
DIVING

METABOLIC EFFECTS OF AQUATIC ACTIVITY

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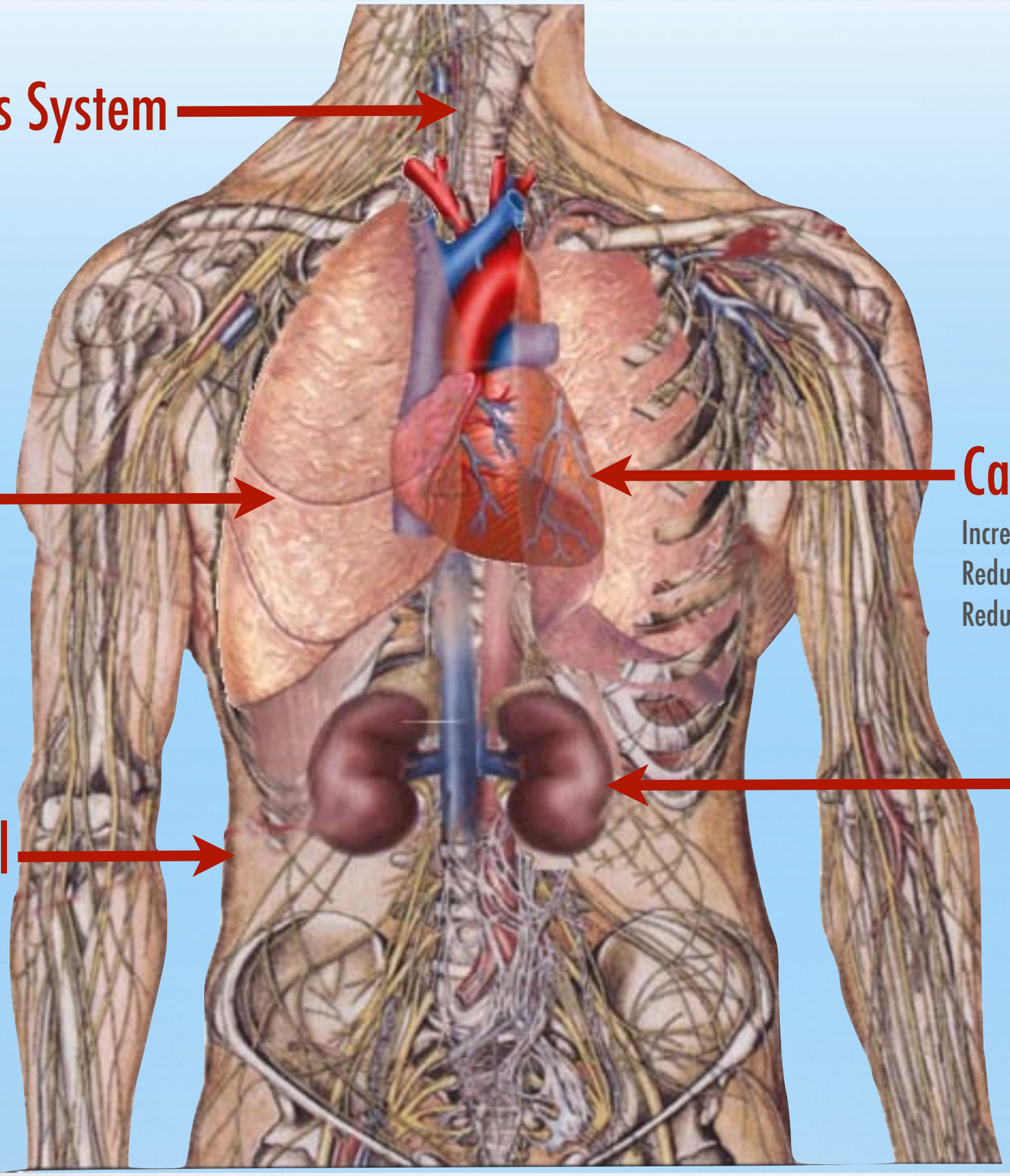
Aquatic Immersion Effects on the Human Body



Central Nervous System

Increases autonomic balance
May increase brain blood flow
Produces relaxation

Respiratory

Increases work of breathing allowing strengthening of respiratory musculature

Musculoskeletal

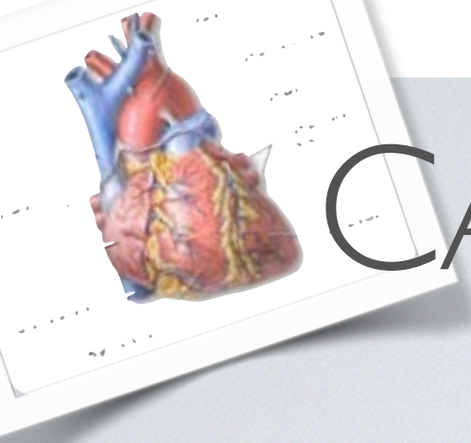
Increases muscle blood flow
Offloads bones and joints
Reduces pain

Cardiovascular

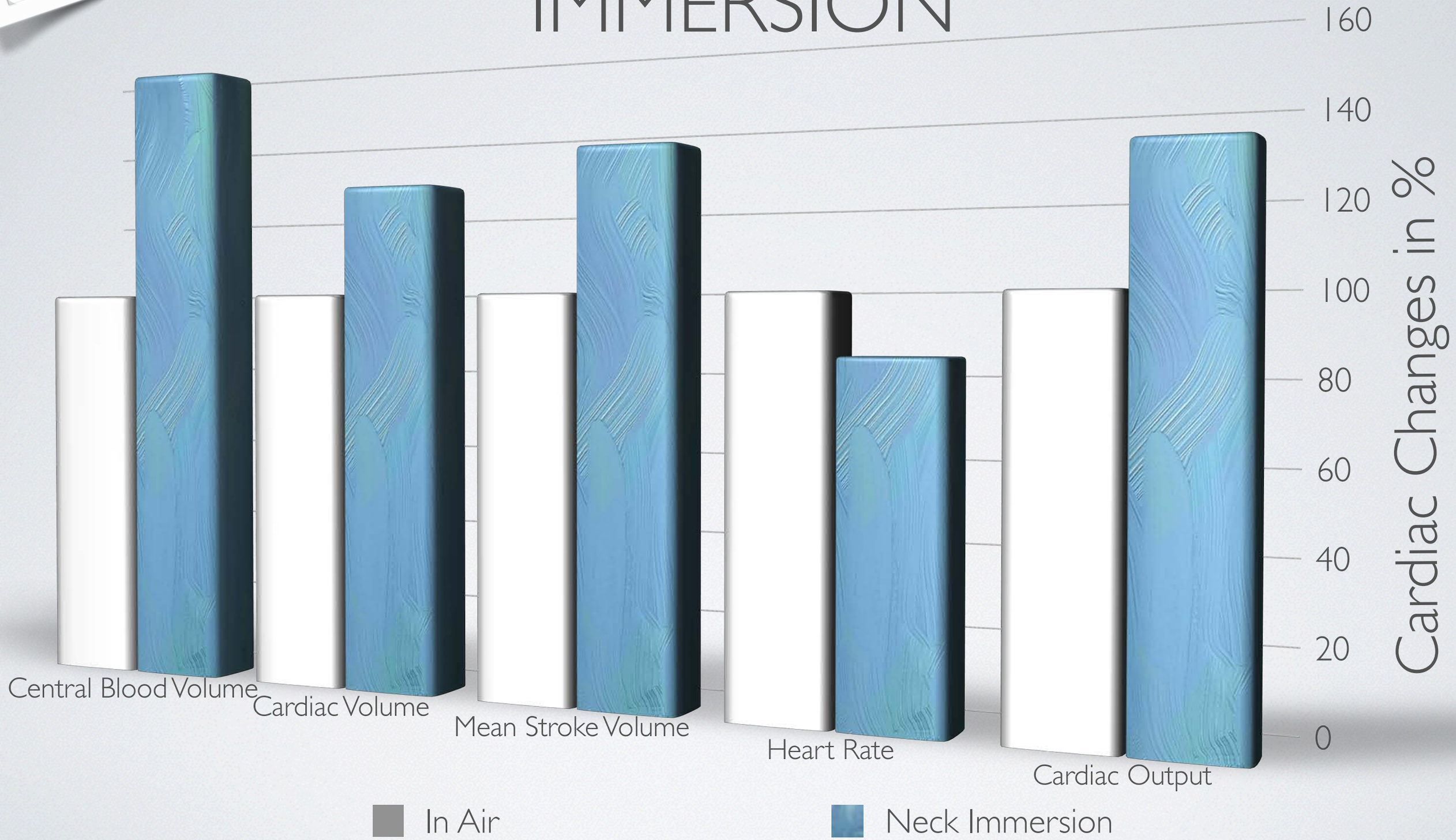
Increases stroke volume and cardiac output
Reduces circulatory resistance
Reduces blood pressure

