Historical Keynote
A Physiological Model for Rock Climbing – The First 2000 Years

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Performance …

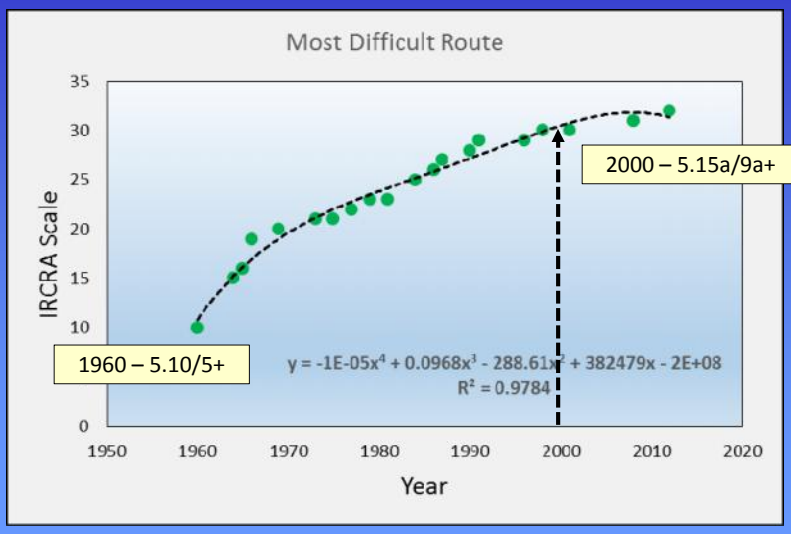
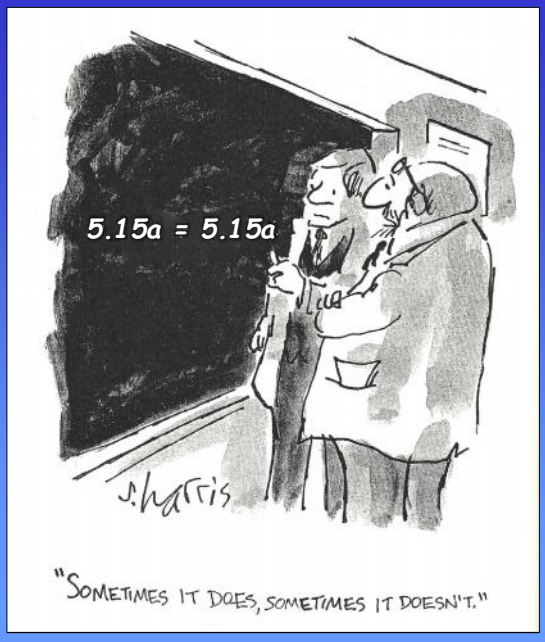


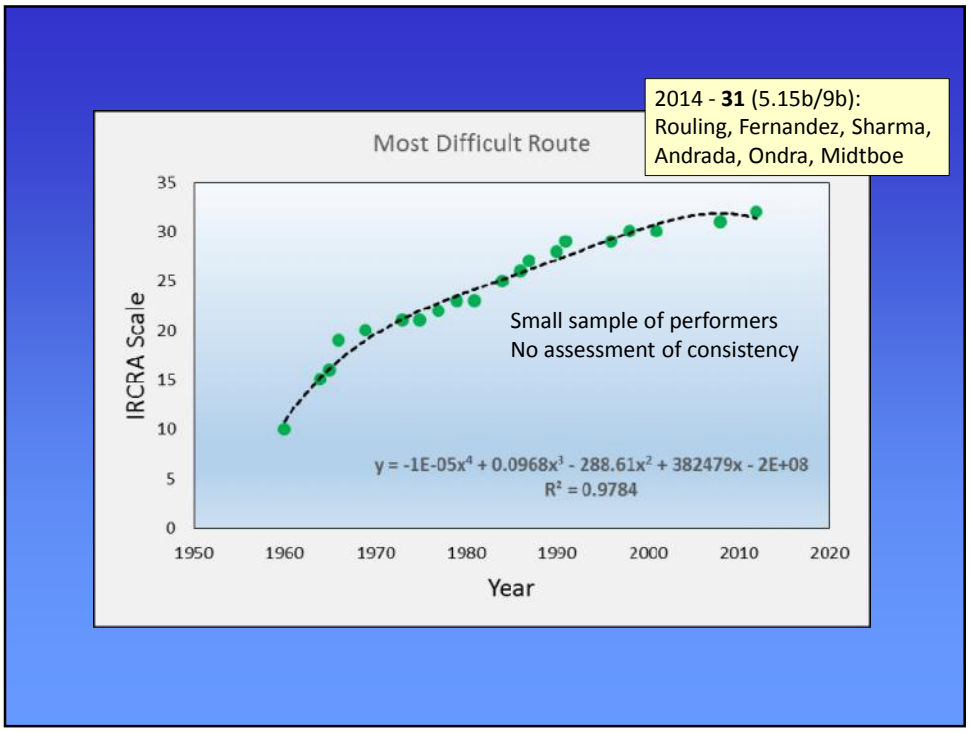
Table 1. Ability grouping for males and females and a range of reporting scales shown alongside the IRCRA scale.

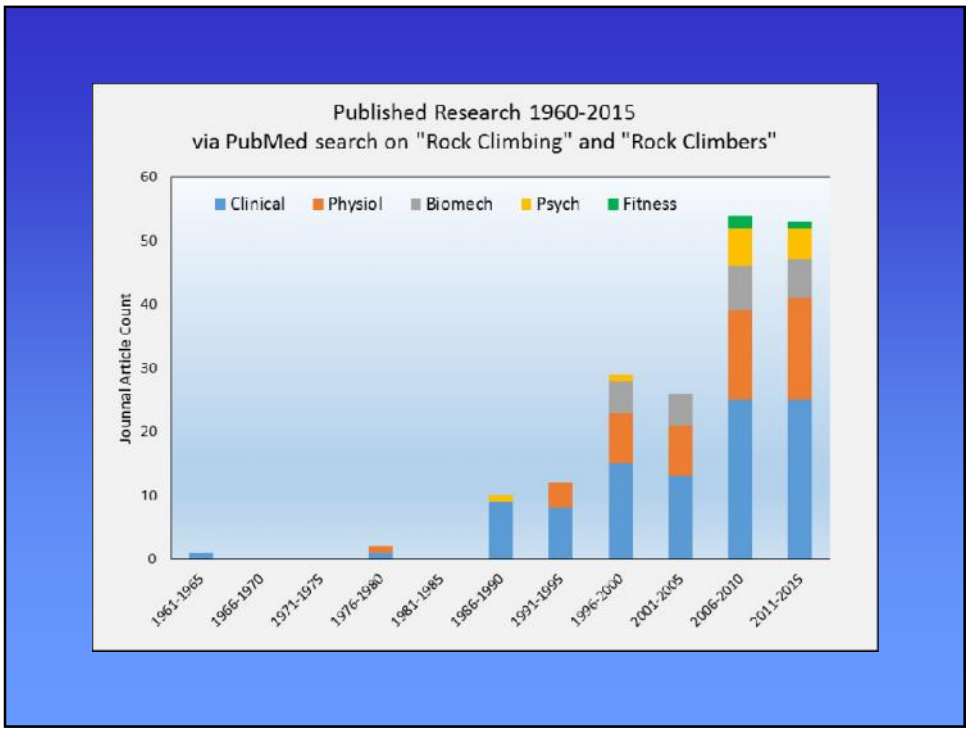
Climbing Group	Vermin	Font	IRCRA Reporting Scale	YDS	French/sport	British Tech	Ewbank	BRZ	UIAA	Metric UIAA	Watts
			1	5.1	1		4	I sup	I	1.00	
			2	5.2	2		6	II	II	2.00	
			3	5.3	2+		8	II sup	III	3.00	
			4	5.4	3+			III	III+	3.50	
Lower Grade (Level 1) Male & Female			5	5.5	3		10	IV	IV	4.00	
			6	5.6	3+		12		IV+	4.33	0.00
			7	5.7	4		14	V	V-	4.66	0.25
			8	5.8	4+				V	5.00	0.50
	V0	3	9	5.9	5		16	V sup	V+	5.33	0.75
			10	5.10a	5+		18	VI	VI-	6.00	1.00
Intermediate (Level 2) Female	V0-	3	11	5.10b	6a				VI+	6.33	1.25
Intermediate (Level 2) Male	V0	4	12	5.10c	6a+		19		VII-	6.66	1.50
	V0+	4+	13	5.10d	6b		20	VI sup	VII	7.00	1.75
	V1	5	14	5.11a	6b+		21	7a	VII+	7.33	2.00
	V2	5+	15	5.11b	6c		22	7b	VIII-	7.66	2.25
	V3	6a	16	5.11c	6c+				VIII	8.00	2.50
Advanced (Level 3) Female	V4	6a+	17	5.11d	7a		23	7c	VIII+	8.33	2.75
	V5	6b	18	5.12a	7a+		24	8a			3.00
Advanced (Level 3) Male	V6	6b+	19	5.12b	7b		25	8b	IX-	8.66	3.25
	V7	6c	20	5.12c	7b+		26	8c			3.50
	V8	6c+	21	5.12d	7c		27	9a	IX	9.00	3.75
Elite (Level 4) Female	V9	7a	22	5.13a	7c+		28	9b	IX+	9.33	4.00
	V10	7a+	23	5.13b	8a		29	9c		9.66	4.25
Elite (Level 4) Male	V11	7b	24	5.13c	8a+		30	10a	X	10.00	4.50
	V12	7b+	25	5.13d	8b		31	10b			4.75
	V13	7c	26	5.14a	8b+		32	10c	X+	10.33	5.00
	V14	7c+	27	5.14b	8c		33	11a	XI-	10.66	5.25
Higher Elite (Level 5) Female	V15	8a	28	5.14c	8c+		34	11b	XI	11.00	5.50
Higher Elite (Level 5) Male	V16	8a+	29	5.14d	9a		35	11c	XI+	11.33	5.75
			30	5.15a	9a+		36	12a			6.00
			31	5.15b	9b		37	12b	XII-	11.66	6.25
			32	5.15c	9b+		38	12c	XII	12.00	6.50

