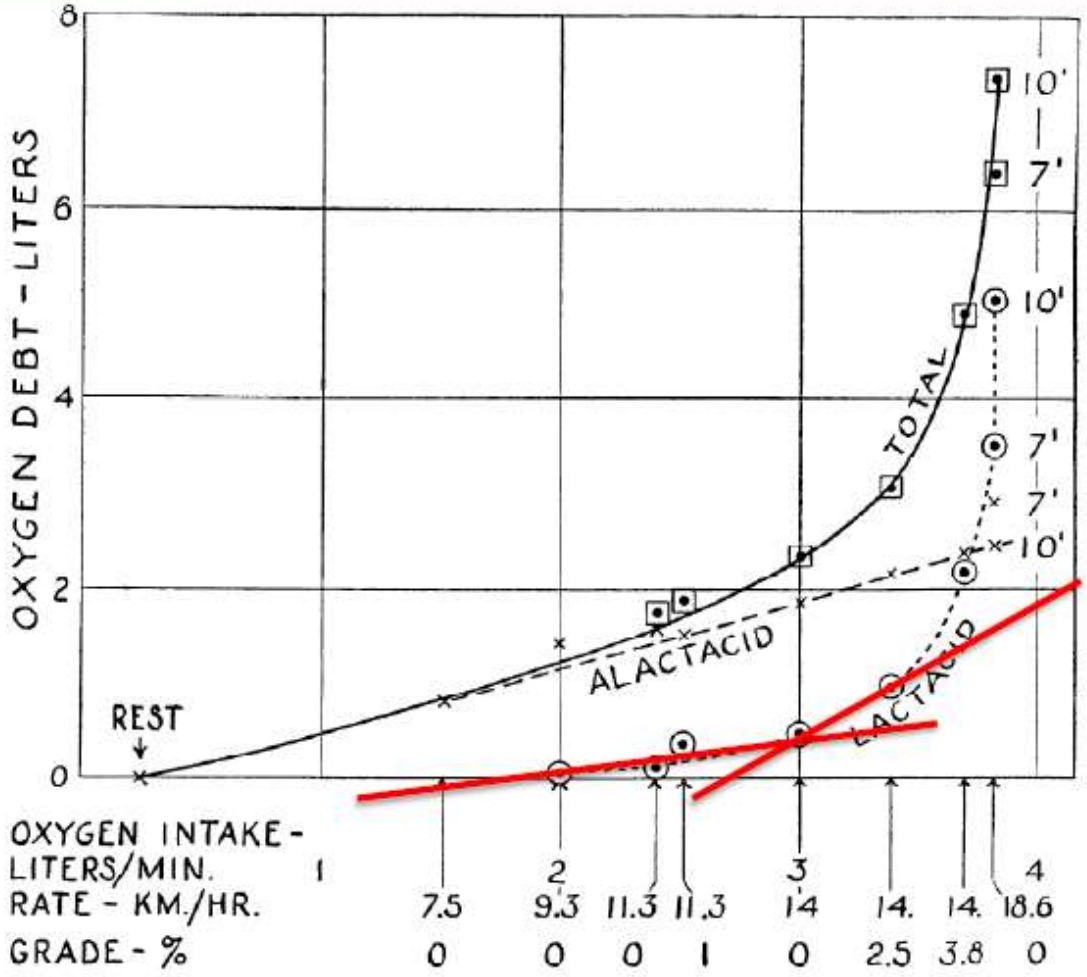
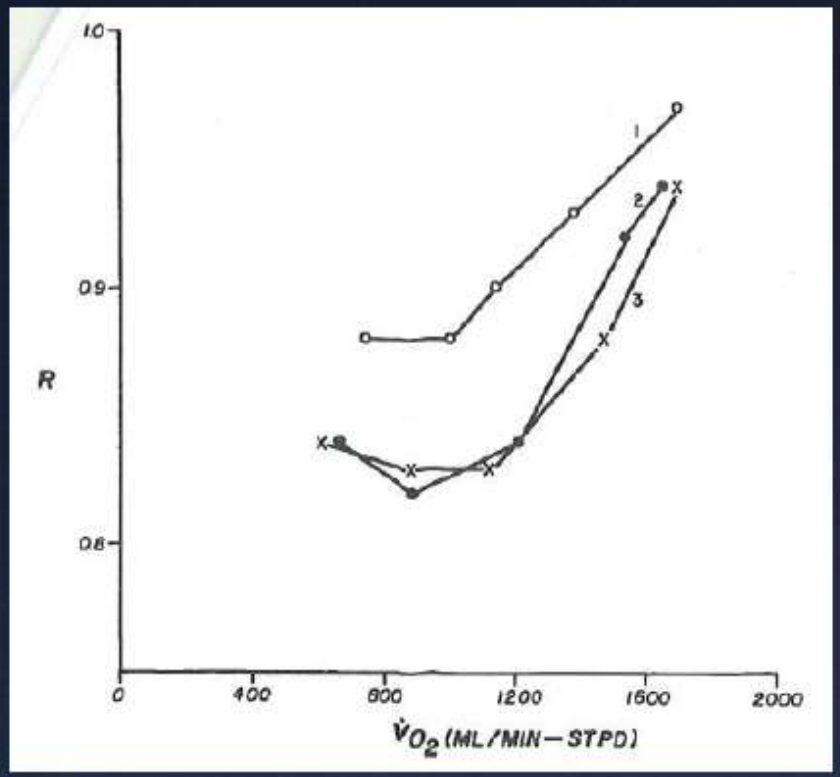
