MECHANICAL AND PHYSIOLOGICAL PROPERTIES OF WATER

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Lecture Aquaevidence Leuven 2009

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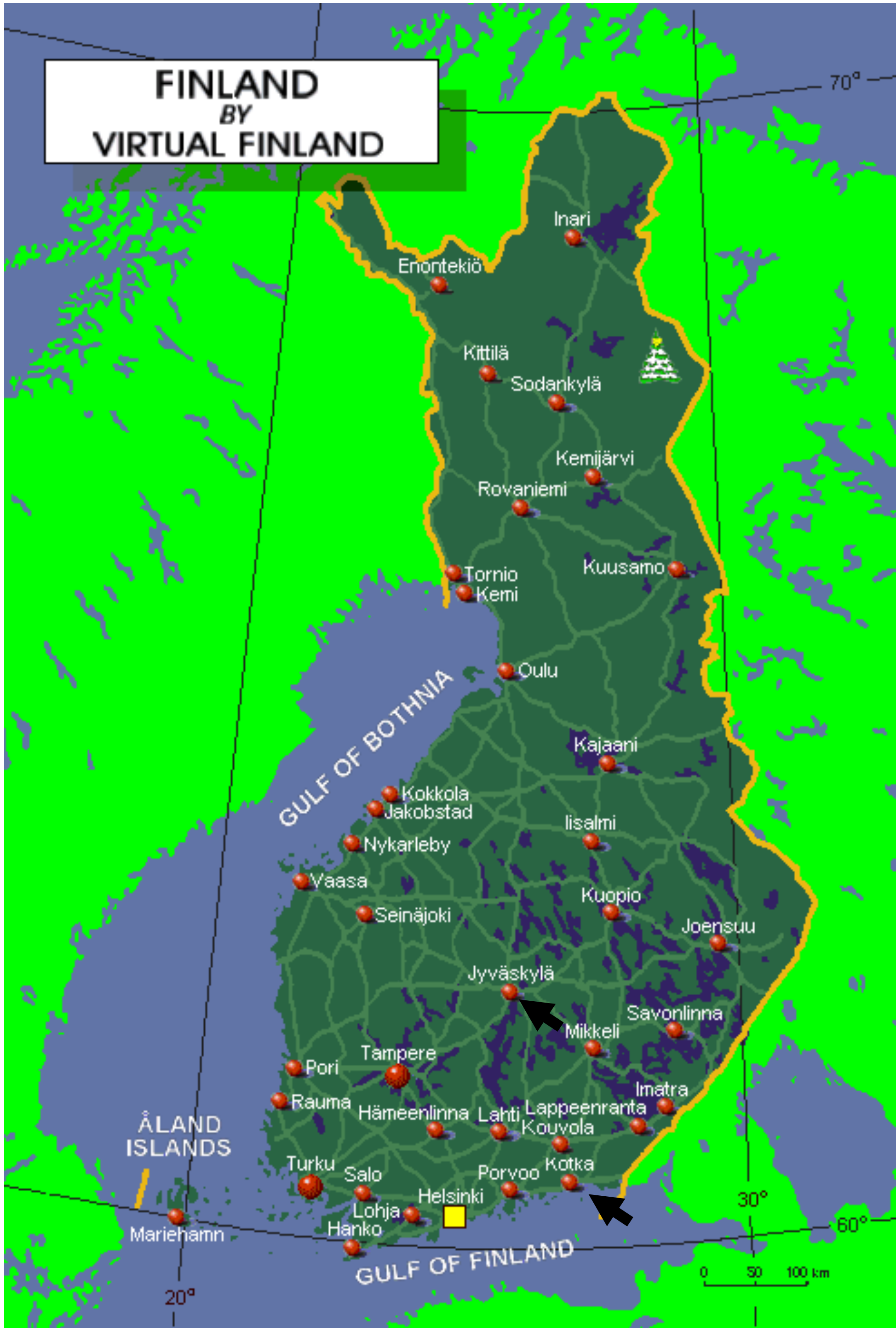

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Kymenlaakso Central Hospital, Kotka

Exercise physiologist:

- biomechanical lab (muscle performance, EMG, gait analysis, balance, exercise programs…)
- research work

Faculty of Sport and Health Sciences, University of Jyväskylä

Researcher / Lecturer in physiotherapy

(clinical biomechanics, gait analysis, therapeutic exercise in water…)

Aquatic exercise therapy research

- RCT studies → evidence based!

  ↓↑

- Physiological bases of aquatic exercises / Biomechanical bases of aquatic exercises

  "In regard to the design of progressive programs for physical conditioning and for therapeutic purposes, there has always been concern about the type, intensity, resistance and duration of the exercises"

  (Basmajian 1990)

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Physical properties of water
- effects on human physiology (brief overview)

PART 1

- Reduced gravity conditions
- Hydrostatic pressure
- Water temperature
  - circulation
  - heart
  - renal / pulmonary funtion
  - musculoskeletal system

PART 2

- Neuromuscular function in water (biomechanics)
  - water resistance
  - muscle function (EMG)
  - reflex sensitivity
  - effects of aquatic exercise programs on neuromuscular function

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Introduction:

water immersion → hydrotherapy

- Aquatic immersion has profound physiologic and biologic effects → immediate and delayed
- Immersion up to thorax and neck level!
- Circulation / heart (extensively studied, healthy)
  - Heart failure patients → promising results!
- Pulmonary function (studied, healthy, patients)
- Renal function (studied, healthy)
- Neuromuscular function / effects of aquatic training on neuromuscular function, RCT studies (poorly studied)

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Physiological and therapeutic effects of immersion in warm water

- Superficial circulation ↑
- Blood supply to muscles ↑
- Heart rate ↓
- General metabolic rate ↑
- Sensitivity of sensory nerve endings ↓
- General muscle relaxation
- Extensibility of collagen ↑
- Joint stiffness ↓
- Relieves pain and spasm
- Sedative effect
- Assists in resolution of inflammatory infiltrates, swelling

Haralson (1986), Genuario and Vegso (1990)