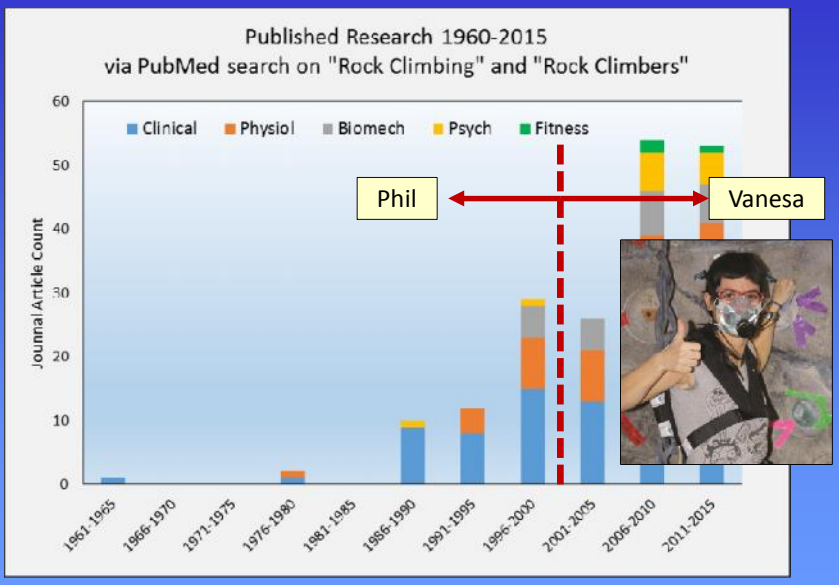
Note: IRCRA stands for the International Rock Climbing Association; YDS for Yosemite Decimal System; BRZ for Brazilian scale, UIAA for the Union Internationale des Associations d'Alpinisme and Font for Fontainebleau. Sources: Watts, Martin, and Durtschi (1993), Benge and Raleigh (1995), Draper et al. (2011b), Schöffl et al. (2010), BMC (2007), Rockfax (n.d.), The American Alpine Club (2012).

Draper, N. et al. *Sports Technology*, 2016. http://dx.doi.org/10.1080/19346182.2015.1107081




2014 - **31** (5.15b/9b):
Rouling, Fernandez, Sharma, Andrada, Ondra, Midtboe
Most Difficult Route
IRCRA Scale
Year
Small sample of performers
No assessment of consistency
y = -1E-05x⁴ + 0.0968x³ - 288.61x² + 382479x - 2E+08
R² = 0.9784


Published Research 1960-2015
via PubMed search on "Rock Climbing" and "Rock Climbers"
Clinical
Physiol
Biomech
Psych
Fitness
Journal Article Count
1961-1965
1966-1970
1971-1975
1976-1980
1981-1985
1986-1990
1991-1995
1996-2000
2001-2005
2006-2010
2011-2015


Published Research 1960-2015
via PubMed search on "Rock Climbing" and "Rock Climbers"
Clinical
Physiol
Biomech
Psych
Fitness
Journal Article Count
60
50
40
30
20
10
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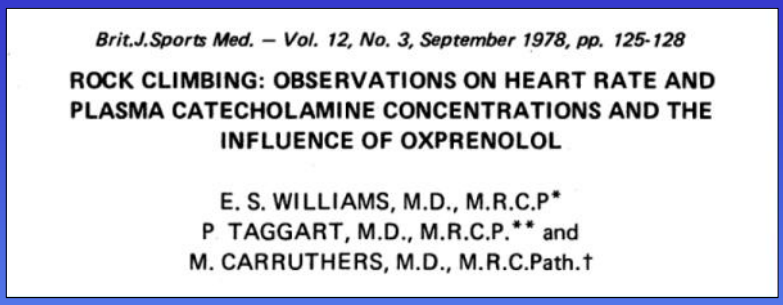
1961-1965
1966-1970
1971-1975
1976-1980
1981-1985
1986-1990
1991-1995
1996-2000
2001-2005
2006-2010
2011-2015
Phil
Vanesa


Brit.J.Sports Med. — Vol. 12, No. 3, September 1978, pp. 125-128
ROCK CLIMBING: OBSERVATIONS ON HEART RATE AND PLASMA CATECHOLAMINE CONCENTRATIONS AND THE INFLUENCE OF OXPRENOLOL
E. S. WILLIAMS, M.D., M.R.C.P*
P. TAGGART, M.D., M.R.C.P.** and
M. CARRUTHERS, M.D., M.R.C.Path.†

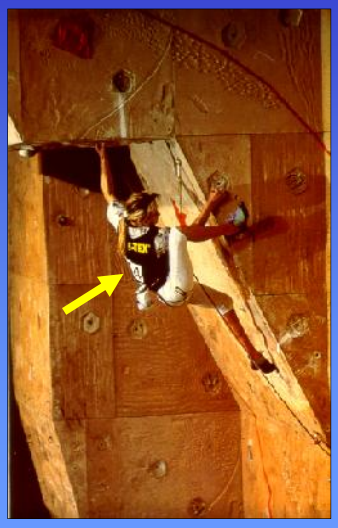

Bowles Rock, Tunbridge Wells, UK

- 11 participants – police and rock climbing instructors.
- 2 routes – 1 wt oxprenolol + 1 wt placebo
- HRmax wt placebo 166±26, wt oxprenolol 120±10
- Adrenaline increased from 0.05 to 0.33 $\mu g \cdot L^{-1}$ wt placebo
- Noradrenaline did not increase.

A few quotes:
"… It is concluded that hard rock climbing on small crags is not, of itself, a sport necessarily requiring, or by its practice producing, physical fitness … it is mainly an emotional rather than physical challenge which is presented by the rock face … we suggest that the dominant emotion involved in rock climbing is one of fear … "

"The rock was open, smooth and dripping with rainwater … (the climbers) engendered considerable anxiety owing to the steepness of the rock face and its slippery nature caused by rain which continued all day."