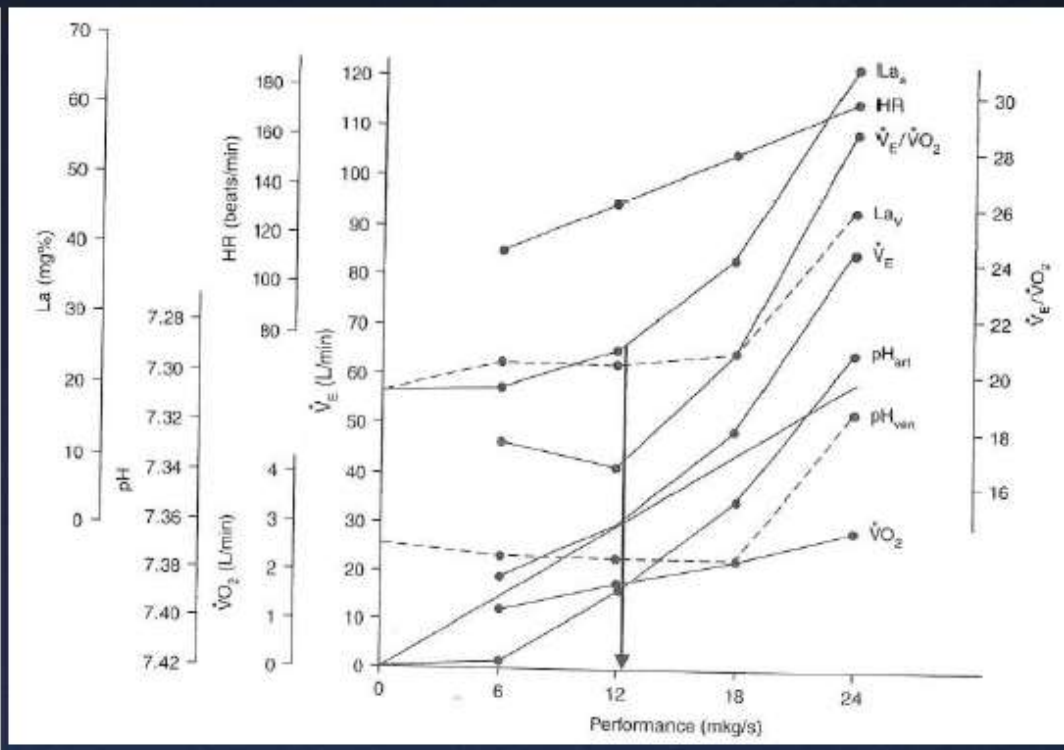