Renal

Increases renal blood flow
Improves renal function
Facilitates sodium excretion



Cardiac Changes during Immersion



Arborelius, M., Jr., U. I. Balldin, et al. (1972). "Hemodynamic changes in man during immersion with the head above water." Aerosp Med 43(6): 592-598.

Water Immersion to chest or higher

Increased hydrostatic pressure

Venous compression

Lymphatic compression

Central blood volume increases

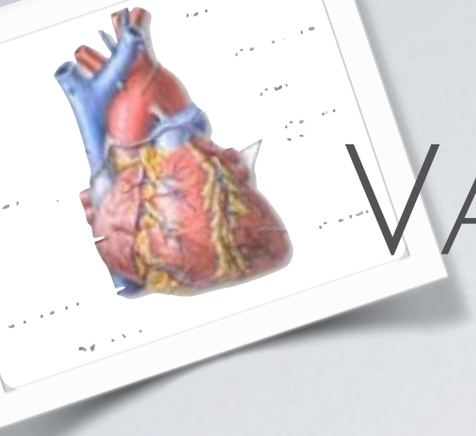
Atrial pressure rises

Pulmonary Arterial Pressure rises

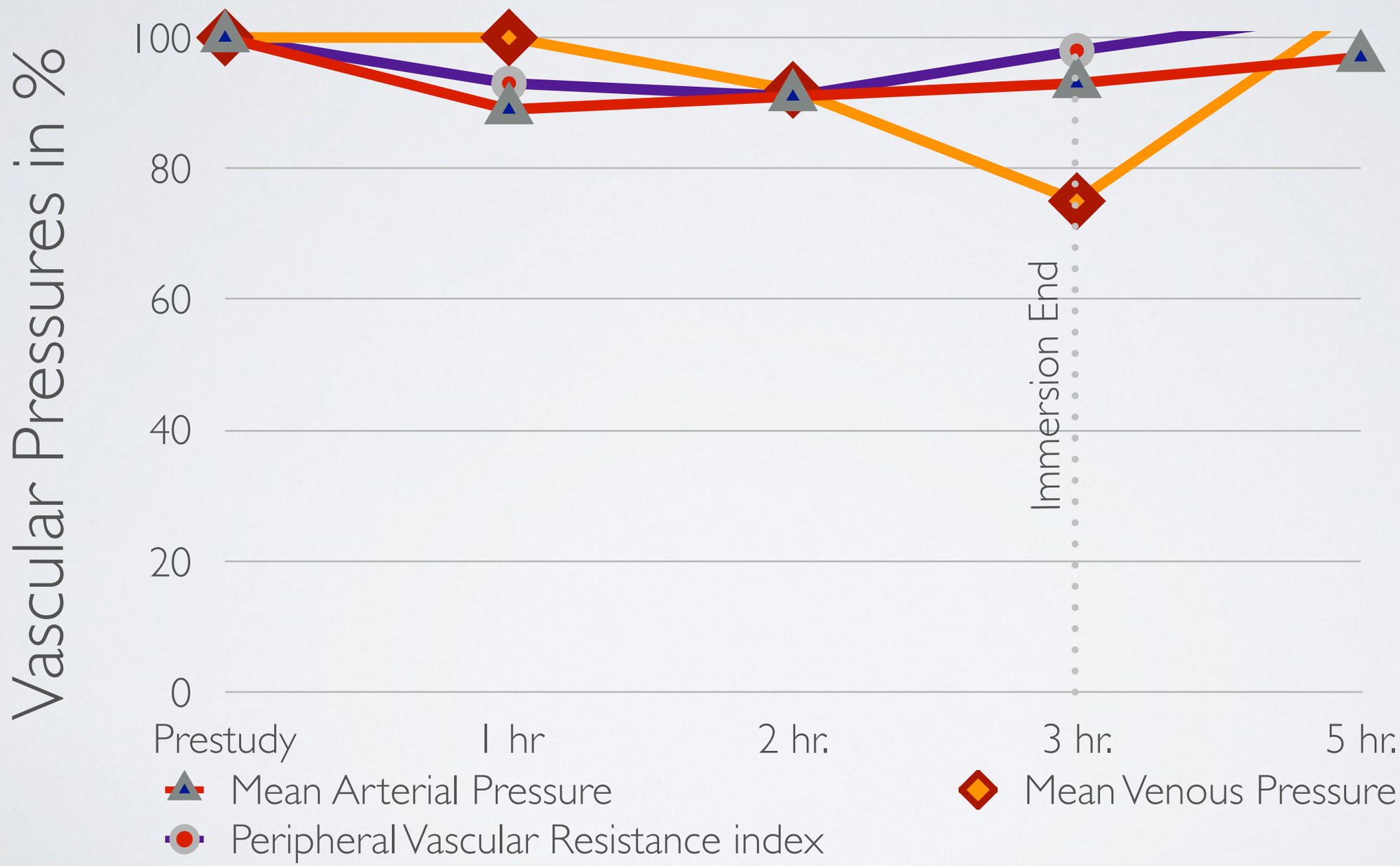
Cardiac volume increases

Stroke volume increases