Animal Model vs Human Model

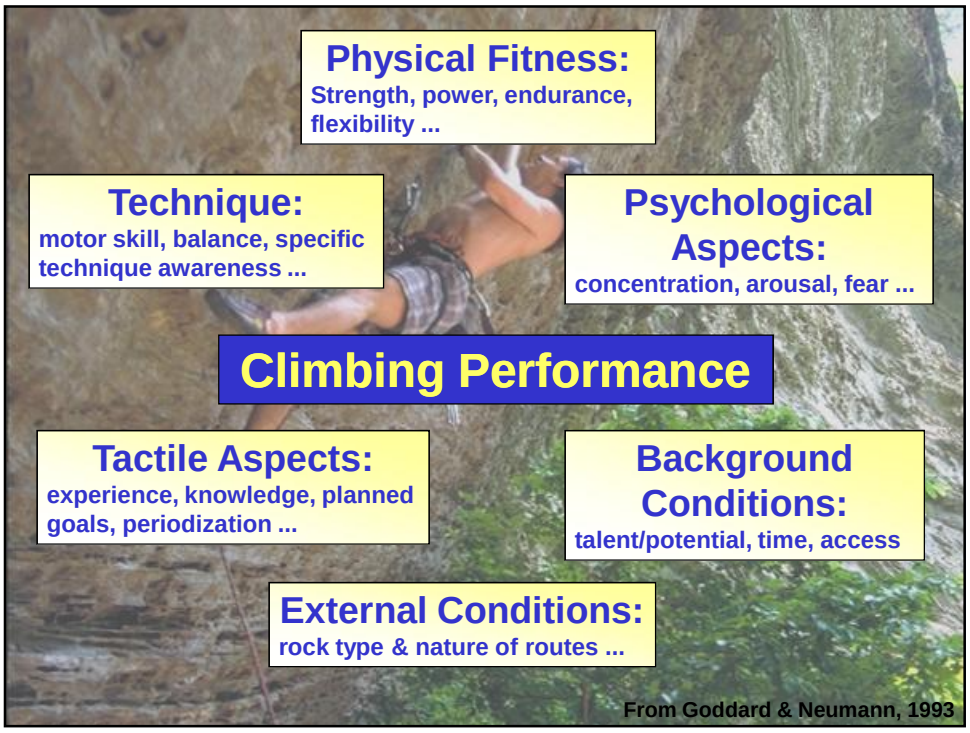


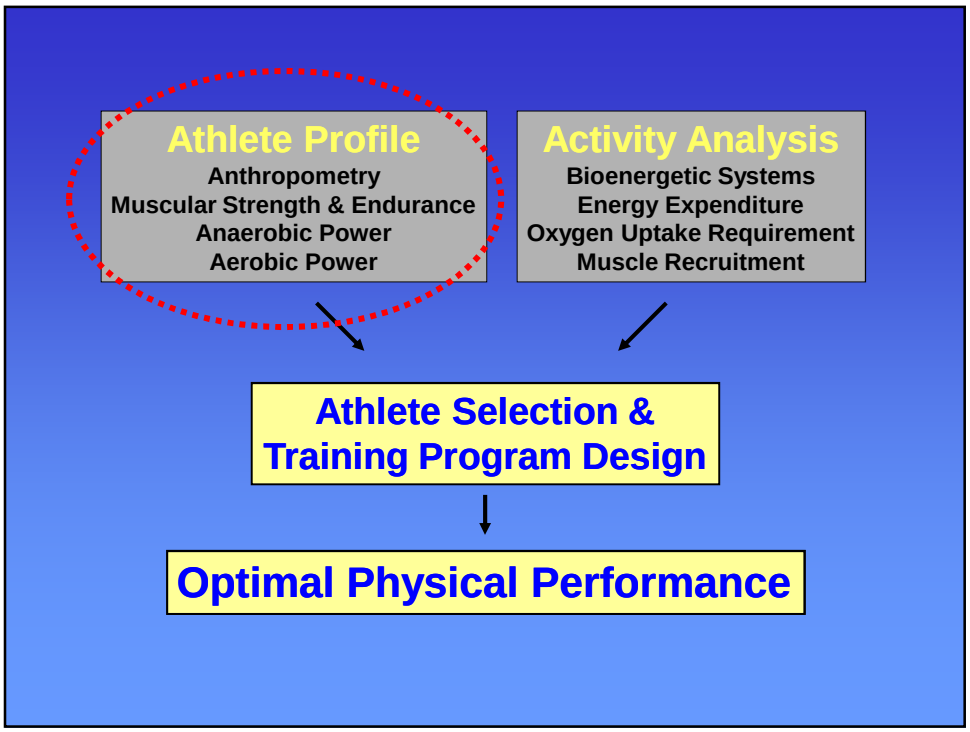
Climber Profile
Anthropometry
Muscular Strength & Endurance
Anaerobic Power & Capacity
Aerobic Power & Capacity …

Climbing Analysis
Bioenergetic Systems
Energy Expenditure
Oxygen Uptake Requirments
Neuromuscular Recruitment …

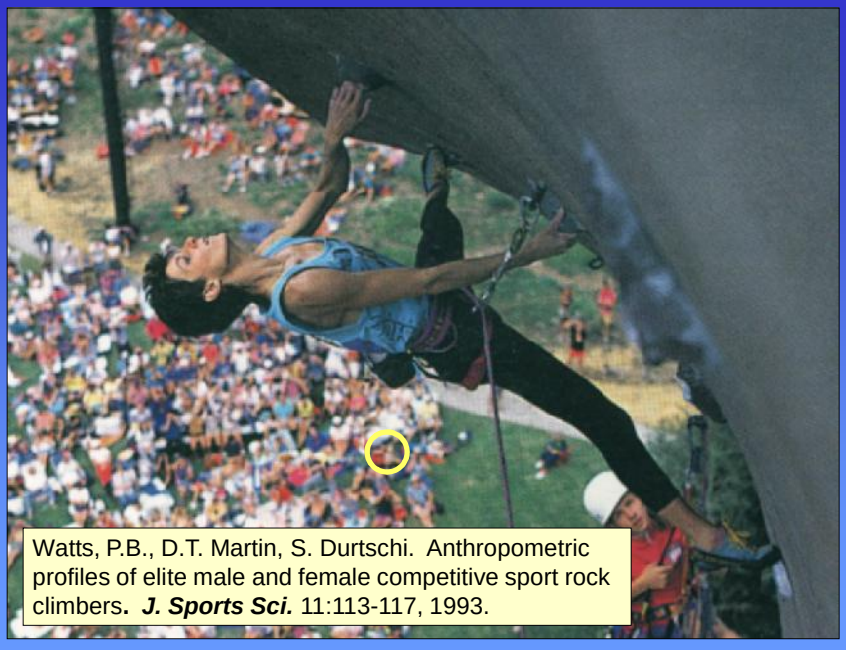
Climber Selection & Training Program Design

Optimal Physical Performance


Physical Fitness:
Strength, power, endurance, flexibility ...
Technique:
motor skill, balance, specific technique awareness ...
Psychological Aspects:
concentration, arousal, fear ...
Climbing Performance
Tactile Aspects:
experience, knowledge, planned goals, periodization ...
Background Conditions:
talent/potential, time, access
External Conditions:
rock type & nature of routes ...
From Goddard & Neumann, 1993


Athlete Profile
Anthropometry
Muscular Strength & Endurance
Anaerobic Power
Aerobic Power
Activity Analysis
Bioenergetic Systems
Energy Expenditure
Oxygen Uptake Requirement
Muscle Recruitment
Athlete Selection & Training Program Design
Optimal Physical Performance

The *traditional* image of an "elite" climber

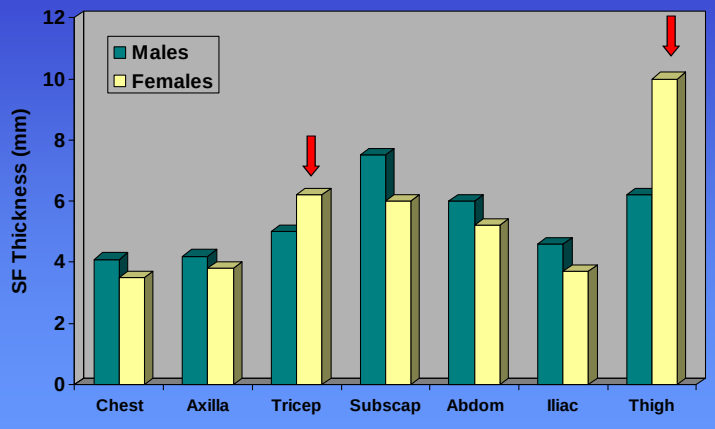


Watts, P.B., D.T. Martin, S. Durtschi. Anthropometric profiles of elite male and female competitive sport rock climbers. ***J. Sports Sci.*** 11:113-117, 1993.