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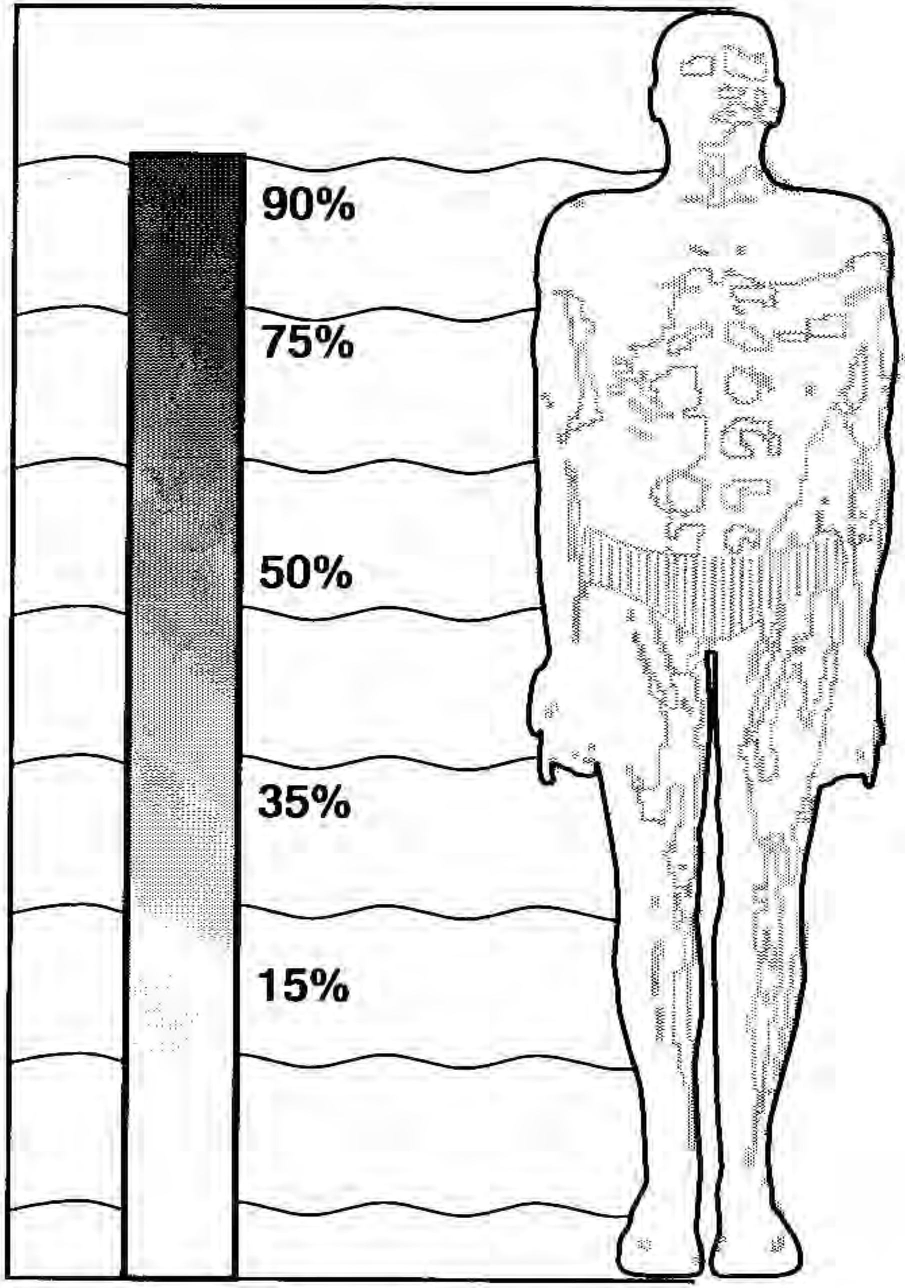
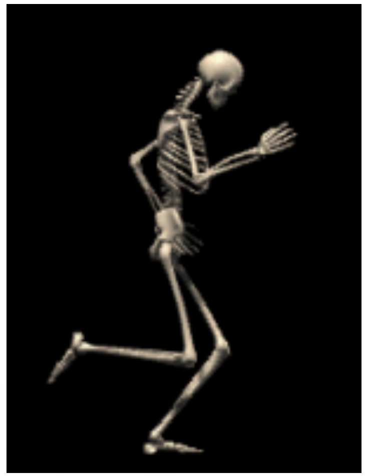


Figure 2-11. Percentage of body weight off-loaded with increasing immersion depth.

80%

50%

30%



Hydrostatic pressure

- A body immersed to a depth of 120 cm is subjected to a force equal to 90 mmHg (slightly greater than diastolic blood pressure) → 1mmHg/1.36cm of water depth
- Swimmers → 40-60mmHg
- Clinically → reduced effusion (exercise without effusion)
- Redistribution of blood volume → venous return (VR) is sensitive to water pressure → central circulation ↑
- VR is enhanced by the sift of blood from periphery into the chest cavity and finally into the heart

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Hydrostatic pressure → central shift of blood volume

→ **HEART**

Great chest cavity vessels

▲

Abdominal cavity vessels

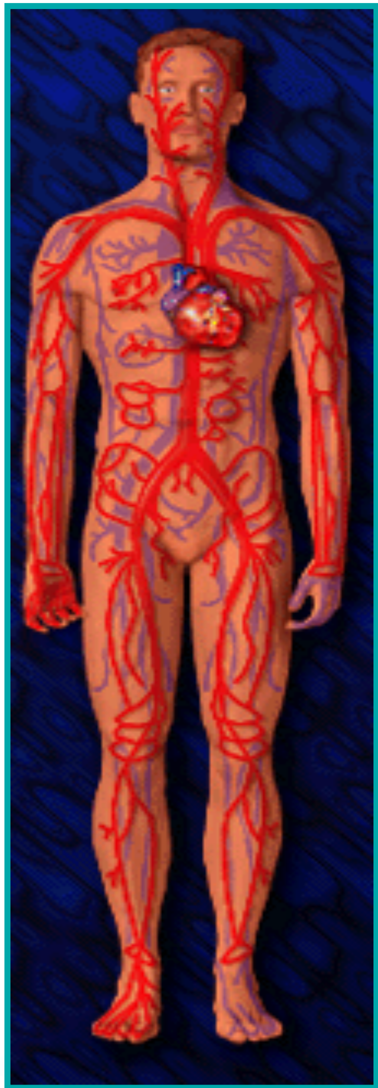
▲

Thighs

▲

Superficial venous compression

(▲ = blood flow)



