



## Ascending Evacuation: Effects of Physical Work Capacity and Fatigue

Kalev Kuklane, Amitava Halder

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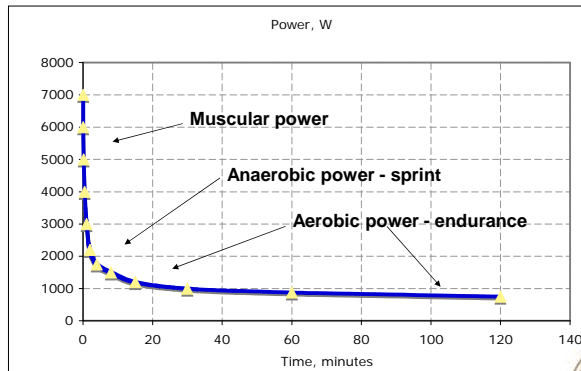
## Physical work capacity is determined by

1. Energy yielding processes
  - aerobic capacity
  - anaerobic capacity
2. Neuro-muscular function
  - strength
  - technique
3. Psychological factors
  - motivation
  - tactics

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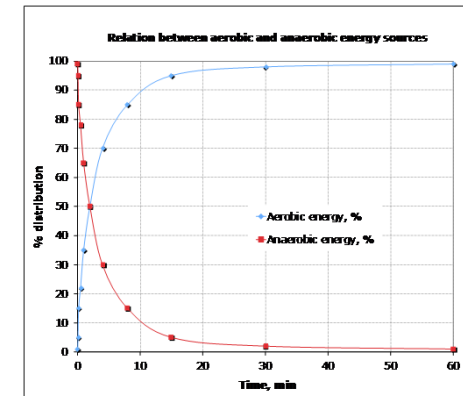
## Human work capacity



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## Energy processes



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### Variety of physical work leading differently to exhaustion

- Static muscle work (holding weights)
- Dynamic work
  - Repetitive work or highly repetitive work
- Heavy work involving large muscle groups



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### Development of the model



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### Sources

- Pre-tests: before field and before lab tests
- Field trials: Ideon Gateway, Kista Science Tower, Västra Skogen subway station
- Laboratory experiments
- Literature:
  - ACSM's guidelines, 2013; Jackson et al., 1990; Shvartz and Reibold, 1990; Loe et al., 2013 etc.
- Databases:
  - Maximal capacity tests at the lab (Kuklane & Gao, 2012)
  - National Health and Nutrition Examination Survey (NHANES), USA, 2005



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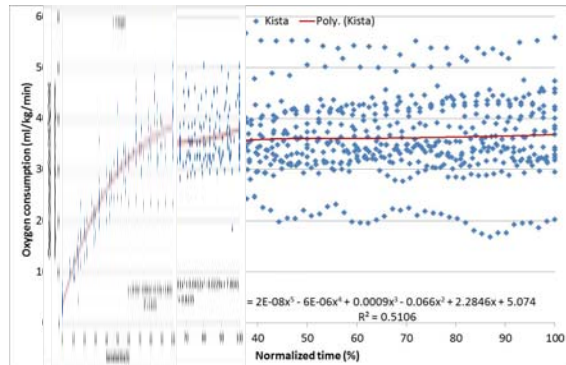
### Lab tests on StairMaster

- 25 subjects
  - 13 male, 12 female
  - 8 persons >40 years (5 male, 3 female)
- Maximal aerobic capacity test
- Heart rate
- EMG (presented by Amitava Halder)
- $VO_2$
- 3 activity levels
  - development on 19 subjects: 50, 70 and 90 % of maximal capacity
  - validation on 6 subjects: 60, 75 and 90 % of maximal capacity



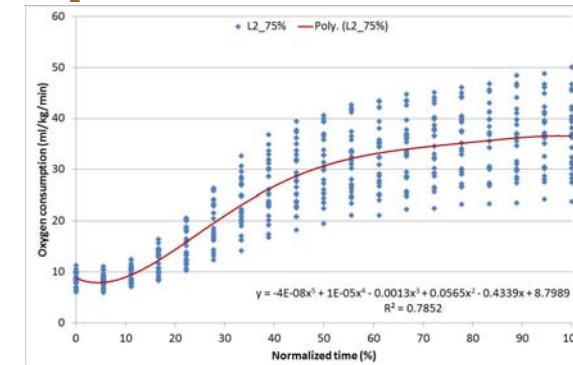
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### Normalized time and VO<sub>2</sub> in Kista