Variable	M Finalists (n=7)	F Finalists (n=6)
Age (yrs)	23.9±5.2	27.3±1.9
Ability	5.14a / 8c	5.13b / 8a+
Height (cm)	179.3±5.2	162.3±4.6
Body Mass (kg)	62.4±4.5	46.8±4.9
p **7 Skinfolds** (mm)	36.3±6.4	36.7±10.5
%Body Fat	4.8±2.3	9.6±1.9
Grip Strength (kg)	48.7±9.1	30.3±3.1
Strength:Mass Ratio	0.78±0.13	0.64±0.04

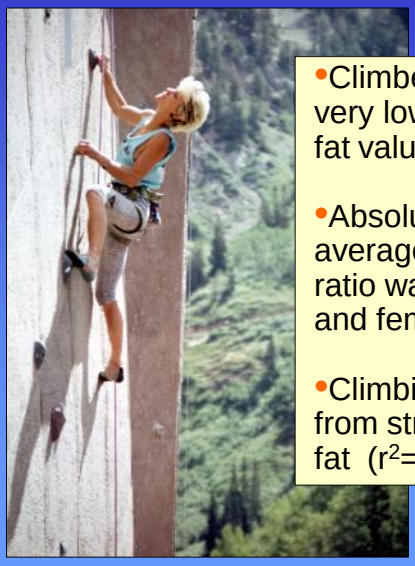
Watts, PB, et al., 2003

Skinfold Thickness
Male & Female Finalists



Watts, PB, et al., 1993

Results



- Climbers were of small stature with very low skinfold thickness & body fat values.
- Absolute grip strength values were average, however, strength:mass ratio was very high in both males and females.
- Climbing ability could be predicted from strength:mass ratio and %body fat (r^2=0.33).

Watts, PB, et al., 1993

Perceived World Champion Sport Climber

May of 1999 Austrian Sport Climbing Commission imposed BMI (mass/height^2) standards for competition climbers:

Females	á14 yr	16.00
	15	16.25
	16	16.50
	17	16.75
	ñ18	17.00
Males	á14 yr	17.00
	15	17.25
	16	17.50
	17	17.75
	ñ18	18.00

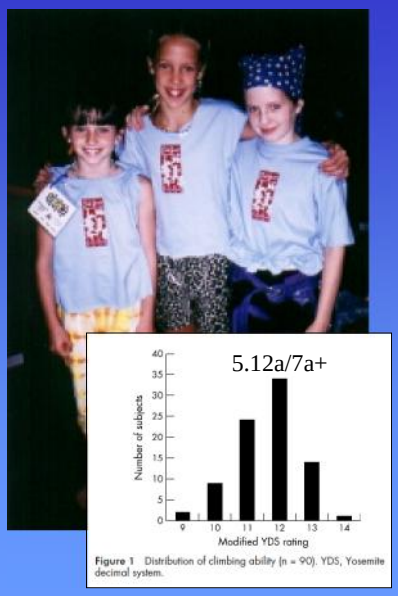
?

Watts PB, Joubert LM, Lish AK, et al.

Anthropometry of young competitive sport rock climbers. *British Journal of Sports Medicine*. 37:420-424, 2003

90 Climbers 10-18 yrs of age

45 age & gender matched physically active though non-climber Control subjects



Control vs JCCA Comparisons

Variable	Control (n=45)	JCCA (n=90)
Age (yrs)	13.7 ±2.7	13.5 ±3.0
Height (cm)	167.1 ±14.0	158.5 ±15.2*
Stature %-tile	**79.3 ±25.3**	**50.0 ±28.7***
Mass (kg)	54.1 ±15.0	47.8 ±13.4*
Mass %-tile	**57.8 ±25.6**	**39.4 ±23.5***
Ht/Wt Ratio	3.28 ±0.78	3.51 ±0.74*
BMI	19.0 ±3.2	18.6 ±2.3
BMI %-tile	38.7 ±29.7	32.7 ±21.5
"Ape Index"	0.95 ±0.15	1.01 ±0.02*
Bilio/Bicristal	0.74 ±0.05	0.86 ±0.08*
Sum 9 Skinfolds (mm)	101.3 ±45.2	66.5 ±20.5*
Hand+Arm Volume (ml)	1148.9 ±426.8	1116.4 ±345.0
Avg. Handgrip (kg)	30.7 ±13.4	32.8 ±12.8
HG/Mass	0.55 ±0.13	0.67 ±0.12*

Watts, PB, et al., 2003

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Stature %-tile	79.3 ±25.3	50.0 ±28.7*
Mass (kg)	54.1 ±15.0	47.8 ±13.4*
Mass %-ile	57.8 ±25.6	39.4 ±23.5*
Ht/Wt Ratio	3.28 ±0.78	3.51 ±0.74#
BMI	19.0 ±3.2	18.6 ±2.3
BMI %-tile	12.6-26.4	14.6–25.6
"Ape Index"		
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HG/Mass	0.55 ±0.13	0.67 ±0.12*

11/45 (24%) below Austrian "cut-off" levels (all <16 yrs).

21/91 (23%) below Austrian "cut-off" levels (all <16 yrs).

Watts, PB, et al., 2003

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Although BMI values did not differ, climbers did present a different body composition.

Watts, PB, et al., 2003

Muscular Strength

http://www.johngill.net/

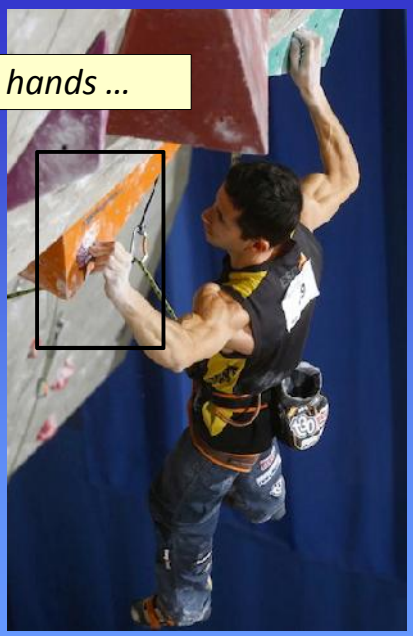
1965	Pat Ament	70.5	150	125 fingertip pull-ups in 5 minutes, etc.
1966	Jack La Lanne	67	175	Held perfect *flag* lever with 77.75 lbs. tied to his waist.
1969	William D. Reed	?	?	Did a record 106 consecutive pull-ups with both arms.
1978	Jim Holloway	78	165?	Held front lever for at least 20 seconds, perhaps a minute. May be the tallest person ever to do a front lever.
1978	John Curd Edmunds	70.5	167	Did a record 117 consecutive dynamic pull-ups at age 66.
1980	John Bachar	67	175	1 OAP + 12.5 lbs. Two-arm pullup + 138.75 lbs.
1982	Wolfgang Güllich	70	150	One arm pullup on one finger & OAP on small ledge + ?
1985	Milos Snajdr			6 two-arm chins + 120 kg.
2006	Jason Armstrong	74	183	2,409 pull-ups in a 12 hour period.
2007	Guy Schott	68	150	3,116 pull-ups in 9 1/2 hours.

http://www.johngill.net/

Lillian Leitzel
(Lillian Alize Pelikan) Poland
1892

Performed 27 1-arm chins in 1918 as a warm-up for a gymnastics photo session.

It's all about the hands …



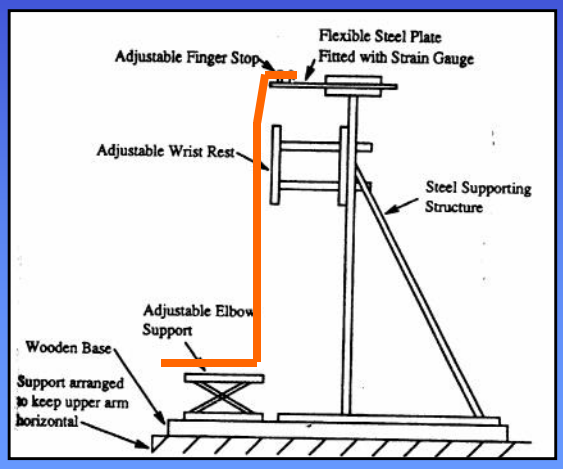
Muscular Strength

Study	Subject Ability	Handgrip Force	Force:Mass Ratio
Watts et al. (1993) (n=21m)	**5.13c/8a+**	**51.6±6.4 kg 50th %-tile**	**0.78±0.06 >80th %-tile**
Watts et al. (1993) (n=18f)	**5.12c/7b+**	**34.2±5.2 kg 75th %-tile**	**0.65±0.06 >90th %-tile**
Watts et al. (1996) (n=11m)	**5.12a-513d 7b-8b+**	**59.3±7.1 kg**	
Ferguson & Brown (1997) (n=5m)	**5.11c-5.13b 7a-8a**	**72.8±3.5 kg**	
Watts et al. (1999) (n=15m)	**5.12c-5.14b**	**51.6±7.5 kg**	**0.77±0.07**
Grant et al. (2001) (n=10f)	**HVS (5.9/5)** "Elite"	**34.4±1.2 kg**	

Specific to Climbing?