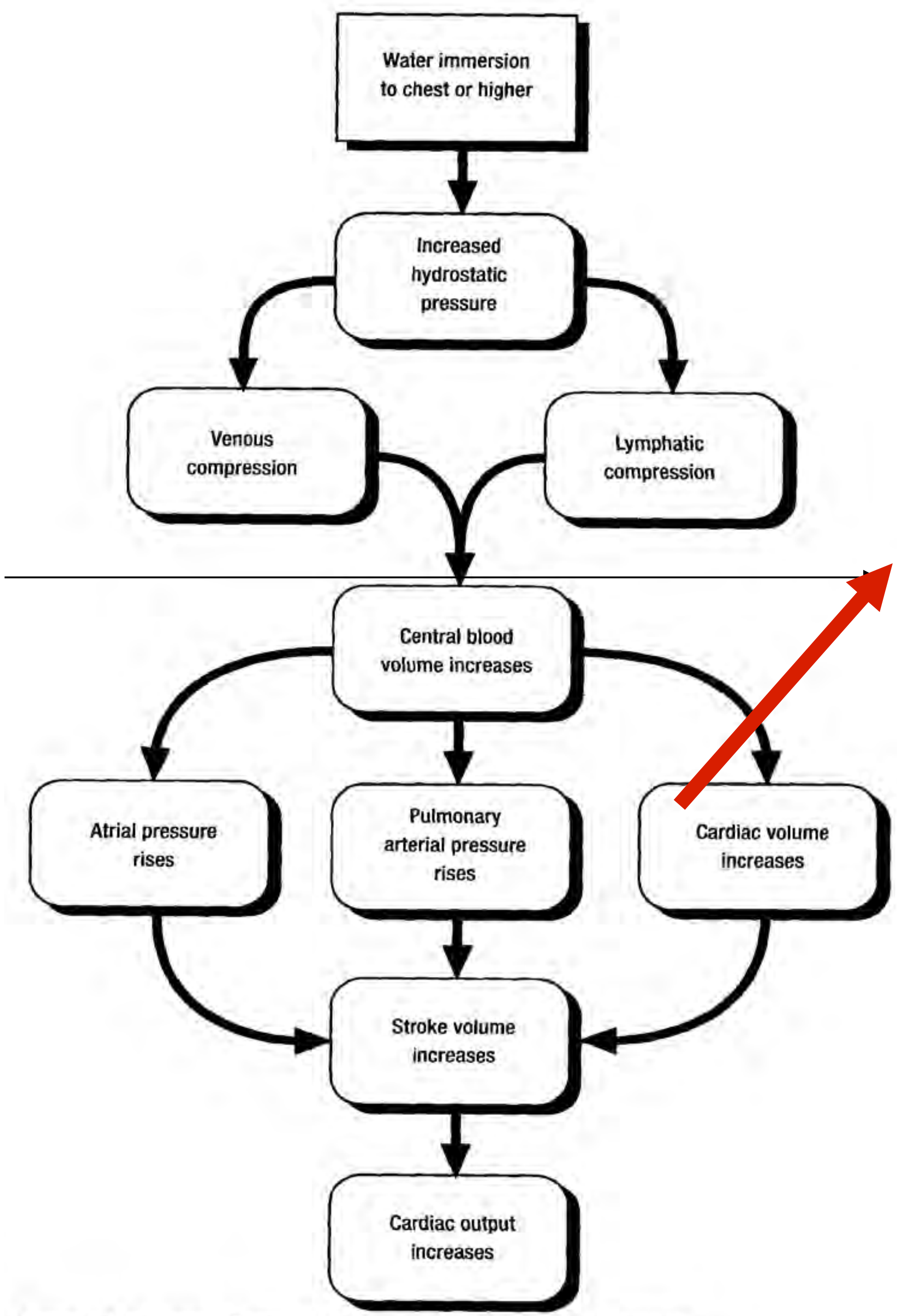


Figure 2-6. Schematic diagram of cardiovascular changes after immersion.

Cardiac blood volume increases (stretch, preload)

↓

Increased force of heart contraction, increased myocardial efficiency

↓

Increased stroke volume (SV)

↓

Increased cardiac output (SV x pulse rate /min)

↓

Heart rate drops

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Cardiovascular changes (mean)

- Central blood volume +700 ml (60%)
- Heart volume +180-250 ml (27-30%)
- Stroke volume +25 ml / beat (35%)
- Heart rate –12 to -15 bpm (12-15%)
- Cardiac output
  - resting person on land 5 l / min and in water 8.6l/min (30%) → cardiac exercise
  - younger persons up to +59%, older persons up to 22%

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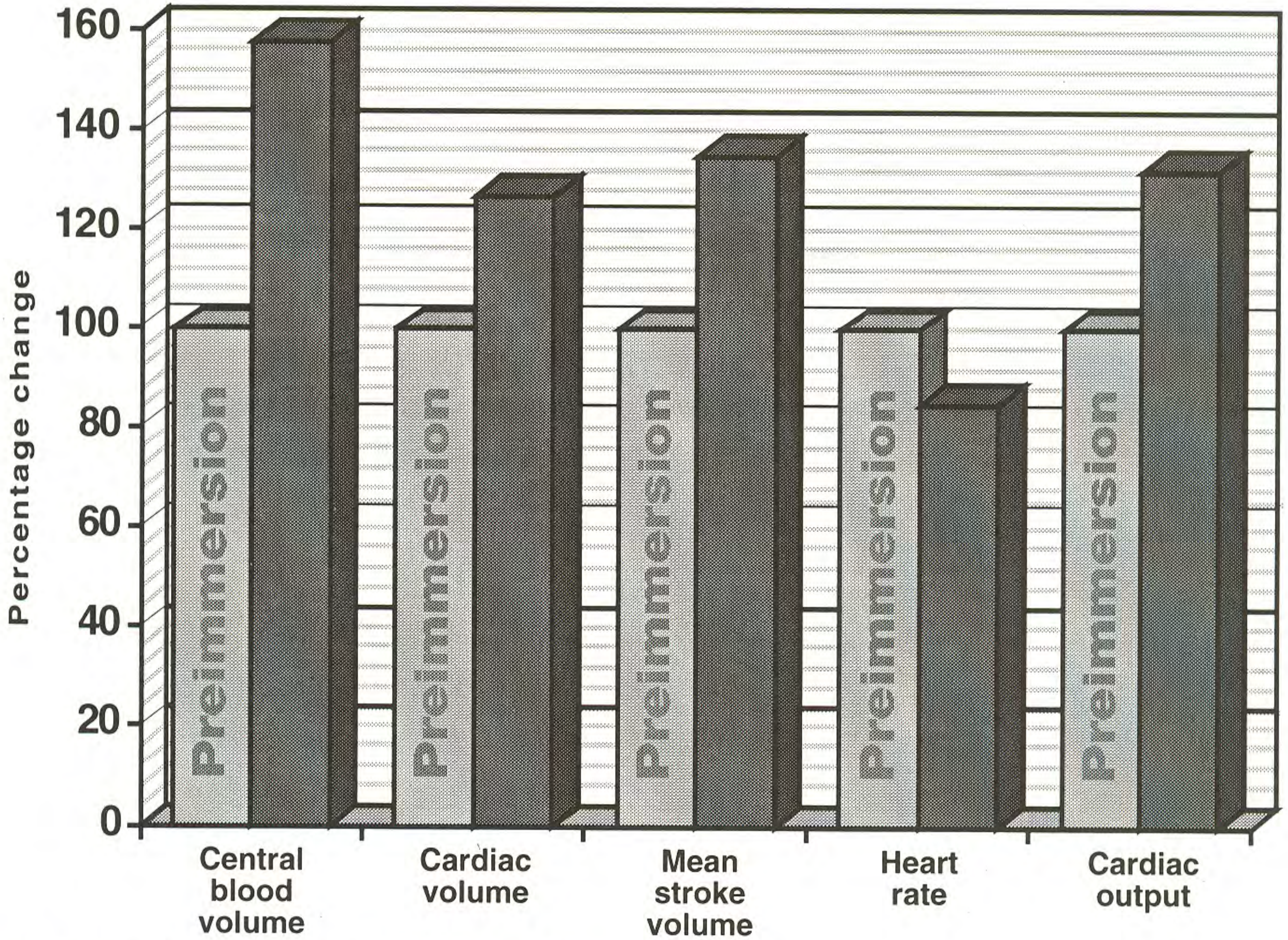
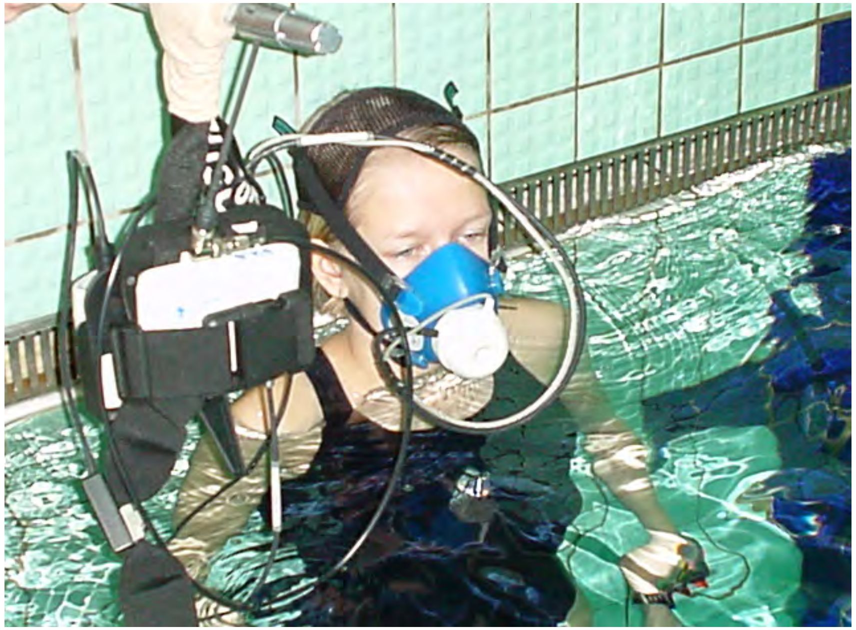


Figure 2-5. Cardiovascular changes after immersion.