Fig. 3. Amounts of alactacid and of lactacid oxygen debts as a function of the metabolic rate: subject Clapham: from protocols 1 to 9.

Lactate seen as a metabolic dead end produced only under tissue hypoxia. This view would live on into the 80s.

Who invented the "anaerobic"/lactate threshold test?





Karlmann Wasserman, 1964?

Wildor Hollmann, 1959
(unpublished congress presentation)

Threshold yes, but *anaerobic*?

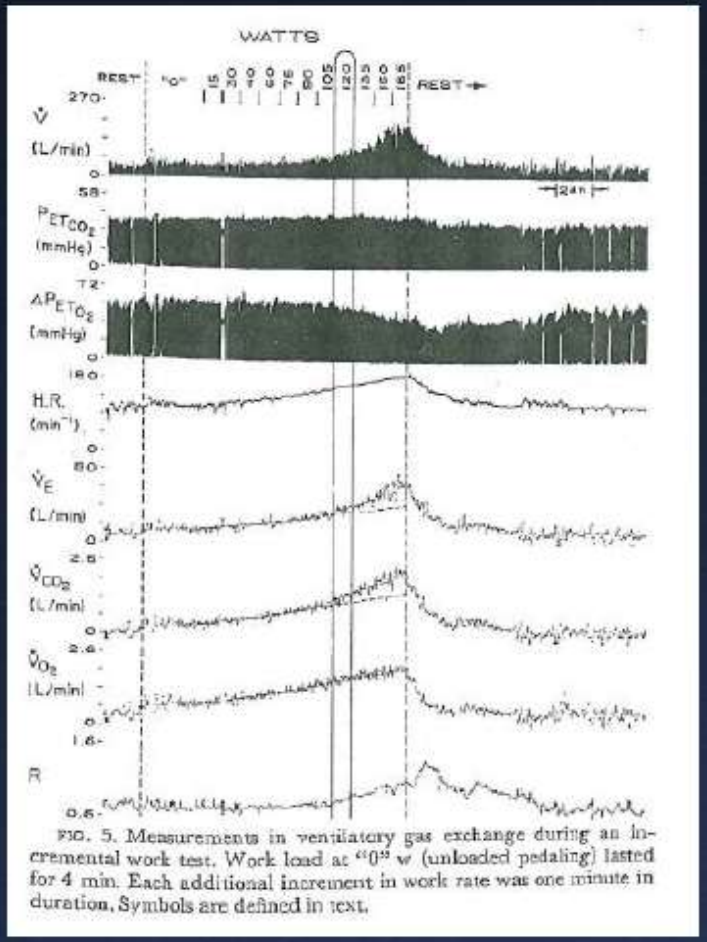
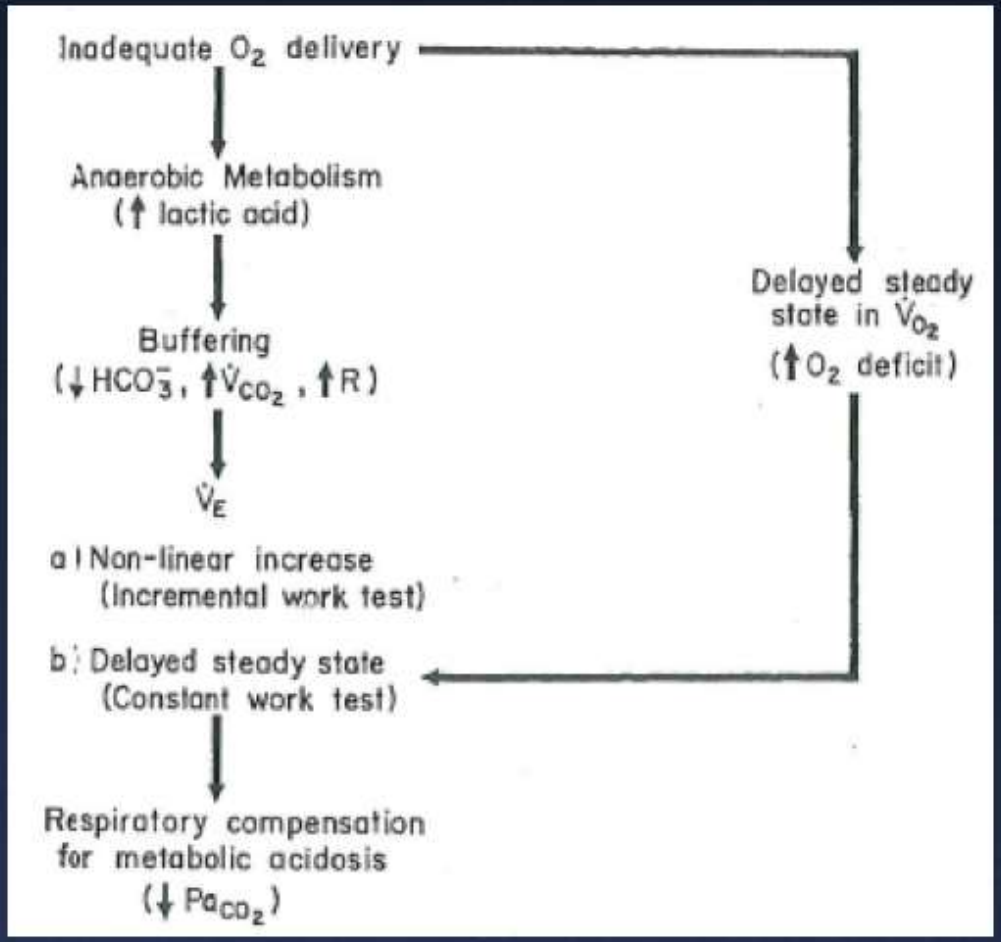


FIG. 5. Measurements in ventilatory gas exchange during an incremental work test. Work load at "0" w (unloaded pedaling) lasted for 4 min. Each additional increment in work rate was one minute in duration. Symbols are defined in text.