Finger Strength

Grant et al. *J. Sports Sci*. 14:301-309, 1996.
10 experienced Male climbers (>5.10 or 6a)

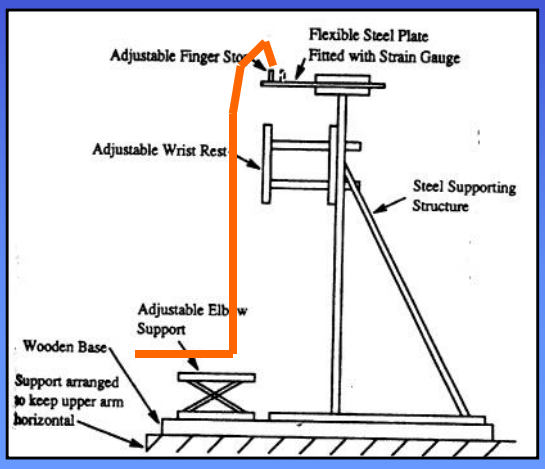


Open Grip
4 rt - 45.5 ±3.1 kg
2 rt - 33.6 ±2.3 kg

Values were not significantly different from recreational climbers.

Finger Strength

Grant et al. *J. Sports Sci*. 14:301-309, 1996.
10 experienced Male climbers (>5.10 or 6a)



Crimp Grip
4 rt - 22.5 ±1.6 kg
2 rt - 15.1 ±2.6 kg

Values were not significantly different from recreational climbers.

Finger Strength - Females

Grant et al. *J. Sports Sci*. 19(7):499-505, 2001.
10 experienced Female climbers (>5.10 or 6a)

4 Fingers ("Open" Grip)

Left	Right
31.3 ±1.4 kg	**32.7** ±1.8 kg

Mean HG_{max} via handgrip dynamometer = 34.4 ±1.2 kg

Muscular Endurance

- **Grant et al. (1996): "Elite Climbers" significantly higher for Bent Arm Hang (53.1± 13.2 vs 31.4 ± 9.0 sec) and Pull-ups (16.2 ± 7.2 vs 3.0 ± 9.0) than "Recreational Climbers".**
- **Cutts & Bollen (1993): Integrals of the force-time curve to 80% of HG_{max} for "whole hand" and 50% for "pinch". Climbers scored higher than non-climbers for left "whole hand" and right & left "pinch".**
- **Haughton (2000) Found two-handed intermittent hang times at 70% MVC in "Elite" climbers to be 167% and 225% higher than "Recreational" climbers for crimp and open grips respectively.**

Muscular Endurance

Ferguson & Brown. *Eur. J. Appl. Physiol.* 76:174-180, 1997.

Variable	Climbers	Sedentary
HG MVC (kg)	72.9±3.5	64.7±5.6
Isometric 40% MVC (sec)	140±11	122±14
Rhythmic 40% MVC (sec)	853±76*	420±69

Results also indicated an enhanced forearm vasodilator capacity in trained climbers.

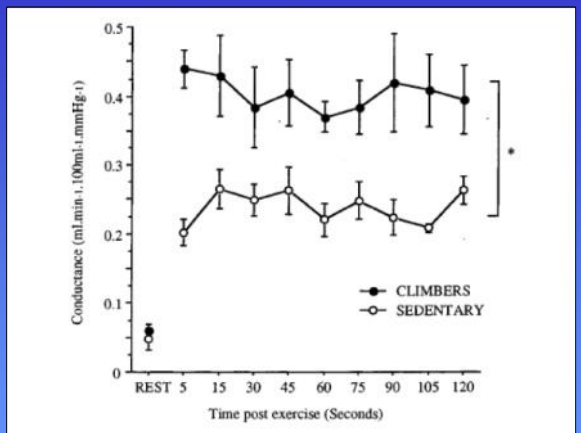
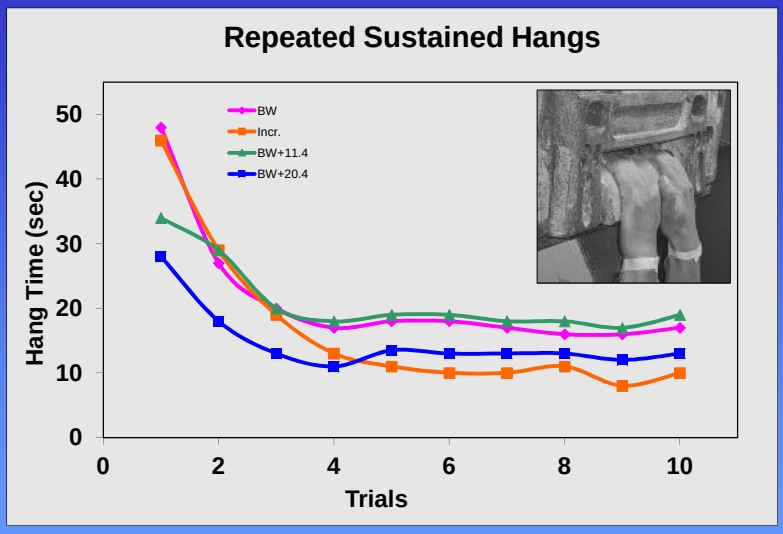


Fig. 2 Forearm vascular conductance at rest and following sustained isometric handgrip exercise to fatigue. *$P < 0.05$; climbers vs sedentary

Ferguson & Brown. *Eur. J. Appl. Physiol.* 76:174-180, 1997



Watts, P.B., D.T. Martin, D. Baumgarten (1989) Factors related to performance on the Metolius Simulator. *Proceedings - International Olympic Committee World Congress on Sport Sciences*, Colorado Springs, Co. USA.

Aerobic Power (VO_2max)

Aerobic Power (VO_2max)

Billat, et al. (1995):

4 “high level” climbers (>5.12a or 7b ability)

Running VO_2max = 54.8 ±5.0 $ml \cdot kg^{-1} \cdot min^{-1}$

Arm Pulling VO_2max = 22.3 ±2.6 $ml \cdot kg^{-1} \cdot min^{-1}$

Wilkins, et al. (1996):

7 “expert” climbers (>5.12a or 7b ability)

Running VO_2max = 55.2 ±3.6 $ml \cdot kg^{-1} \cdot min^{-1}$

Watts, et al. (1998):

14 “experienced” climbers (5.8/5b to 5.11c/7a ability)

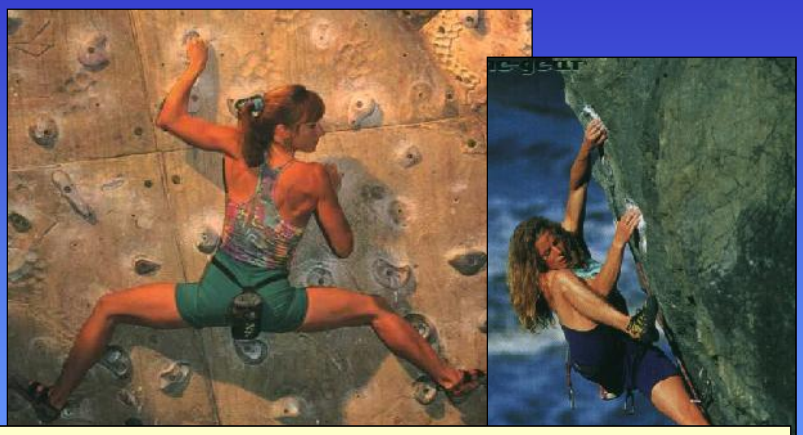
Running VO_2max = 52.0 ±4.7 $ml \cdot kg^{-1} \cdot min^{-1}$

Booth, et al. (1999):

7 “highly skilled” climbers (6b-7a UK)

Fast Climbing VO_{2peak} = 43.8±2.2 $ml \cdot kg^{-1} \cdot min^{-1}$

Flexibility – Range of Motion



Grant et al. (1996):
Sit-and-Reach - NS climbers vs non-climbers for male or female.
Leg Span - “elite” greater than “recreational” for males.
Foot-Raise - higher for climbers though not significantly (m or f).