Human cardiorespiratory responses to resting water immersion to the neck with changing body positions



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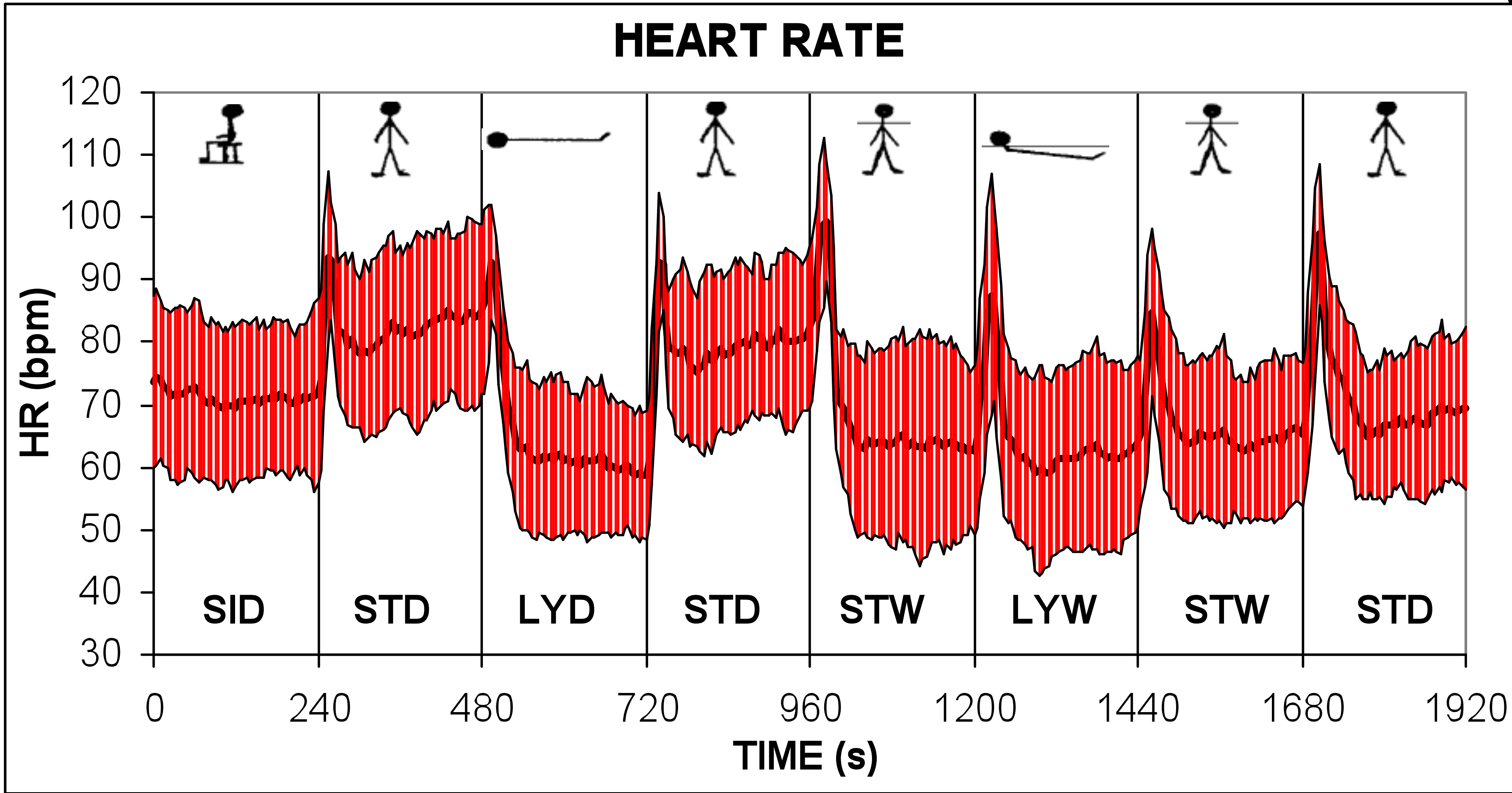
HUMAN CARDIORESPIRATORY RESPONSES TO RESTING WATER IMMERSION TO THE NECK WITH CHANGING BODY POSITIONS



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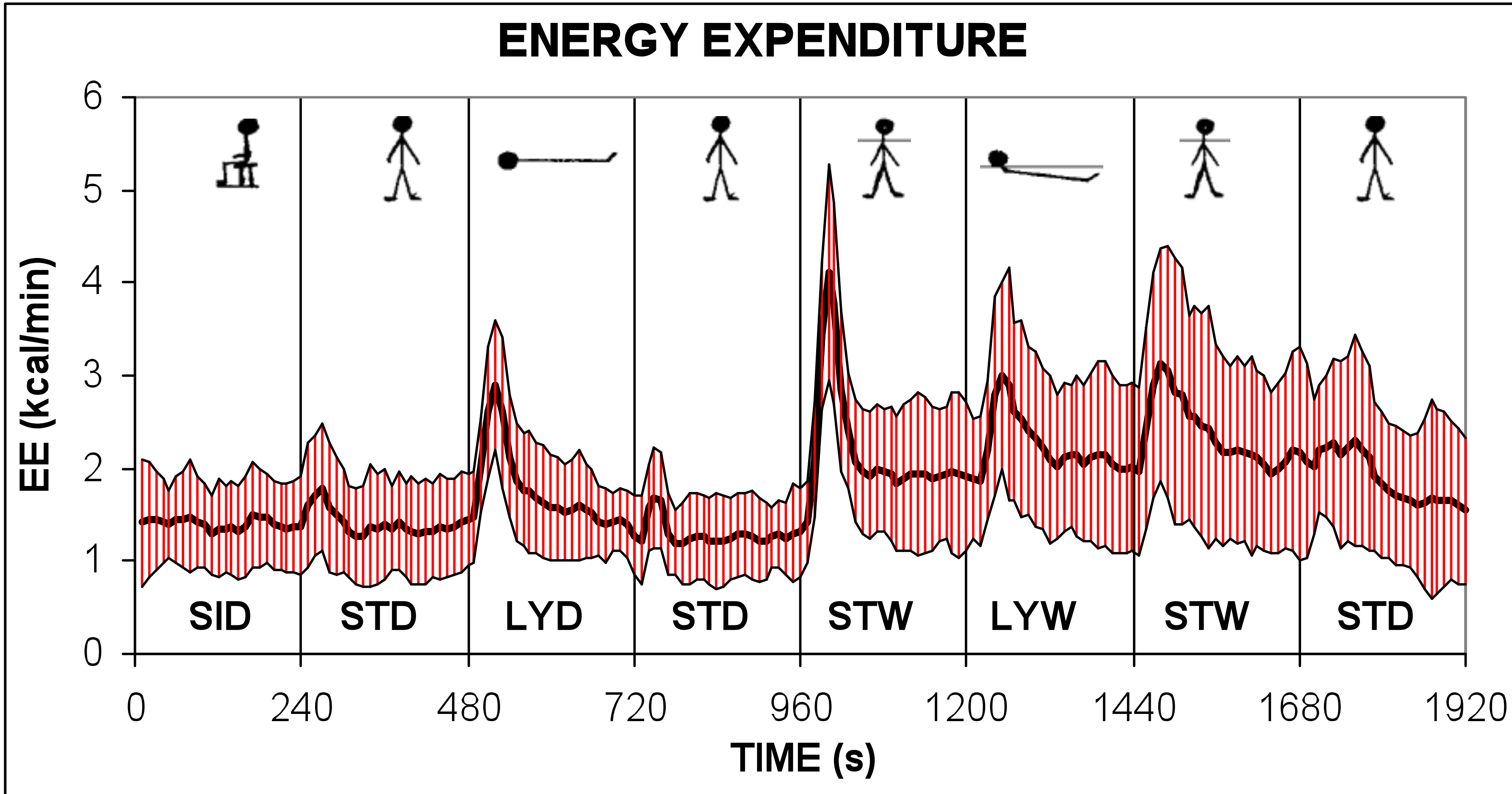
Increased EE during Water Immersion