Wasserman, K, Whipp BJ, Koyal, SN, Beaver WL. Anaerobic threshold and respiratory Gas exchange during exercise. J. Applied Physiol. 35(2):1973.

"The anaerobic threshold is a useful concept."

in Wasserman et al, 1973.

~ 5,500 studies involving terms *anaerobic threshold-* or *lactate threshold* published since!

A dear child has many names

- Point of Optimal Respiratory Efficiency (Hollman, 1959)
- **Anaerobic** Threshold (Wasserman, 1964)
- **Aerobic-Anaerobic** threshold (Mader, 1976)
- **Aerobic** Threshold (Kindermann, 1979)
- Individual **Anaerobic** Threshold (IAT, Stegmann and Kindermann, 1981)
- Respiratory Compensation Point (Beaver, Whipp, & Wasserman, 1986)
- Onset of Blood Lactate Accumulation (OBLA, Sjodin & Jakobs, 1981)
- Maximal Lactate Steady State (MLSS, Mader and Heck, 1974-86)

David Costill- leads a new generation of applied sport scientists in 70's-80's

1980's

Physicians hooked on exercise: Kenneth Cooper
George Sheehan

Covert Bailey: "If exercise could be packaged int
pill, it would be the most prescribed medication in
history".

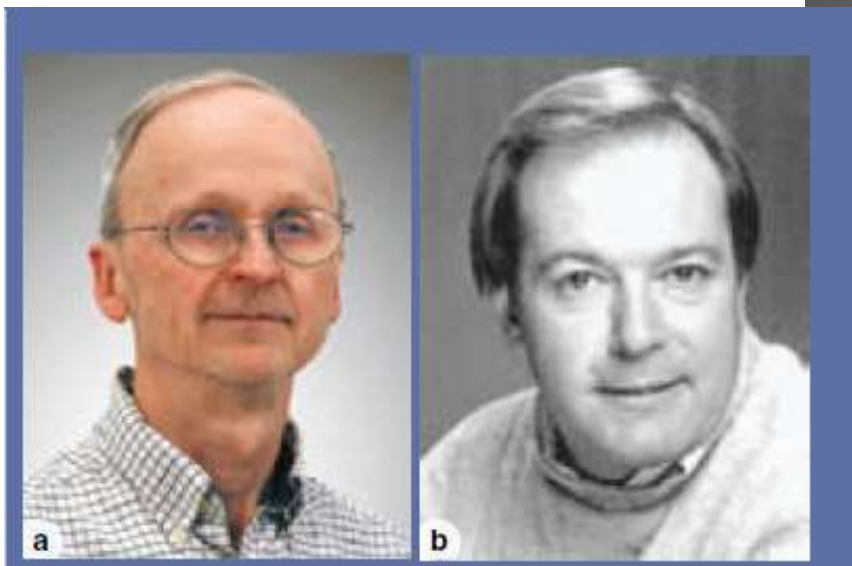
The benefits of exercise training on the following
recognized:

- Health Promotion & Quality of Life
- Blood lipids
- Heart Function in Diseased Populations
- Disease Prevention & Rehabilitation

Evolution of Exercise Physiology Tools and Techniques

The history of exercise physiology has, in some ways, been driven by advancements in technologies adapted from basic sciences. The early studies of energy metabolism during exercise were made possible by the invention of gas-collecting equipment and chemical analysis of oxygen and carbon dioxide. level.

Chemical determination of blood lactic acid seemed to provide some insights regarding the aerobic and anaerobic aspects of muscular activity, but these data told us little regarding the production and removal of this by-product of exercise. Likewise, blood glucose measurements taken before, during, and after exhaustive exercise proved to be interesting data but were of limited value for understanding the energy exchange at the cellular



(*a*) Frank Booth and (*b*) Ken Baldwin.