Determinants of Climbing Performance

Mermier, C. et al. *Br. J. Sports Med*. 34:359-366, 2000
Principle Components Analysis
(2 routes – Moves from 5.7 up to 5.13)

Variable	Men (n=24)		Women (n=20)	
	Mean±SD	Range	Mean±SD	Range
Age	30.4 ±6.0	21.0-45.0	32.2 ±9.2	18.0-49.0
Ability (YDS)	5.10c/12*	5.8-5.13d	5.9/9*	5.6-5.12c
Performance (64 pts =max)	30.62 ±13.6	11.0-59.6	18.96 ±6.4	11.2-36.4

* YDS/IRCRA

Mermier, C. et al., 2000.

Determinants of Climbing Performance

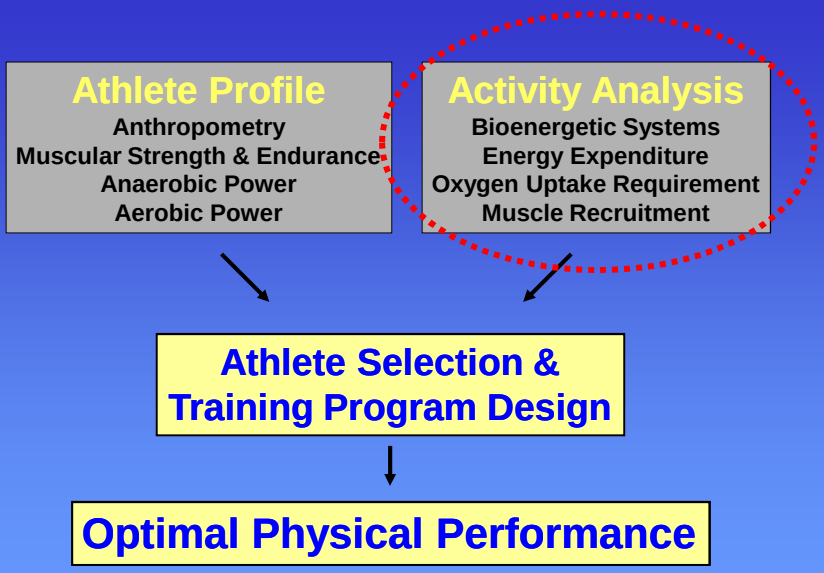
Mermier, C. et al. *Br. J. Sports Med.* 34:359-366, 2000
(2 routes – 63 possible moves at 5.7 up to 5.13)

Component 1 *Training*	Component 2 *Anthropometry*	Component 3 *Flexibility*
Knee Strength	Weight	Hip Flexion
Shoulder Strength	Height	Hip Abduction
Grip Strength	Leg Length	Climbing Experience
Upper Body Power	Arm span	
Lower Body Power	Ape Index	
Hang Time		
Percent Body Fat		
Self-reported Ability		
% of Variance 39.06%	**% of Variance 15.35%**	**% of Variance 10.36%**

Mermier, C. at al., 2000.

Athlete Profile

- Small stature and high strength:body mass ratio for grip
- Low percent fat (ģskinfolds)
- High endurance for static and rhythmic isometric contractions
- High upper body power?
- High hip flexibility (other ROM)?
- Moderate aerobic power (VO_2max)



Billat et al. *J. Sports Med. Phys. Fitness*. 35:20-24, 1995

Four climbers - Two routes at 5.12a (7b)
Climbing times ranged 3:30 to 4:15 min:sec

Variable	Route 1	Route 2
HR ($b \cdot min^{-1}$)	176±14	159±15
VO_2peak ($ml \cdot kg^{-1} \cdot min^{-1}$)	24.9±1.2	20.6±0.9
VO_2 %Run max	46.0±4.9	37.5±5.4
VO_2 %Pull max	113±12.6	95.6±6.2
Blood Lactate ($mmol \cdot L^{-1}$)	5.75±0.95	4.30±0.77

Billat, V. et al., 1995

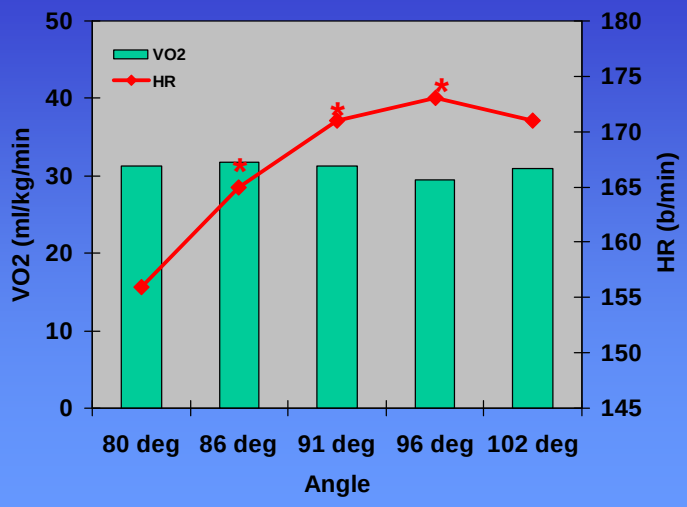
Mermier et al. *Br. J. Sports Med.* 1997

Variable	5.6 (<5a)	5.9 (5c)	5.11+ (7a)
HR ($b \cdot min^{-1}$)	142±19	155±15	163±15
VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	20.7±8.1	21.9±5.3	24.9±4.9
BLA ($mmol \cdot L^{-1}$)	1.64±0.63	2.40±0.68	3.20±0.97

Watts, PB and KM Drobish. Physiological responses to simulated rock climbing at different angles. *Med Sci Sports Exerc* 30:1118-1122, 1998.

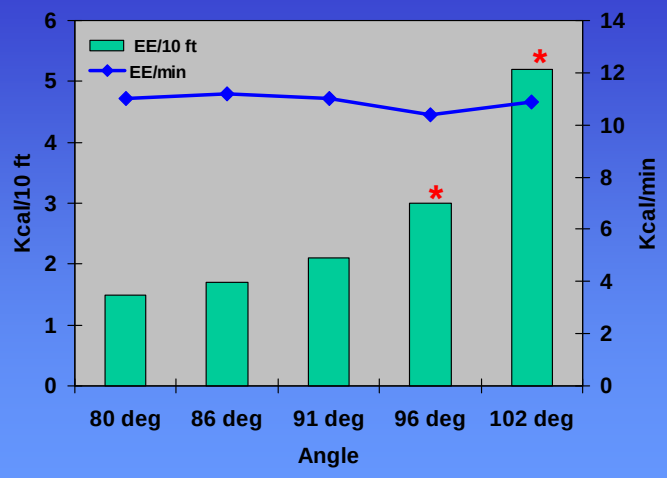
Watts and Drobish, 1998

Heart Rate and Oxygen Uptake



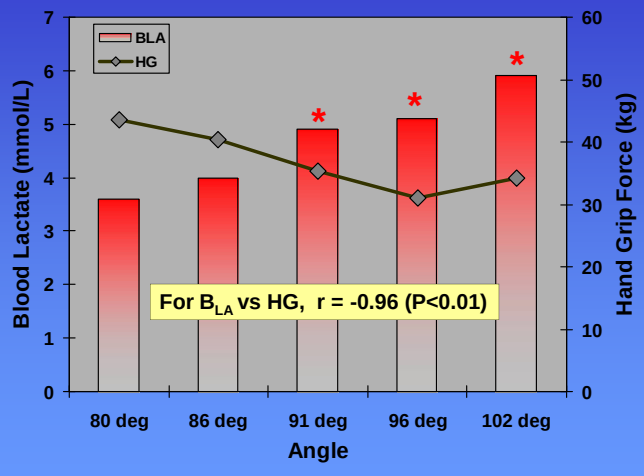
Watts and Drobish, 1998

Energy Expenditure



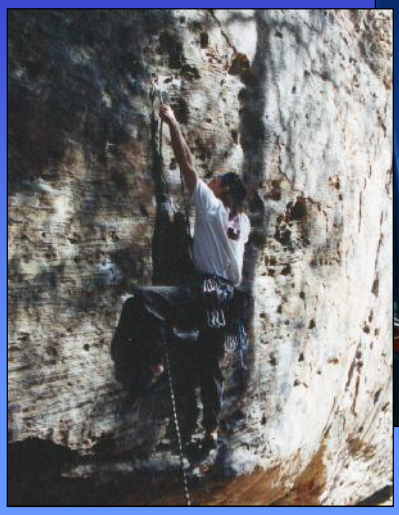
Watts and Drobish, 1998

Blood Lactate & Hand Grip



Watts and Drobish, 1998

Physiologically …
Are These The Same?