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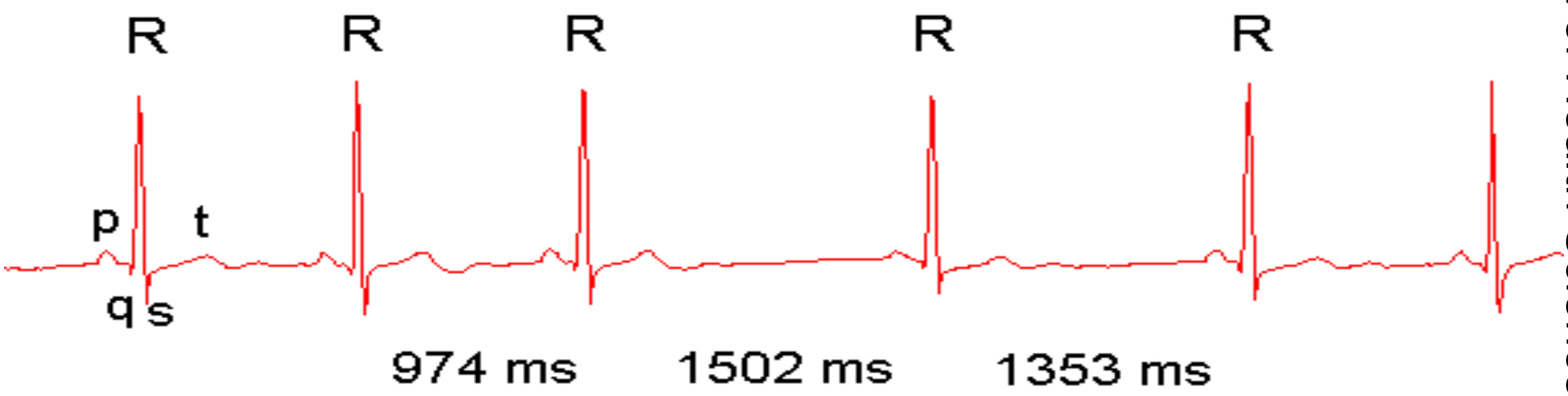
Autonomic nervous system: heart rate variability (HRV)

Symphatetic → heart rate ↑ (flight or fight)
Parasymphatetic → heart rate ↓
Vagal nerve controls / reduces hear rate (parasymphatetic)!



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Autonomic nervous system and HRV

- Physical exercise → vagal activity (parasymphatetic activity)↑ → heart rate variability↑ → heart problems↓
- Myocardial infarct → symphatetic activity↑ → heart rate↑ → HRV↓
- In water increased blood volume stretches the heart chambers activating mechano- and baroreceptors vagal nerve activation!
  – decreased sympathetic activity → effects on blood pressure, renal function, relaxation, muscle function (?), pain reduction (?) in water
- Perini et al (1996) reported increased HRV during water immersion at rest

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Cardiovascular autonomic function during head-out water immersion

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PURPOSE

To investigate the association between cardiovascular autonomic regulation and head-out water immersion

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METHODS

- 16 healthy females (33 ± 9 yr.)
- A patient elevator chair
- Dry land 5 min (baseline), water 5 min
- Temperature: room 27° C and water 35° C

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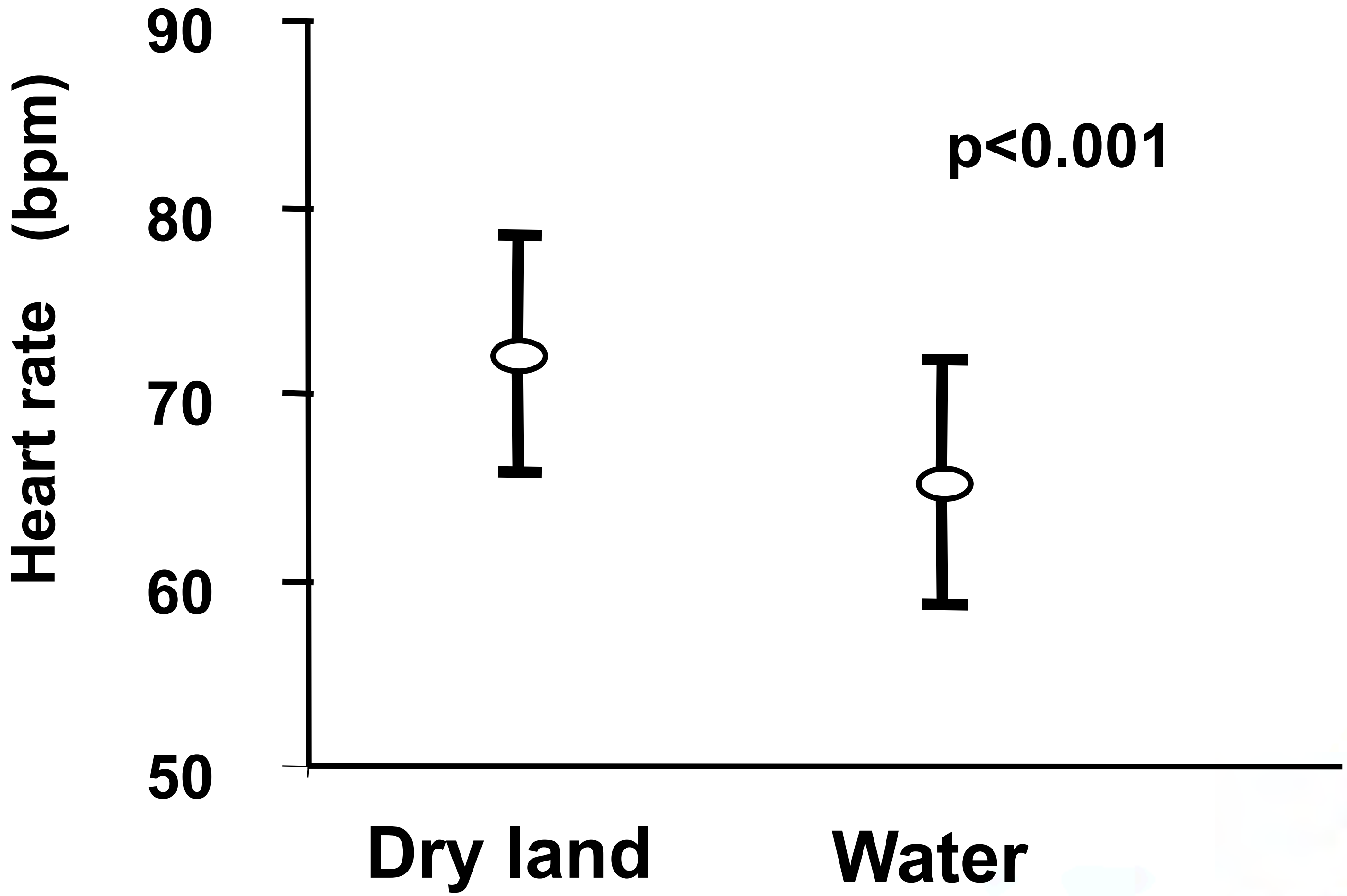
Heart rate