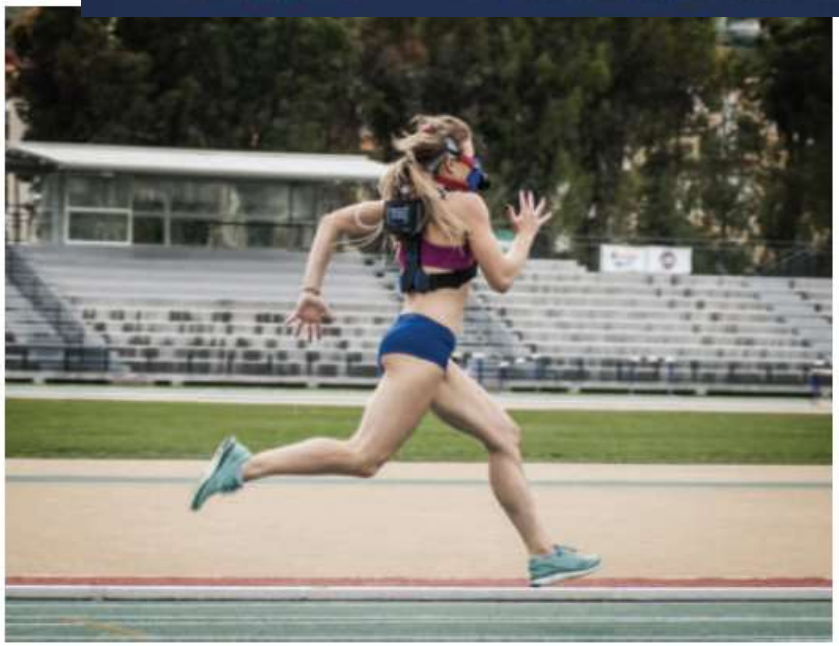


Figure 0.1 Comparison of old and new technology used to measure oxygen consumption and carbon dioxide production during exercise. (*Right:* COSMED.)

THEN

Photo provided by Prof. Frank Katch

NOW

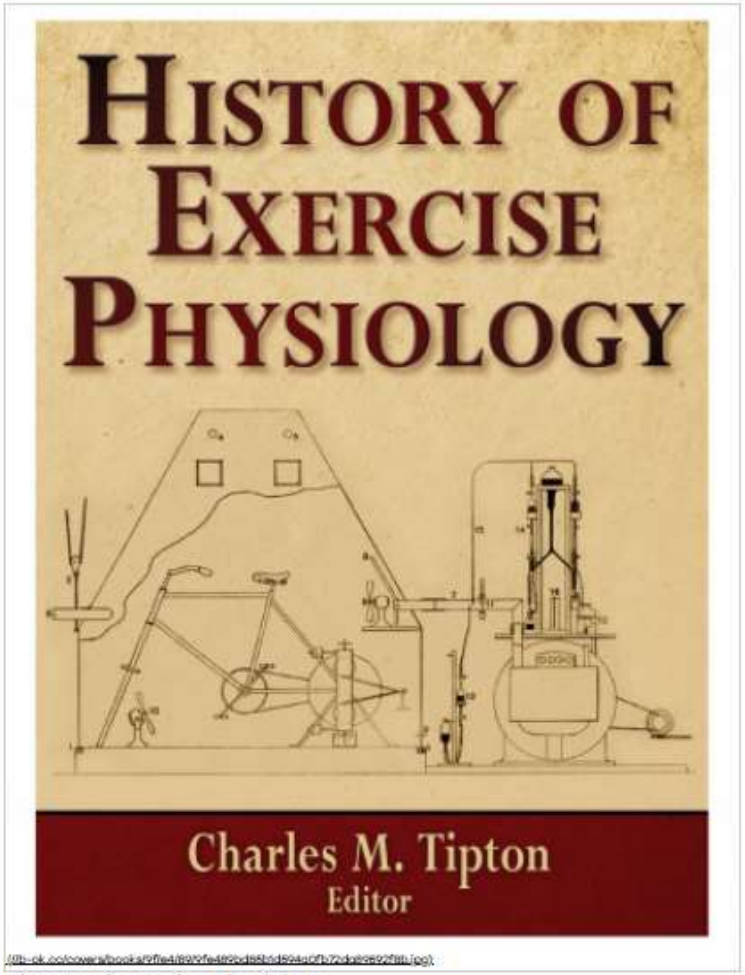
Photo provided by Dr. AG Zapico

Do all athletes and their coaches NEED laboratory testing to train best and WIN?

Conclusions

- Laboratory testing of endurance athletes has a ~100 year history.
- Most of what we now know was established between 1950 and 1980; best practice has not changed meaningfully.
- Modern testing is faster, more convenient and potentially more sport specific, but not more accurate.
- We are indebted to many extremely smart and innovative ”forefathers” who paved the way for modern physiological testing of athletes.

Reference Book/ Online Resources



History of exercise physiology

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