Cardiac output increases



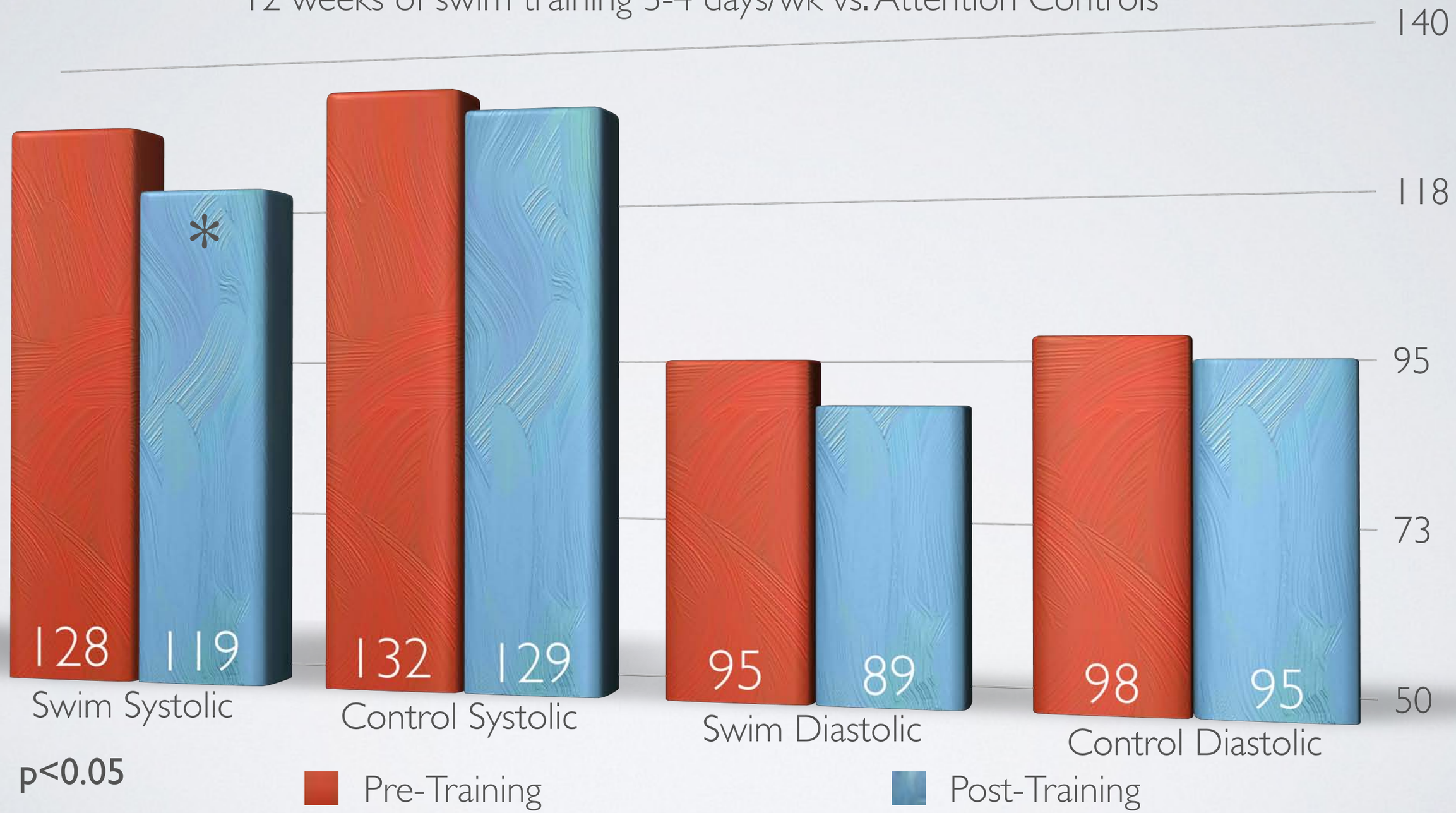
Vascular Pressures during Immersion



Arborelius, M., Jr., U. I. Balldin, et al. (1972). "Hemodynamic changes in man during immersion with the head above water." Aerosp Med 43(6): 592-598.

Effects of Swim Training on Blood Pressure (mmHg)

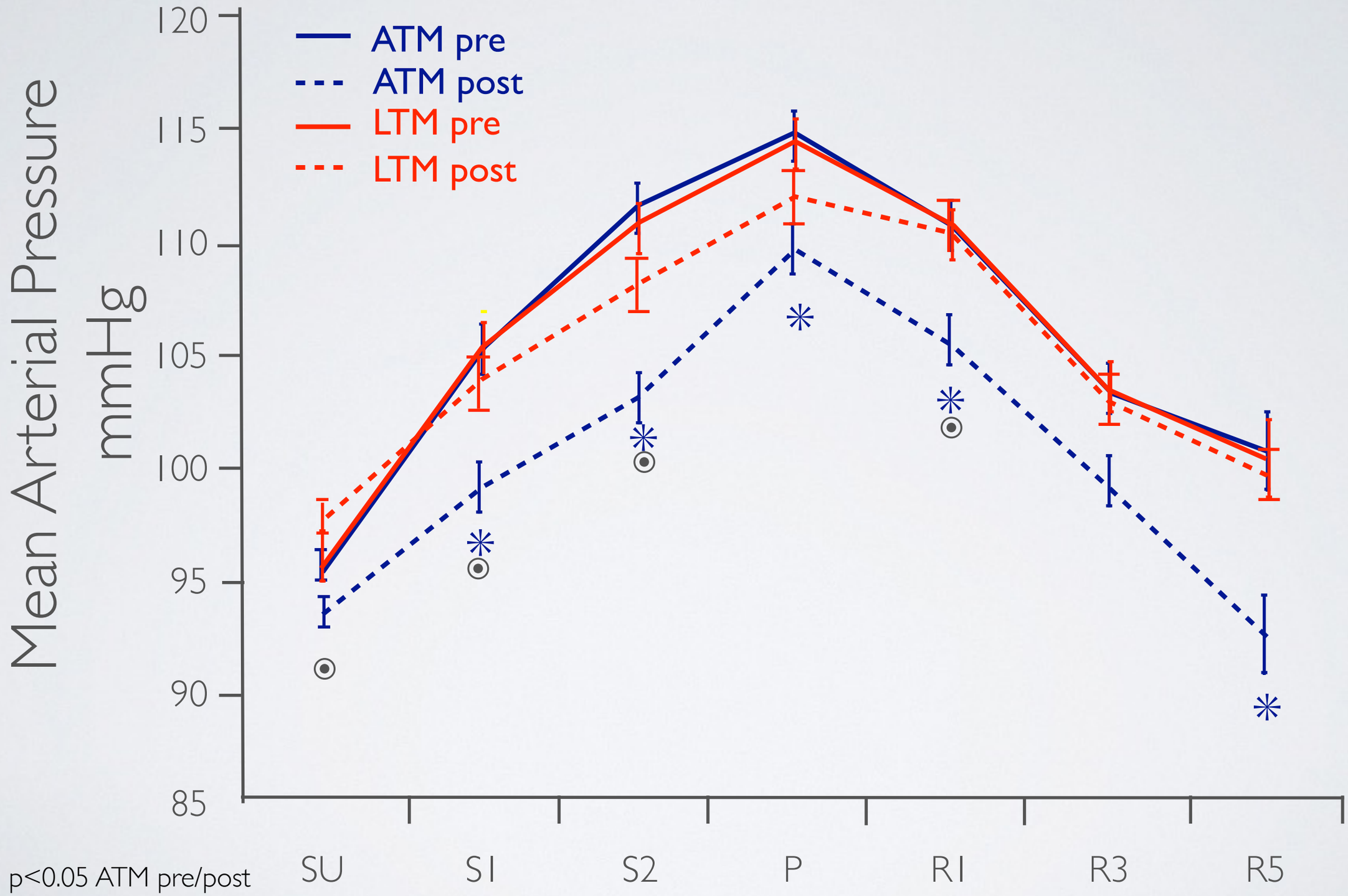
12 weeks of swim training 3-4 days/wk vs. Attention Controls



* $p<0.05$

Source: Nualnim et al, Effects of Swimming Training on Blood Pressure and Vascular Function in Adults >50 Years of Age, Am. J of Cardiol, 109(7),2012, 1005-1010