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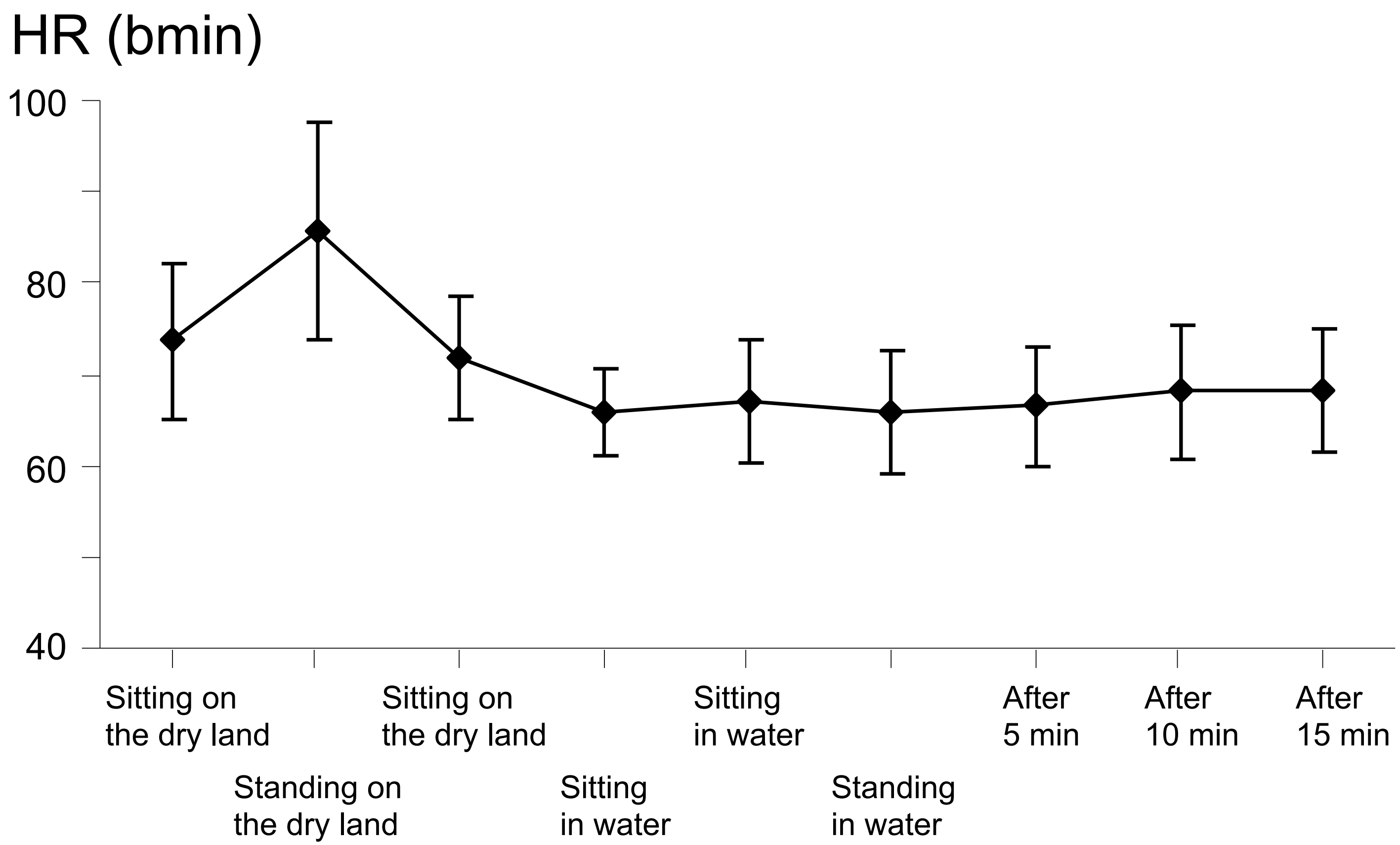

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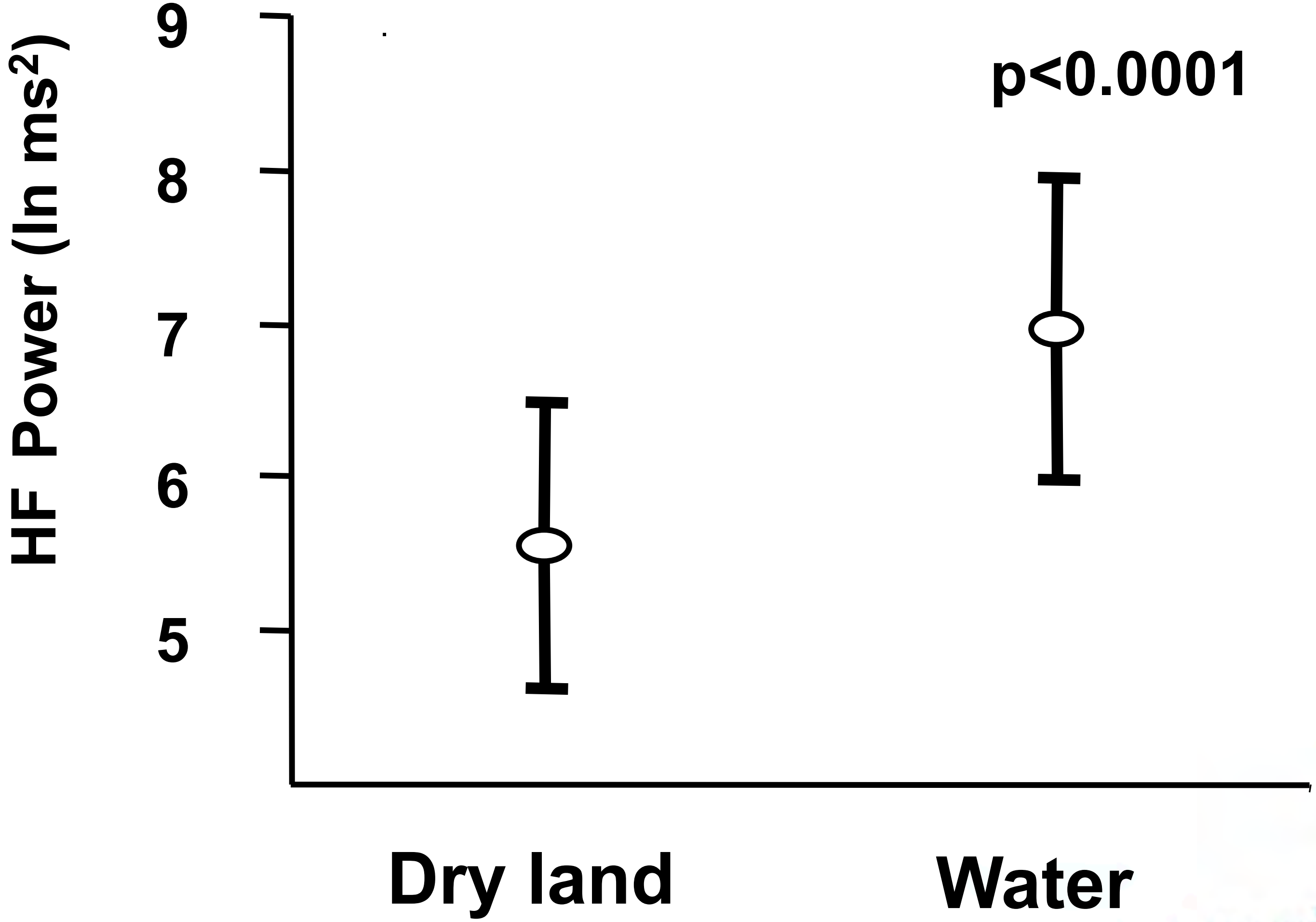
High frequency power (vagal activity)