P.B. Watts, M. Daggett, P. Gallagher, B. Wilkins
***Int. J. Sports Med.* 21:185-190, 2000**

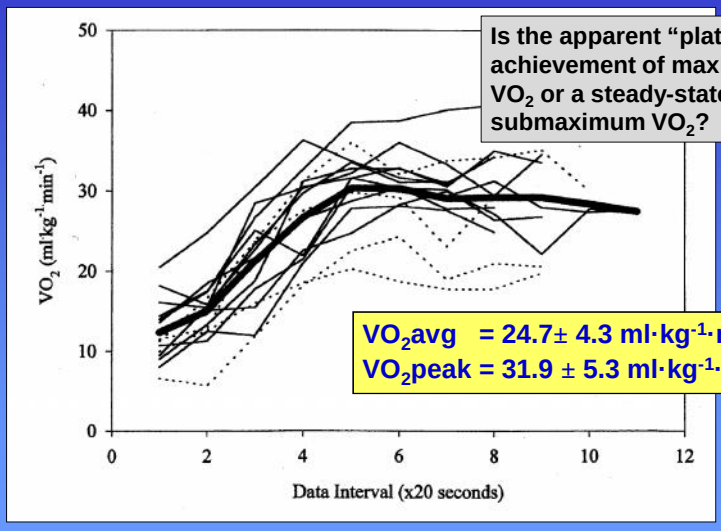
- **15 expert male climbers.**
- **Mean ability was 5.13b (5.12c-5.14b).**

Watts, et al., 2000

- Route - 5.12b (7b)
- 27 hand positions (moves) - 7 bolt clips
- Mean climbing time = 2.57± 0.41 mins
- Continuous expired air analysis - climbing + 10 min - rest or active recovery (25 Watts)
- Blood lactate - pre, post, 10-, 20- & 30-min post climb

Watts, et al., 2000

Climbing VO_2



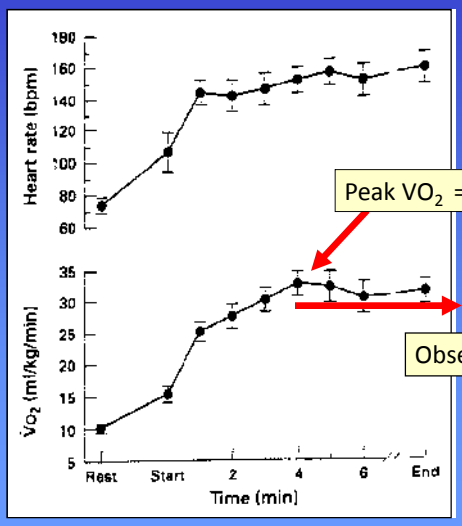
Is the apparent "plateau" achievement of maximum VO_2 or a steady-state submaximum VO_2?

VO_2avg = 24.7± 4.3 ml·kg^{-1}·min^{-1}
VO_2peak = 31.9 ± 5.3 ml·kg^{-1}·min^{-1}

Watts, et al., 2000

VO_2 During Outdoor Rock Climbing

Booth et al. *Br. J. Sports Med.* 33:14-18, 1999.



Route 24.4 m long & overhanging; 5c UK (5.10) and required 7:36±0:33 min:sec for ascent.

Peak VO_2 = 32.8±2.0 ml/kg/min

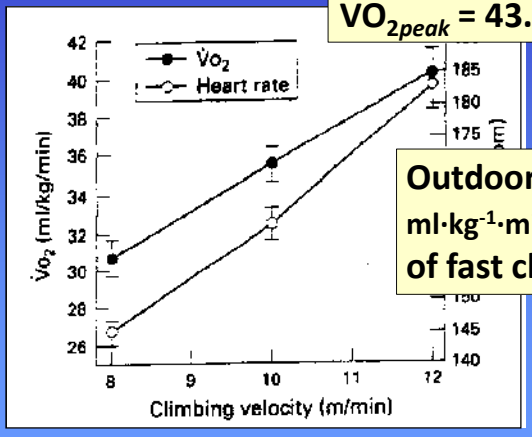
Observed a "plateau"

Booth et al., 1999

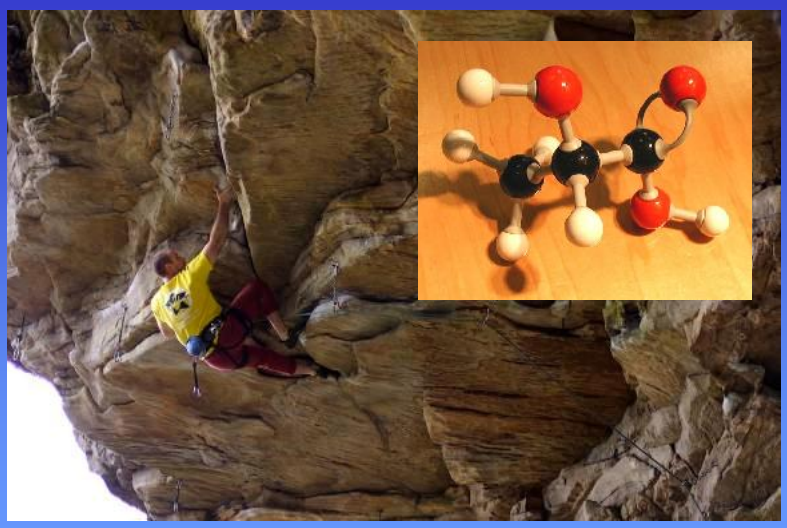
Effect of Climbing Pace

Booth et al. *Br. J. Sports Med.* 33:14-18, 1999.

VO_{2peak} = 43.8 ±2.2 ml·kg^{-1}·min^{-1}



Outdoor VO_2 of 32.8 ±2.0 ml·kg^{-1}·min^{-1} was 75 ±4 % of fast climbing VO_{2peak}.



Lactic Acid Bath – New River Gorge, USA

Summary of Blood Lactate Responses to Climbing

Reference	Condition	B_{LA} (mmol•L^{-1})
Billat, et al. 1995	3-min post route (5.12a/b)	5.8 ±1.0
Watts, et al. 1996	1-min post climbing to fall (512.a)	6.1 ±1.4
Mermier, et al. 1997	1-2 min post indoor route (5.11+)	3.2 ±0.9
Watts, et al. 1998	1-min post 4-min bout at 102˚	5.9 ±1.2
Booth, et al. 1999	Post outdoor route (ù5.10)	4.5 ±0.5
Watts, et al. 2000	1-min post indoor route (5.12b)	6.8 ±1.9

Werner & Gebert. (2000) 1-min post UIAA World Cup. Range = 3.9-8.9 mmol•L^{-1} & distance dependent

Blood Lactate

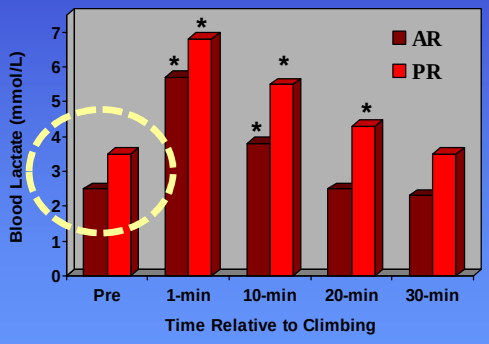
3-7 mmol·L^{-1}

12-13 mmol·L^{-1}
(15 km)

15-16 mmol·L^{-1}
(GS)

Blood Lactate

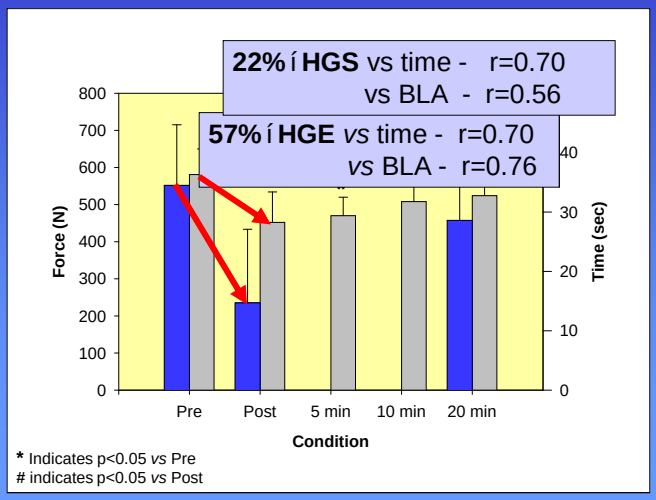
aBLA = +3.2 ± 0.8 mmol ·L^{-1}



Watts, et al., 2000

Acute Changes in Handgrip Strength & Endurance with Sustained Climbing

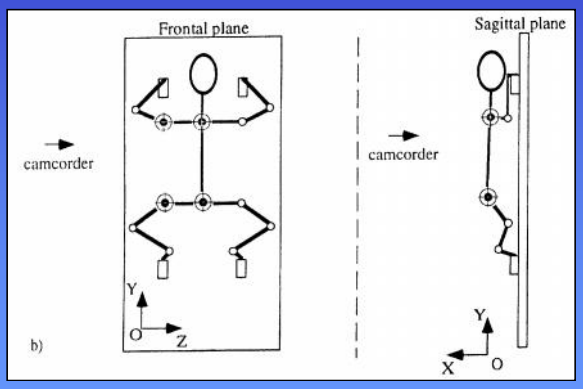
Watts et al. *J. Sports Med. Phys. Fit .* 36:255-260, 1996



Watts et al. 1996

Finger Contact Force

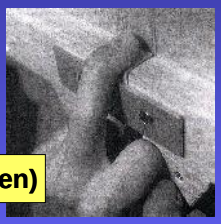
Quaine et al. *J. Appl. Biomech.* 13:14-23, 1997.