Aquatic Treadmill Exercise and Exercising Blood Pressure



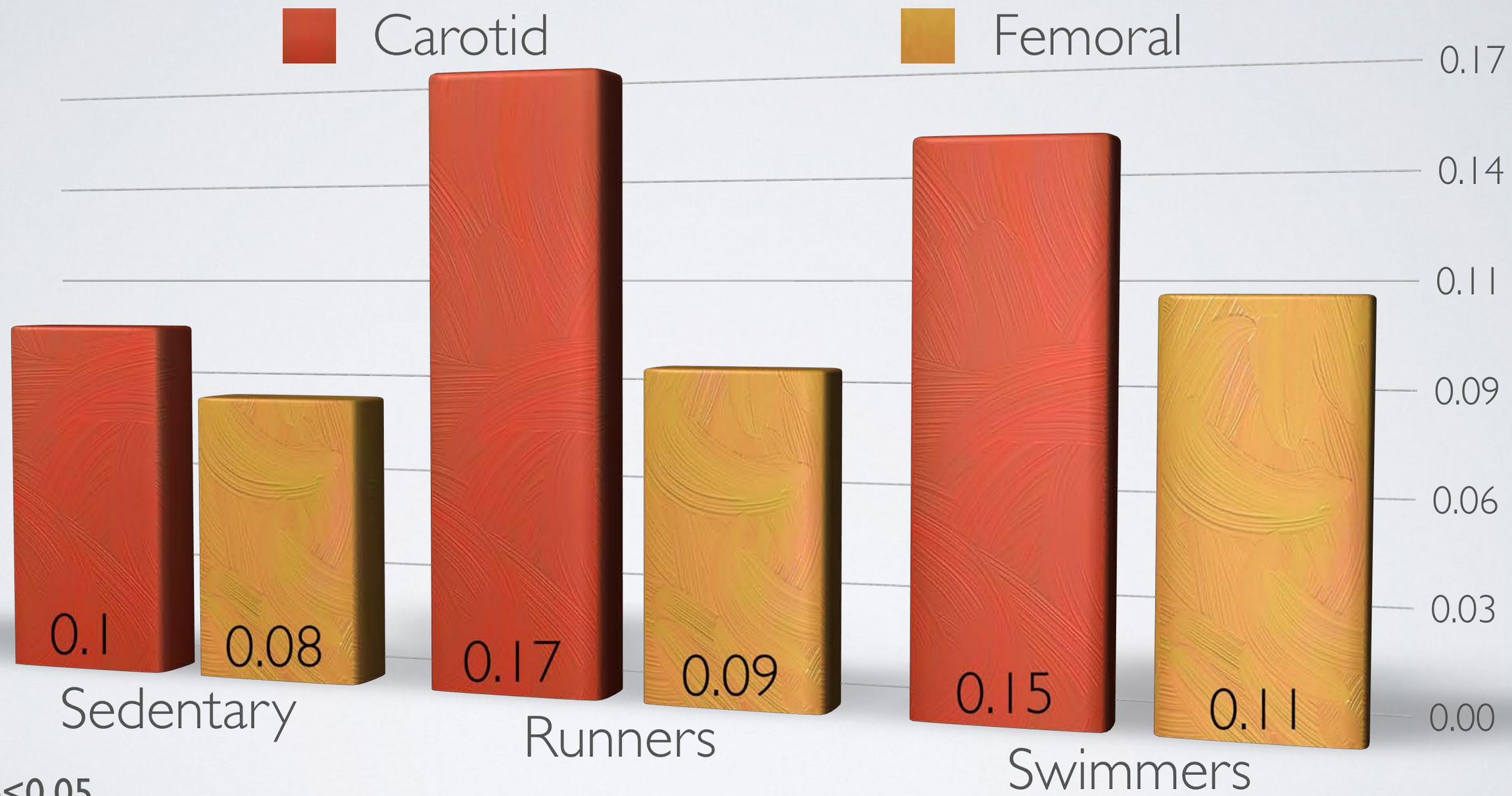
* p<0.05 ATM pre/post

⦿ p<0.05 LTM to ATM

Lambert et al, Aquatic Treadmill Training Reduces Blood Pressure Reactivity to Physical Stress, MSSE 46:4, 809-816

Arterial Compliance Comparisons

$mm^2/mmHg$

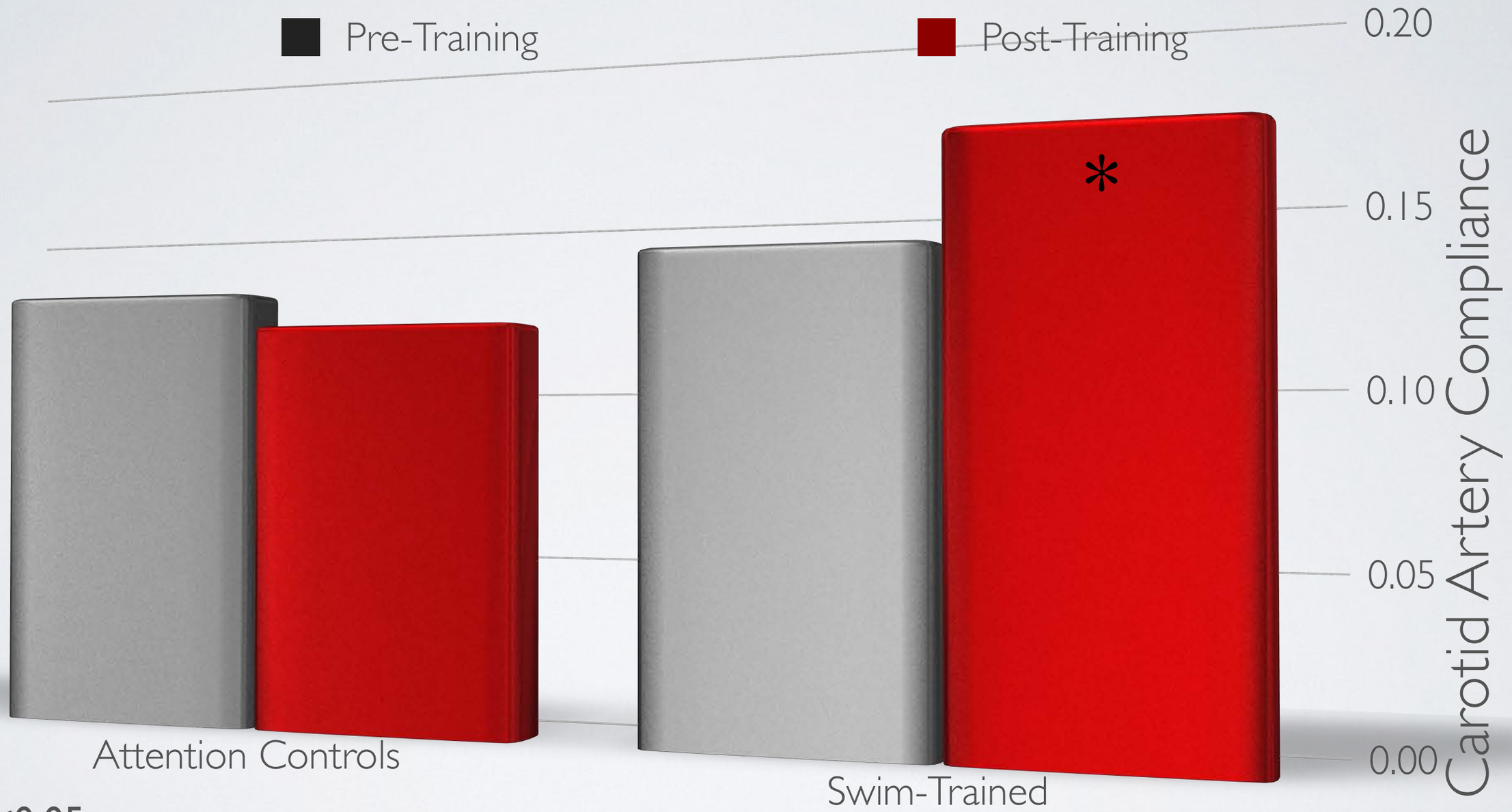


* $p<0.05$

Source: Nualnim N, Barnes JN, Tarumi T, Renzi CP, Tanaka H. Comparison of central artery elasticity in swimmers, runners, and the sedentary. *The American journal of cardiology*. Mar 1 2011;107(5):783-787.