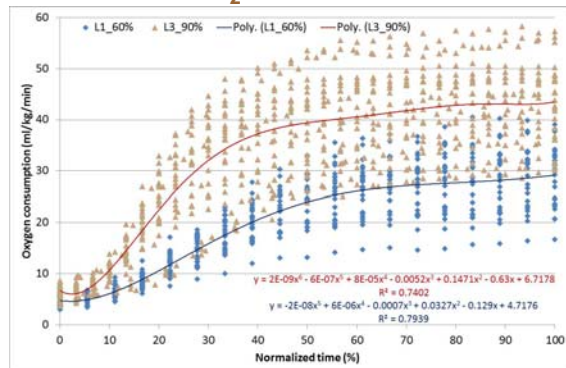
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### Normalized time and VO<sub>2</sub> in lab at 75 % of VO<sub>2</sub>max



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### Normalized time and VO<sub>2</sub> in lab at 60 and 90 % of VO<sub>2</sub>max



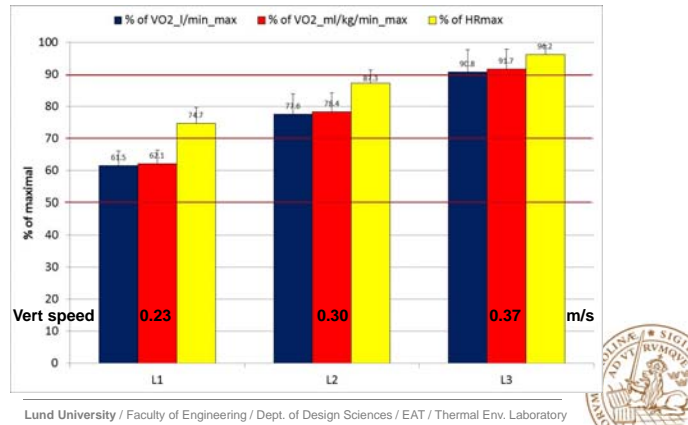
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### Examples of metabolic energy production ISO 8996

5	290	Average for full work shifts including breaks Very intense activity at fast pace, working with an axe; intense shovelling or digging; climbing stairs, ramp or ladder; walking quickly with small steps; running; walking at a speed greater than 7 km/h.
6	400	Continuous work for up to 2 hours without breaks Safety and rescue work with heavy equipment and/or personal protective equipment. Mine or tunnel escape. Fit individuals pacing themselves at 50-60% of their maximal aerobic capacity. Walking quickly or running with protective equipment and/or tools and goods. Walking at 5 km/h, 10 % elevation.
7	475	Continuous work for up to 15 minutes without breaks Rescue and fire fighting work at high intensity. Fit and well-trained individuals pacing themselves at 70-80% of their maximal aerobic capacity. Searching contaminated spaces; crawling under and climbing over obstacles; removing debris; carrying a hose. Walking at 5 km/h, 15 % elevation.
8	600	Continuous work for less than 5 minutes without breaks Rescue and fire fighting work at maximal intensity. Fit and well-trained individuals pacing themselves at 80-90% of their maximal physical work capacity. Climbing stairs and ladders at high speed; removing and carrying victims. Walking at 5 km/h, 20 % elevation.

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### Initial prediction from field and pre-test



### Relationship between maximal capacity and vertical displacement

- Estimated step rate (steps/min):

$$\text{Step rate} = -108.8633 + 2.0121 \cdot \text{VO}_{2\text{max}} + 1.3289 \cdot \% \text{VO}_{2\text{max}}$$