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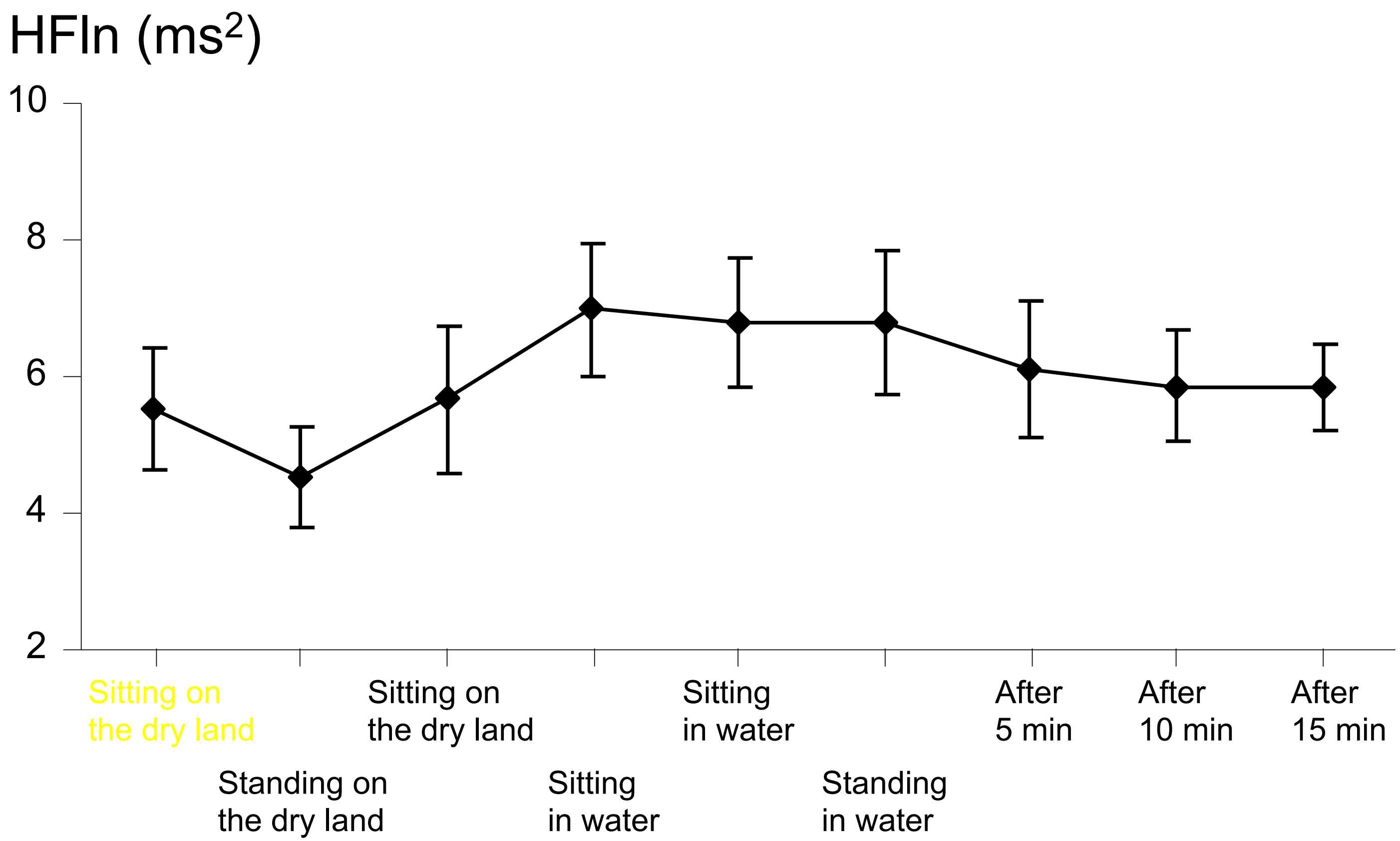

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Vagus nerve stimulation and Cytokine production: the cytokine theory of disease

- Cytokine production by the immune system contributes importantly to both health and disease
- Health requires that cytokine production is balanced (low levels)
- Overproduction of some cytokines seem to cause dieseases → in arthritis some cytokines (TNF, IL-1 or HMGB1 cause tissue damage, atrophy…
- Stimulation of the vagus nerve prevents the damaging effects of cytokine overproduction → inflammation ↓ edema ↓
- *Water environment stimulates the vagus nerve!*

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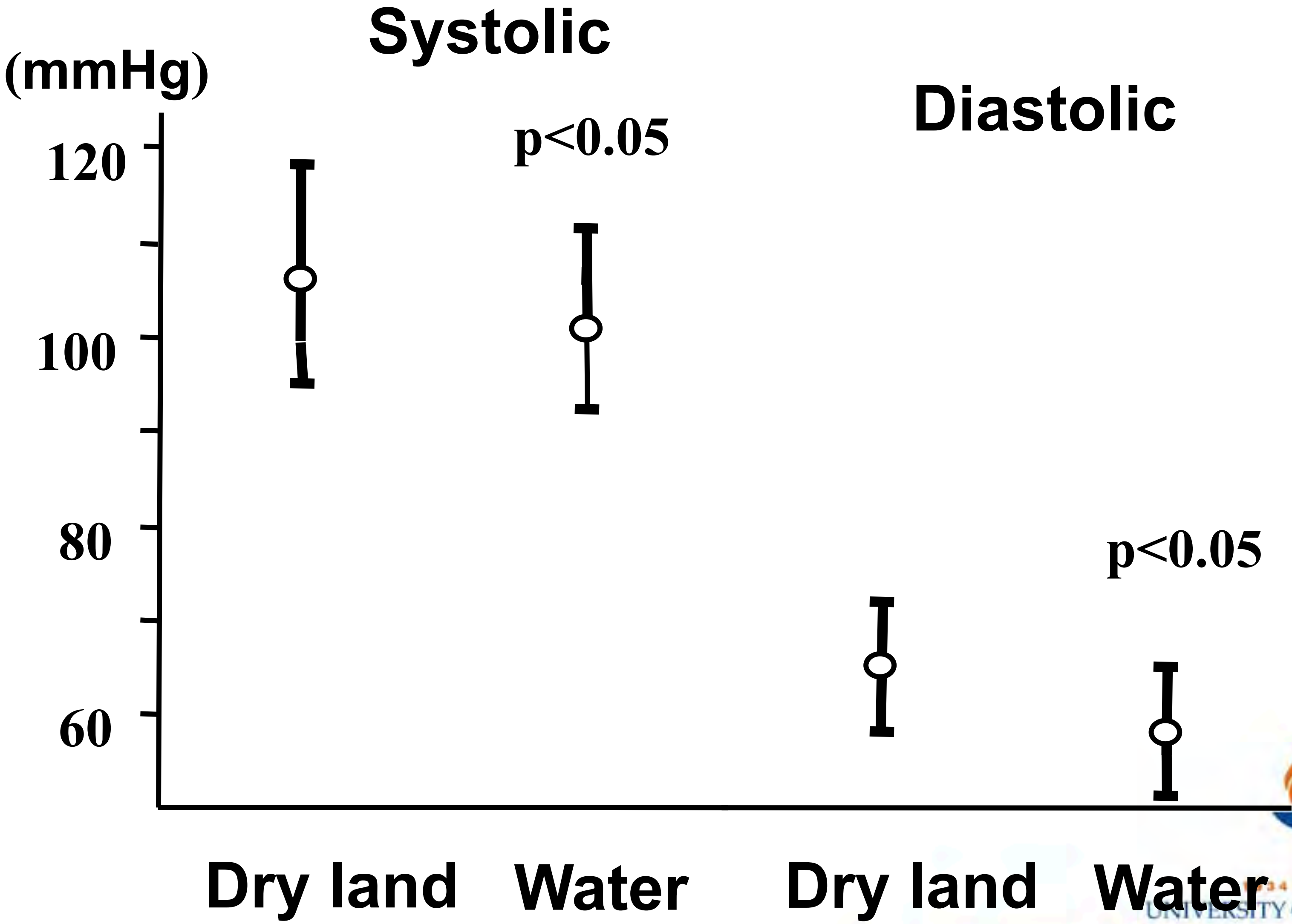
Blood pressure