Effects of Swim Training on Carotid Artery Compliance

12 weeks of swim training 3-4 days/wk vs. Attention Controls



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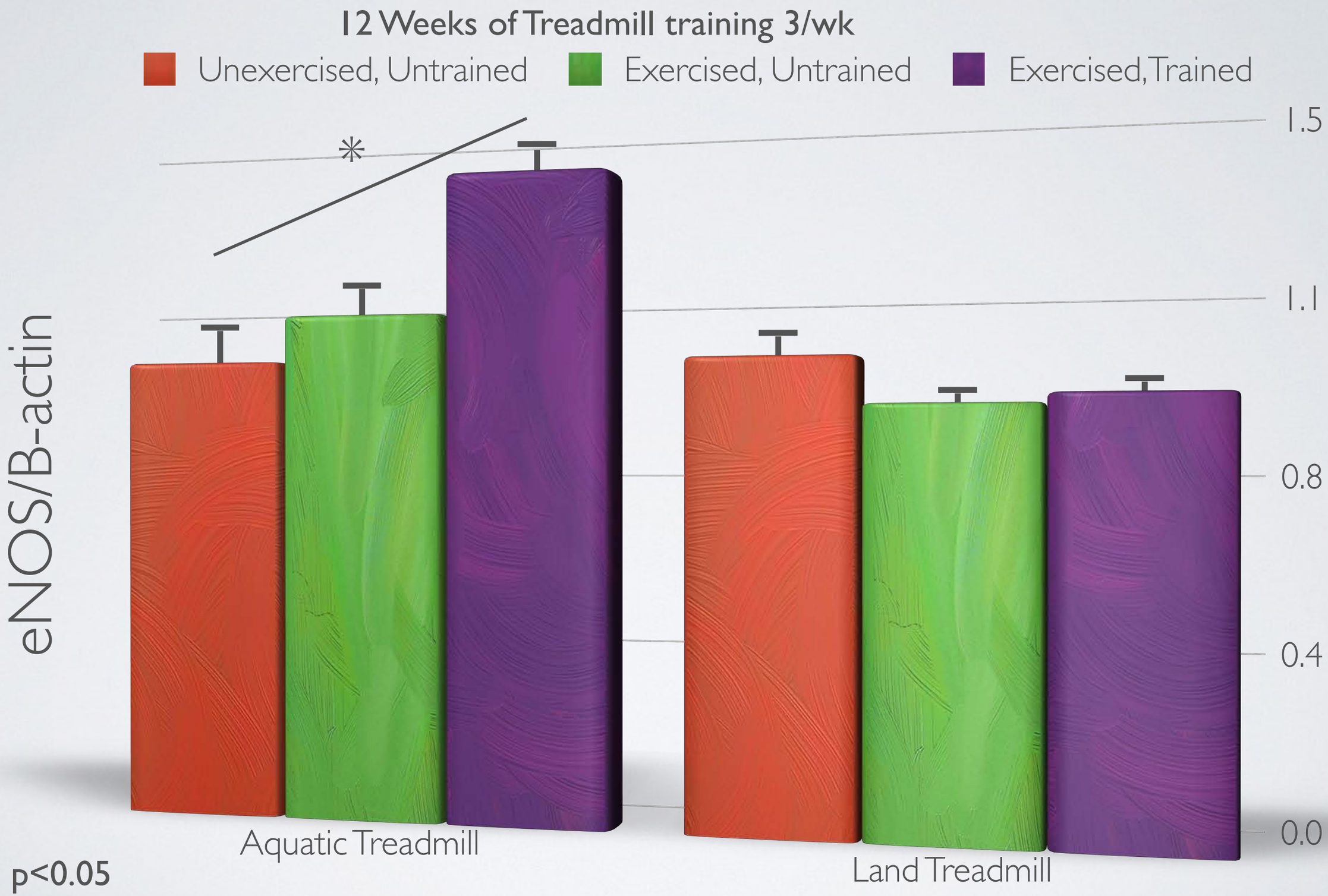
Endothelial Function Change



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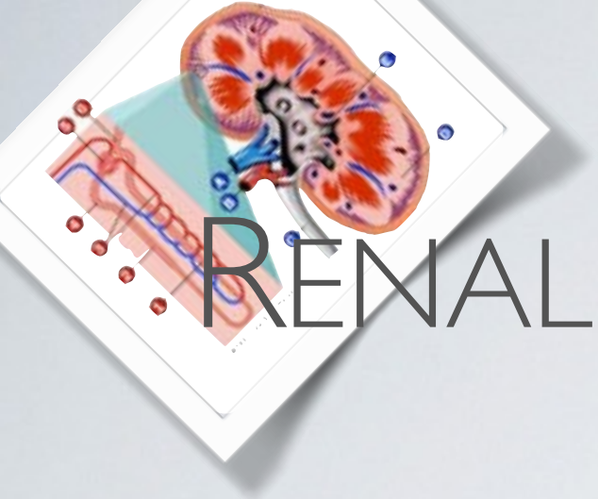
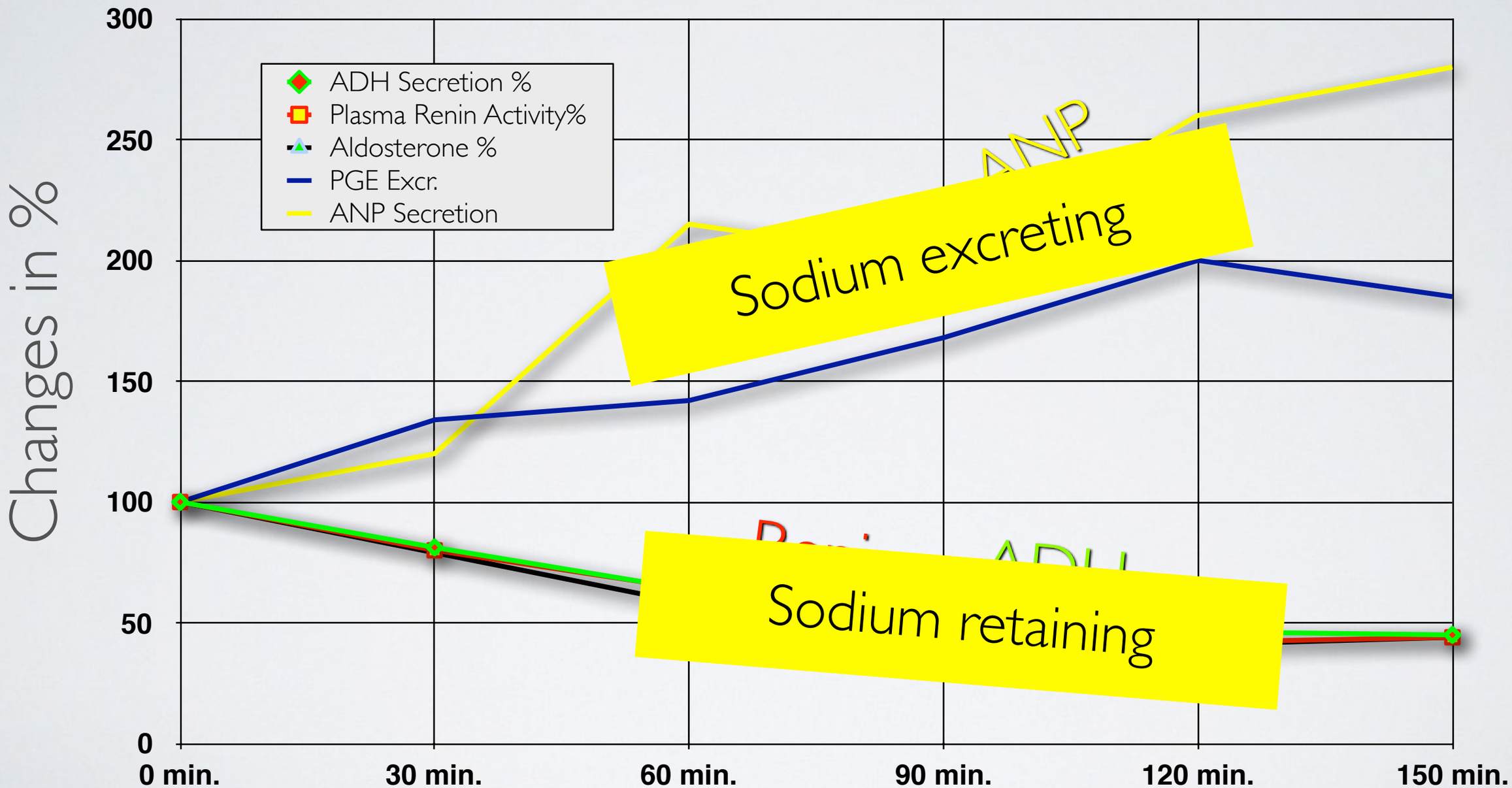
Source: Lambert et al, Aquatic Treadmill Training Reduces Blood Pressure Reactivity to Physical Stress, MSSE 46:4, 2014, 809-816