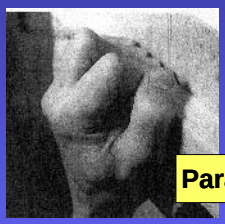
- Optimized Position with 4-limb holds produced hand contact force of 5.07±1.17 kg
- Optimized Position with 3-limb holds produced hand contact force of 9.77 ±3.20 kg

Single Finger Force

Schweizer, A. 2001. Biomechanical properties of the crimp grip position in rock climbers. *Journal of Biomechanics*. 34:217-223.



Isolated (Open)



Parallel (Crimp)

Condition	Crimp	Open
Isolated	9.8 ±2.1 kg	11.8 ±3.1 kg
Parallel	8.3 ±1.9 kg	7.9 ±2.2 kg

Activity Analysis Summary

- Climbing route ascent times range from 2-7 minutes with ≈38% static.
- VO_2 averages 20-25 ml·kg^{-1}·min^{-1} with peaks to over 30 ml·kg^{-1}·min^{-1}.
- VO_2 can "plateau" with sustained climbing of >2 min yet remains elevated into recovery.
- Higher VO_2 is possible; >40 ml·kg^{-1}·min^{-1} with "fast" climbing.
- Energy Expenditure (kcal·min^{-1}) remains constant as angle changes, but EE per distance climbed increases with increasing angle.

Activity Analysis Summary

- Blood lactate increases to 3-9 mmol·L^{-1} and remains elevated through 20+ min of passive recovery - may or may not be correlated with decreased handgrip force.
- Sustained climbing impacts handgrip endurance more than handgrip strength.
- Fatigue likely occurs within the contractile mechanism of muscle.

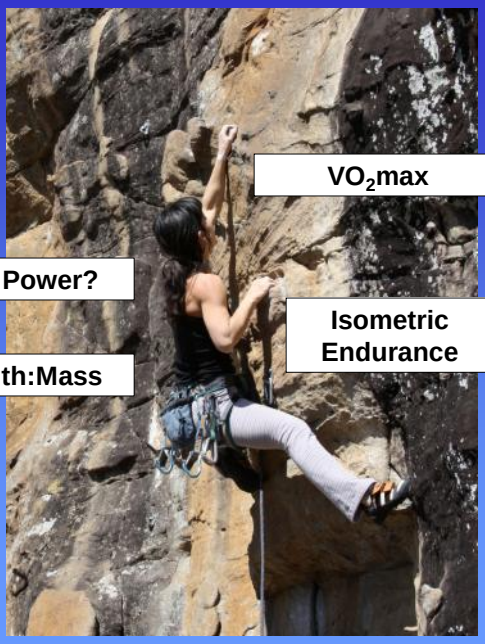
Athlete Profile
Anthropometry
Muscular Strength & Endurance
Anaerobic Power
Aerobic Power

Activity Analysis
Bioenergetic Systems
Energy Expenditure
Oxygen Uptake Requirement
Muscle Recruitment

Performance Model

Training Program Design

Theoretical Performance Model

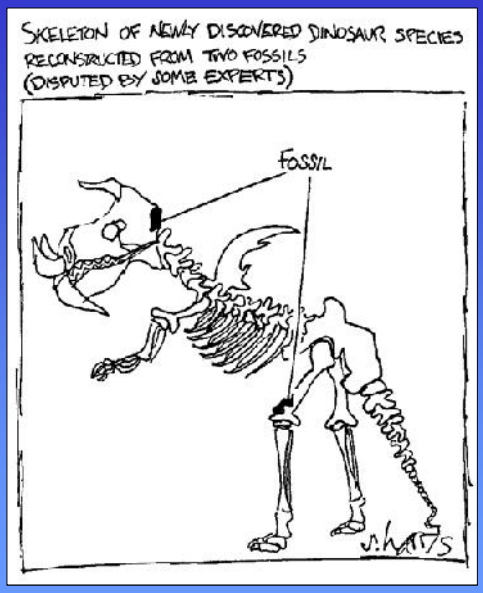


VO_2max

Anaerobic Power?

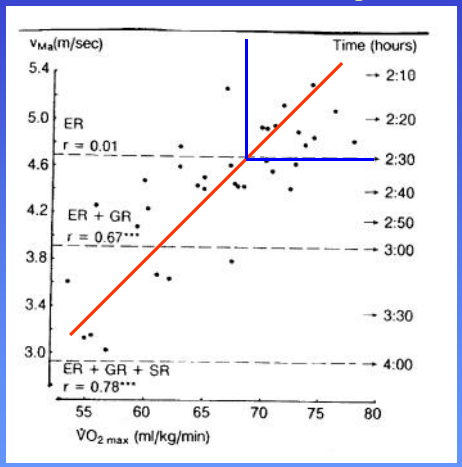
Isometric Endurance

Strength:Mass



Testing A Theoretical Model Via Correlation Analysis

VO_2max and **Marathon Running Speed**



Sjodin, B. & J. Svedenhag. Applied physiology of marathon running. *Sports Med.* 2:83-99, 1985.

In the first 2000 years, no studies tested the Model

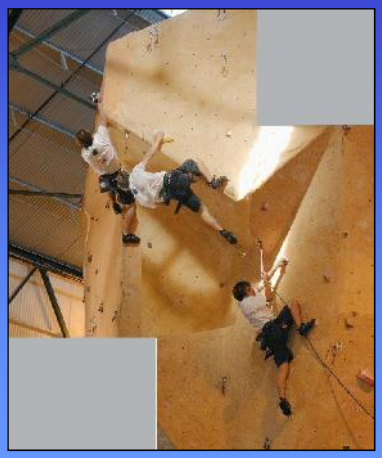
If one trains and increases Strength:Mass Ratio by 10% … How much does climbing performance change?

Training Program Design

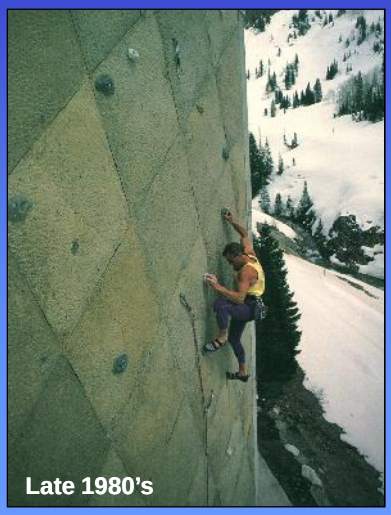
Importance of *Fitness …*

Competition?

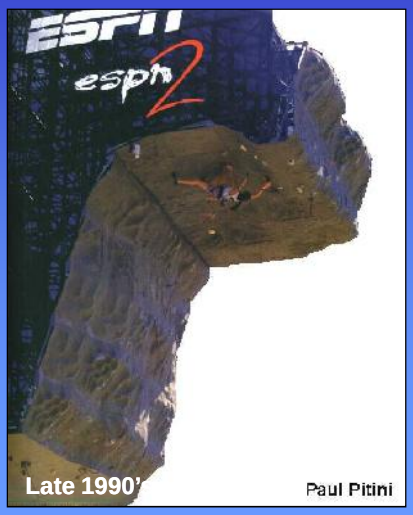
High volume practice of complex skills?



Changing Nature of Performance
&
Composite Factors for Success



Late 1980's



Late 1990's

Paul Pitini

Contemporary Theoretical Performance Model

?