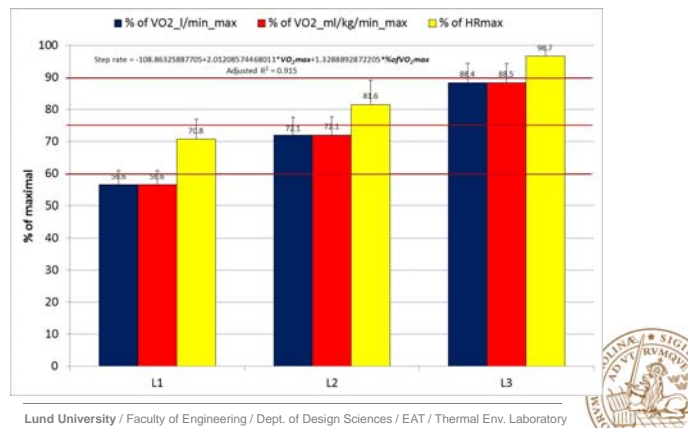
- Estimated vertical displacement (m/min):

$$h_{\text{vert}} = -21.7727 + 0.4024 \cdot \text{VO}_{2\text{max}} + 0.2658 \cdot \% \text{VO}_{2\text{max}}$$

$$\text{Adjusted } R^2 = 0.915$$

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### Validation of lab test predictions (6 subjects)

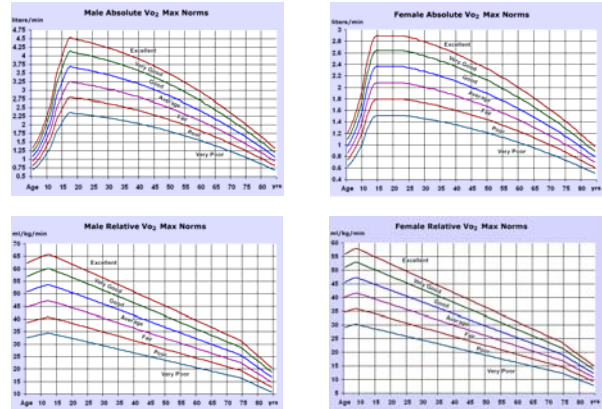


### Future research questions

- Stair machine based prediction vs. real life?
- What is the effect of carried load?
- What is the effect of clothing?
- How would step height affect the results?
- How about taking double steps?
- At various heavy physical load levels one can last **up to** x minutes.
  - How long does an average person manage?
  - What are the confidence intervals?
- Can NHANES self-estimated fitness results be used?

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## Max VO<sub>2</sub> and fitness



Shvartz E, R.C. Reibold. *Aerobic Fitness Norms For Males And Females Aged 6-75: A review.*  
Aviation, Space and Environmental Medicine. 61:3-11,1990

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## Loe et al., 2013

**Table 2.** Physiological variables in the HUNT 3 Fitness study stratified by sex and age groups.

	Male	Female
	20-29 years	
	(n = 199)	(n = 215)
VO <sub>2max</sub> (L·min <sup>-1</sup> )	4.32 ± 0.71	2.78 ± 0.46
VO <sub>2max</sub> (mL·kg <sup>-1</sup> ·min <sup>-1</sup> )	54.4 ± 8.4	43.0 ± 7.7
VO <sub>2max</sub> (mL·kg <sup>-1</sup> ·min <sup>-1</sup> )	162.1 ± 23.7	121.7 ± 20.1
EqVO <sub>2max</sub> (V <sub>E</sub> ·VO <sub>2max</sub> <sup>-1</sup> )	33.9 ± 4.0	34.1 ± 5.3
Body mass (kg)	80.1 ± 10.6	65.5 ± 10.4
Height (cm)	181 ± 6	166 ± 6
R (CO <sub>2</sub> :VO <sub>2</sub> <sup>-1</sup> )	1.15 ± 0.05	1.15 ± 0.05
f <sub>e</sub> (beats·min <sup>-1</sup> )	196 ± 10	194 ± 9
Workload (Watts)	200 ± 39	128 ± 24
BORG	19 ± 1	18 ± 1
PAI	4.64 ± 4.03	3.96 ± 3.25
	30-39 years	
	(n = 324)	(n = 359)
VO <sub>2max</sub> (L·min <sup>-1</sup> )	4.22 ± 0.63	2.75 ± 0.48
VO <sub>2max</sub> (mL·kg <sup>-1</sup> ·min <sup>-1</sup> )	49.1 ± 7.5	40.0 ± 6.8

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## Example

**75 year old lady with fitness level between poor and very poor:  
VO<sub>2max</sub> from Shvartz and Reibold 1990 is about 14 ml/kg/min**

Exercise level (% VO <sub>2max</sub> )	75	90
Vertical displacement (m/min)	3.8	7.8
Time that the pace can be kept (min)	15	5
Vertical distance covered before exhaustion (m)	57	39
Possible effect of muscle fatigue is not considered here.		

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