Lipid Metabolism Basics

- Exercise promotes lipid mobilization and free fatty acid release from adipose tissue and other fat deposits
- Fat oxidation rates increase from low to moderate exercise, but can decrease beyond that (exercise intensity determines magnitude of lipolysis)
- Exercise oxidizes mobilized fat in muscle tissue
- This process is impaired in many obese individuals, esp. in Type 2 DM
- The main hormonal regulators of lipid mobilization are insulin, catecholamines and ANP
- ANP stimulates lipolysis from human adipocytes as well as oxidizing lipids from serum postprandially
- **Immersion increases ANP release through atrial stretch receptors**
- **Immersion reduces resting catecholamine levels**

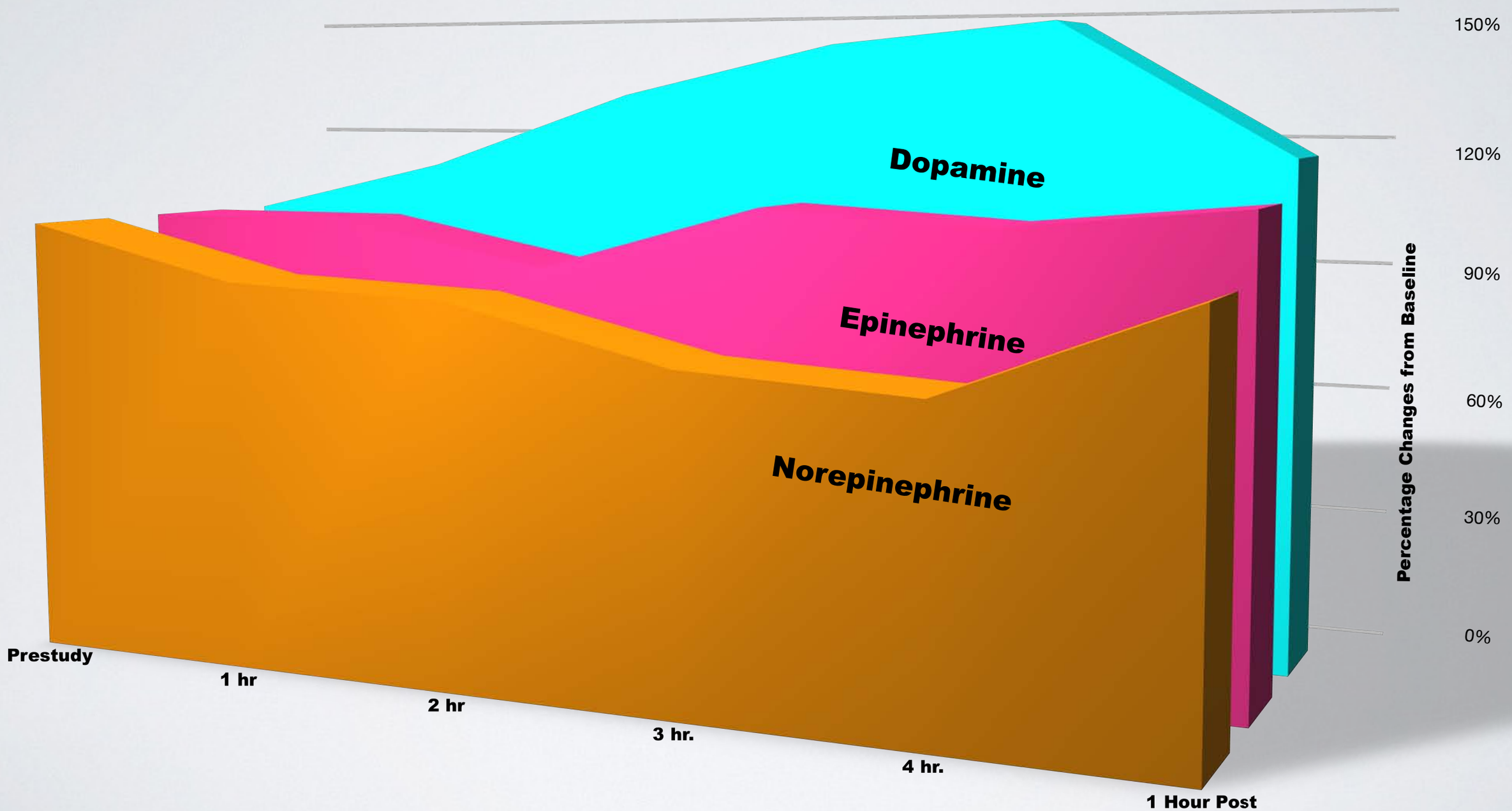


Renal Hormone Changes during Immersion



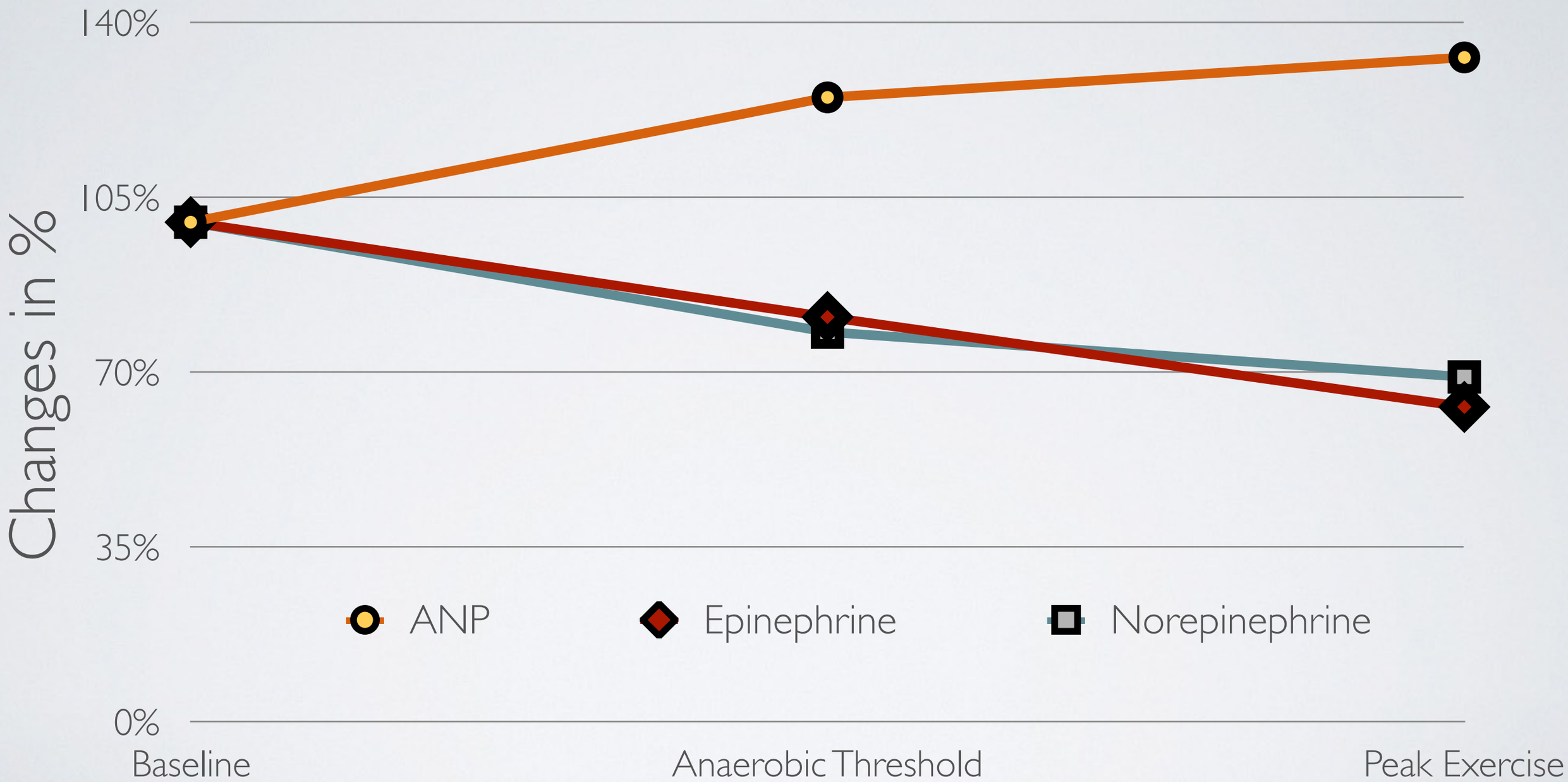