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Water immersion and blood pressure

- In literature → blood pressure BP has been reported to slightly increase (immediately), *decrease*, no effect in persons with normal BP
- BP regulation during immersion → combined effects of cardiovascular, autonomic and renal responses
- Some evidence → subjects with hypertension showed significant decrease in BP during 2-hour extended immersion → effects lasted many hours thereafter

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Today / future

- Long term effects of water immersion on cardiovaskular autonomic function (healthy)
  - pre -heart rate recordings 24 h on dry land
  - water immersion 1-2 h
  - post –heart rate recordings 24 h on dry land
- Cardiovascular autonomic function during exercise
- Patients suffering from hypertension
- Patients after myocardial infarct

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Table 2-4. Temperature Effects Upon Biologic Functions in Young Males

	Water Temperature		
Fluid	**Cold (15°C)**	**Neutral (35°C)**	**Hot (44°C)**
Heart rate	–15%	–15%	32%
Stroke volume	19%	39%	9%
Cardiac output	–1%	18%	44%
Systolic blood pressure*,†	19%	–8%	–17%
Diastolic blood pressure*,†	2%	–7%	–14%
Peripheral vascular resistance‡	–32%	–14%	–32%
Diuresis	365%	400%	225%
Muscle blood flow	80%	44%	4%

Data from Bonde-Petersen et al: Aviat Space Environ Med 63:346–350, 1992.

*Craig & Dvorak, J: Appl Physiol 21(5):1577–1585, 1966.

†Allison, et al: Mayo Clin Proc 68:19–25, 1993.

‡Nakamitsu, et al, J Appl Physiol 77(4):1919–1925, 1994.

Water immersion and pulmonary system

- The pulmonary system is profoundly affected
- Blood shift into the chest cavity, compression of the chest walls by water → increase the work of breathing (60%)
- Increased work occurs mostly during inspiration → function of primary and accessory muscles of respiration at higher workloads
- Inspiratory muscle weakness is a component of many diseases: heart failure, lung diseases, muscle dystrophy
- Inspiratory muscle strenghtening exercises in water seem to be effective in improving exercise capacity of patients and even in elite athletes.

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Water immersion and renal system

- Effects on renal blood flow, regulation and endocrine system → extensively studied
- Immediately after immersion blood flow to kidneys increases (10%) → renal efficiency ↑
- Vagal responses decrease renal sympathetic activity → sodium transport ↑ → sodium excretion ↑
- Immersion induced central volume expansion
  - Increased urinary output (diuresis), 250% ↑
  - Increased sodium and potassium excretion
- Time and depth dependent phenomenon
- Immersion reduces normal thirst mechanisms → patients, therapists → cooling down period!

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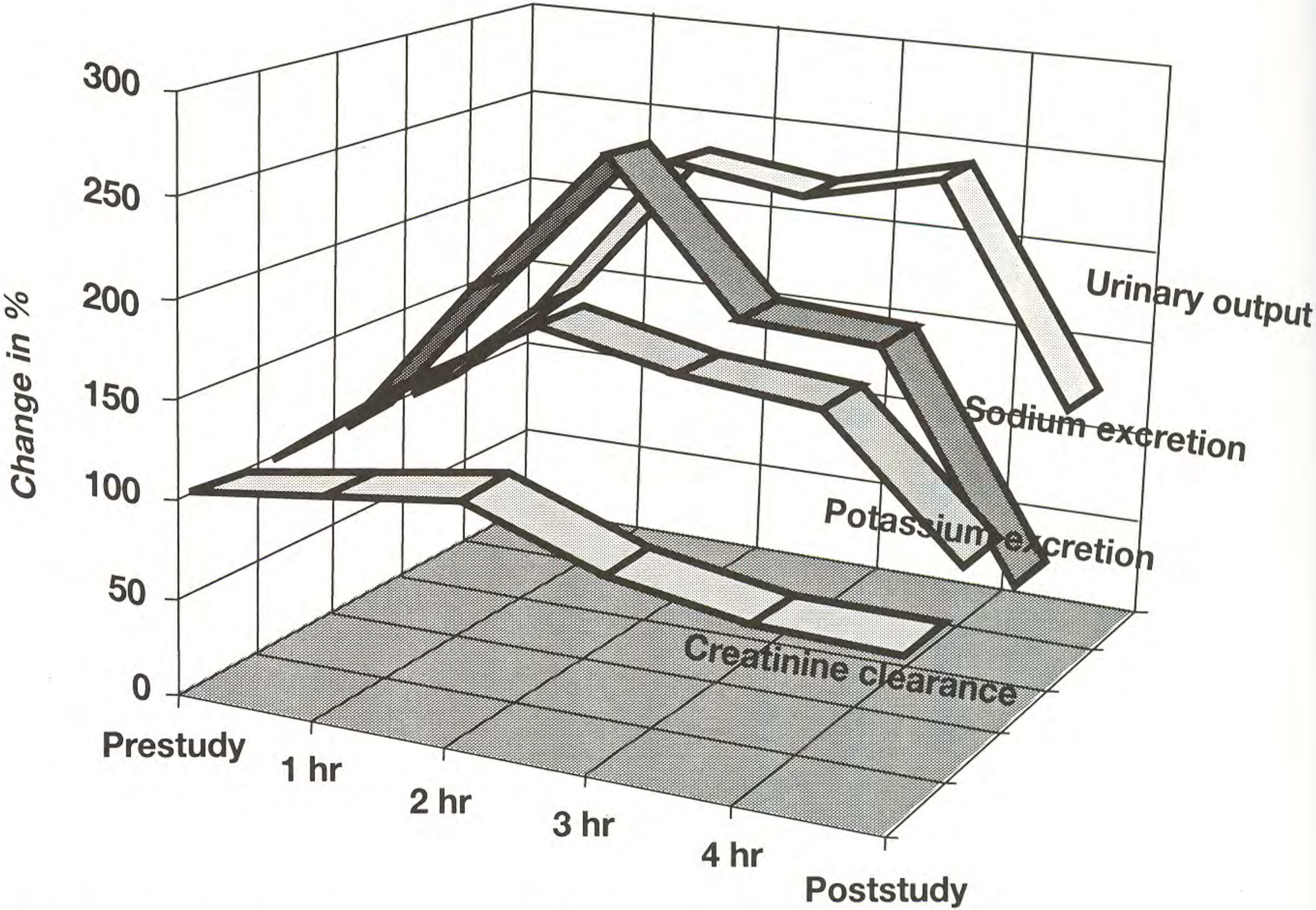

Figure 2-15. Renal function changes during immersion.

Musculoskeletal system

- Most of the increased cardiac output is redistributed to muscles and skin
- Resting muscle blood flow increased from1.8 to 4.1 l/min/ 100g of muscle tissue (neck immersion)
  - exercising muscle blood flow?
- Immersion at rest
  - oxygen delivery increased
  - circulatory drive to remove muscle metabolic waste products is increased
  - decreased sympathetic vasoconstriction → decreased peripheral resistance → increased muscle blood flow and decreased blood pressure

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