Epstein, Murray; Renal effects of head out immersion in humans: a 15-year update; Physiological Reviews. 1992

Catacholamine Changes During Immersion



Metabolic Hormone Changes during Aquatic Exercise

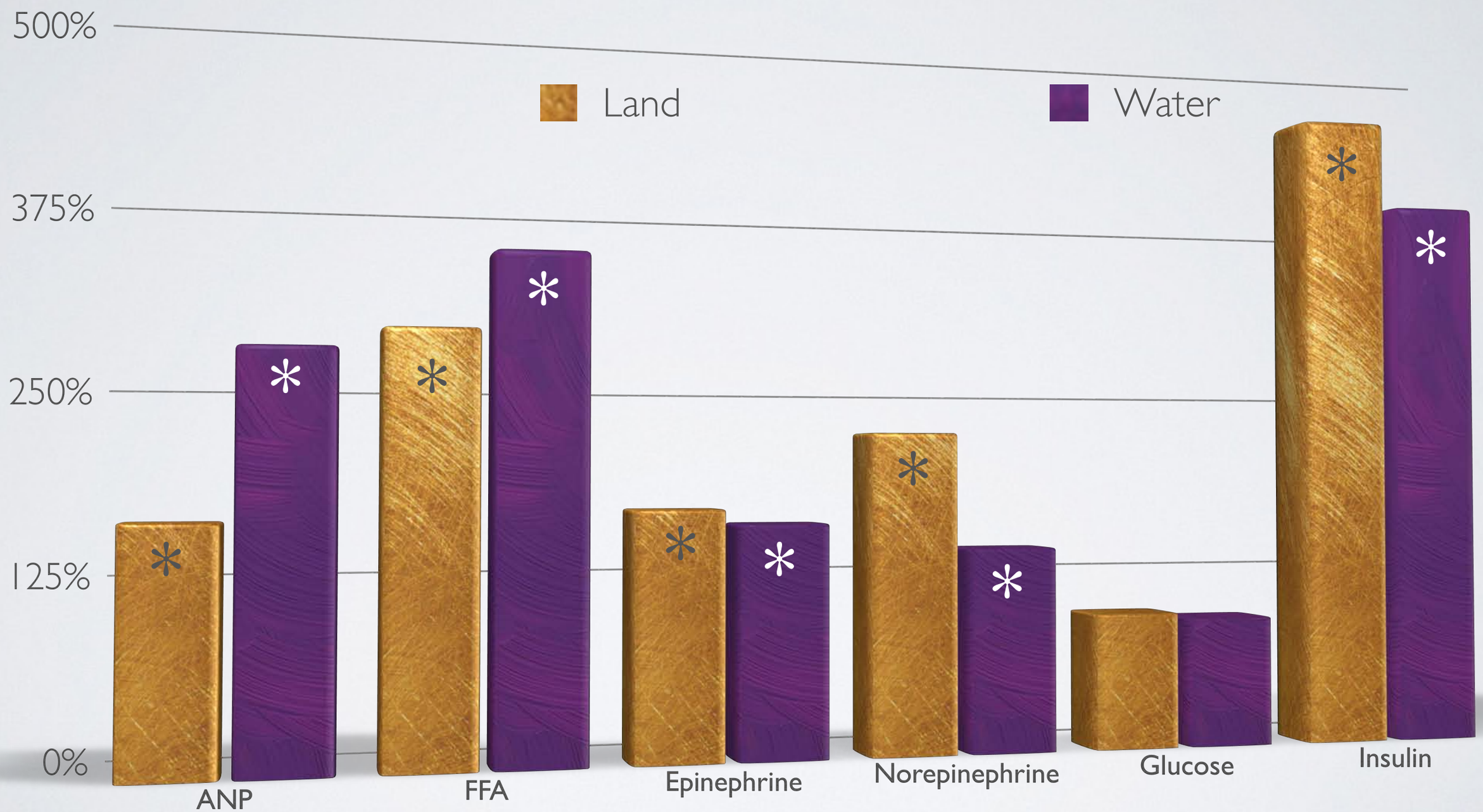
17 **male** subjects,avg. age 31, comparing randomized, cross-over incremental cycling exercise on land and immersed @ H2O temp 28°, incremental cycling to exhaustion



WIESNER, S., et al, 2010. Neurohumoral and metabolic response to exercise in water. Horm Metab Res, 42, 334-9.

ANP Release and Fat Oxidation Following Aquatic vs Land Aerobic Exercise in Overweight persons

Randomized cross-over study of 14 overweight adults (6 ♂, 8 ♀), BMI >26-31, exercised at AT for 1 hr on a cycle on land or water, with blood draws pre/post for ANP, FFA, insulin, glucose and catecholamines

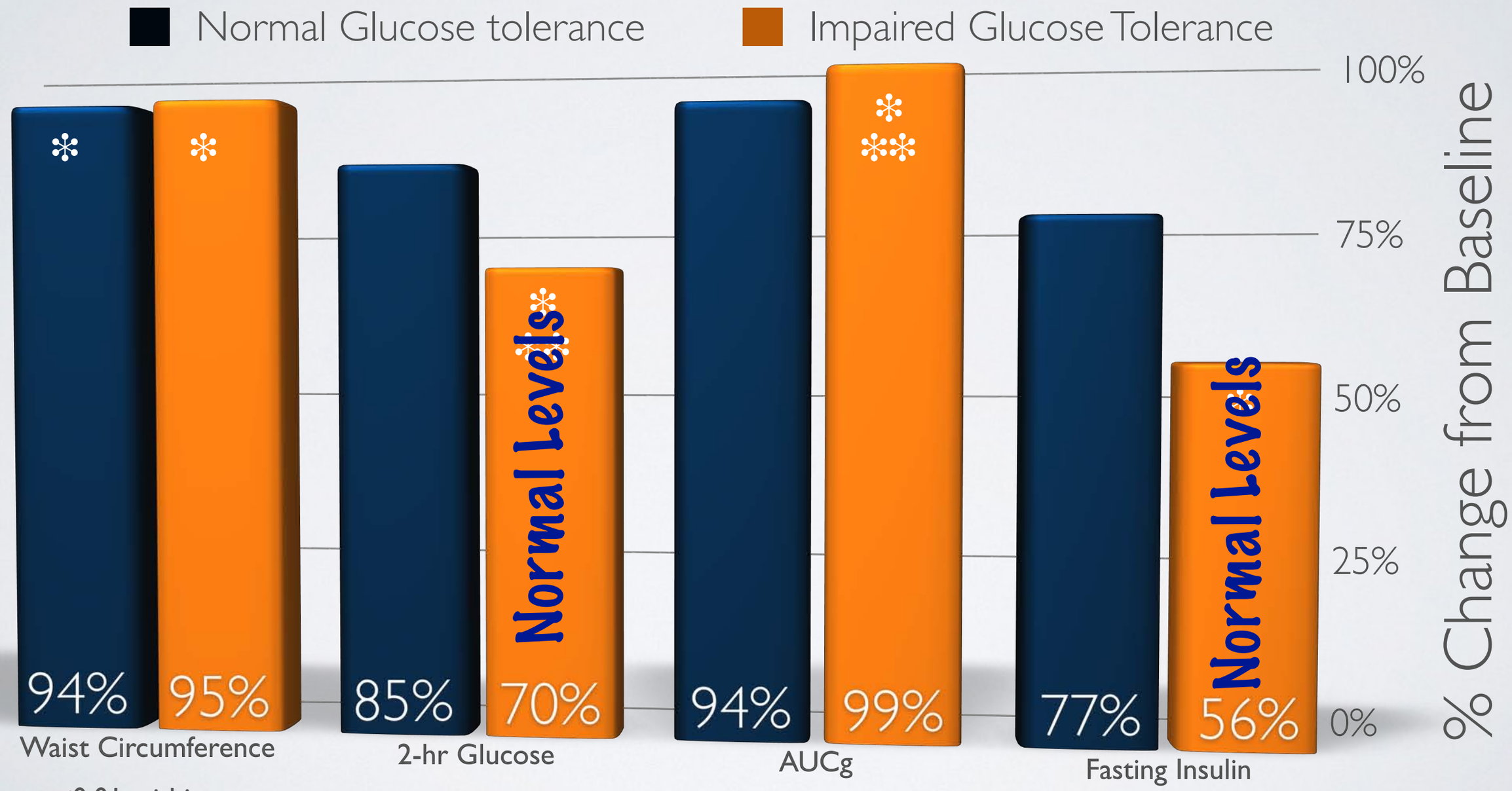


* $p<0.05$

FENZL, M., et al, 2013. Release of ANP and fat oxidation in overweight persons during aerobic exercise in water. Int J Sports Med, 34, 795-9.

Aquatic Exercise Effects on Glucose & Insulin in Overweight Women

12 week prospective observational study of 15 women BMI>33.7 with normal glucose tolerance, 8 impaired GT, 60 min aquarunning and resistance sessions 3x/wk, at 70-75% HR_{max}



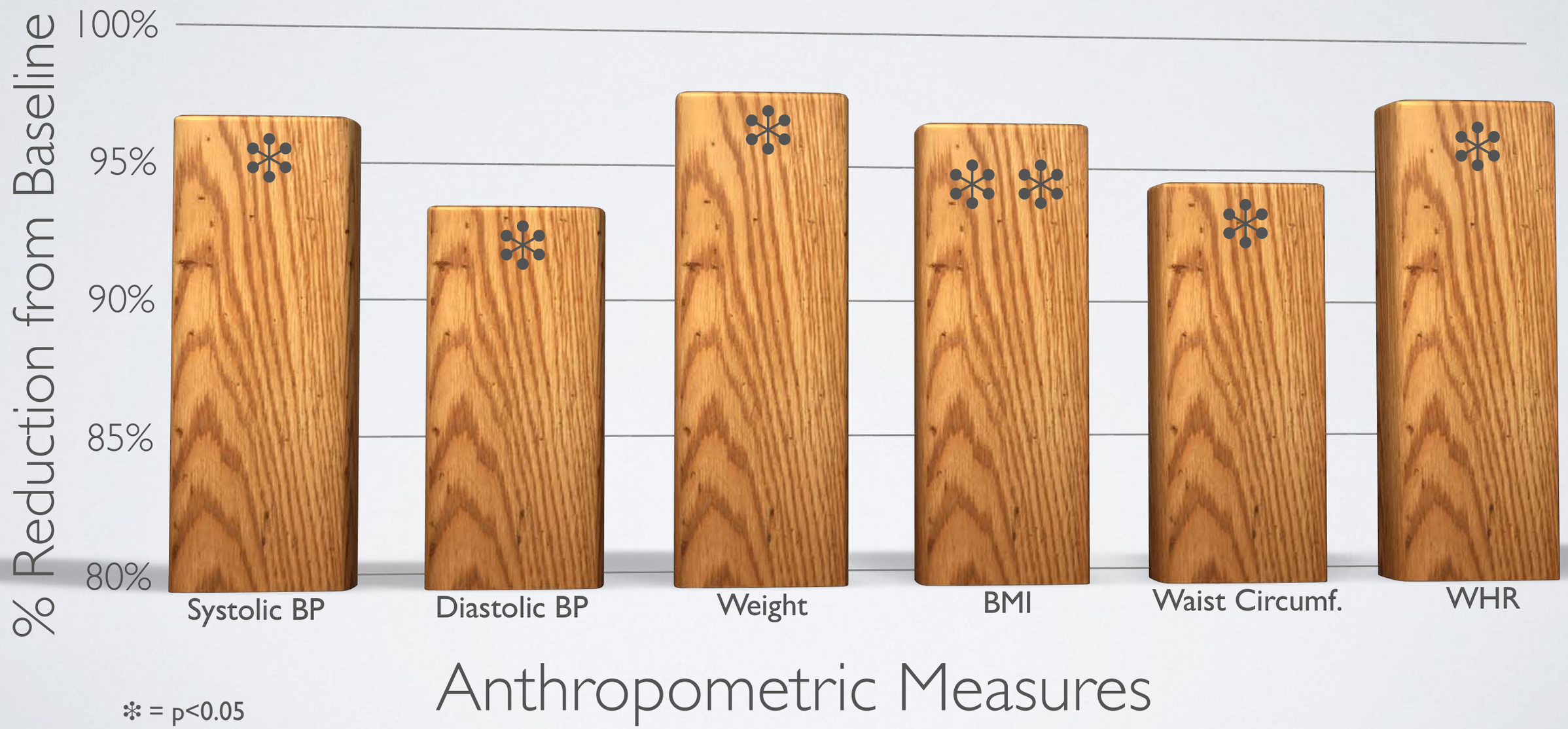
* = p<0.01 within group

** = p<0.05 between groups

JONES, L. M., MEREDITH-JONES, K. & LEGGE, M. 2009. The effect of water-based exercise on glucose and insulin response in overweight women: a pilot study. J Womens Health (Larchmt), 18, 1653-9.

Aquatic Exercise Effects on Men with Type 2 Diabetes

12 wk prospective observational study of 18 men with Type II DM, 50 min aquatic sessions 3x/wk at 50-75% VO_{2max} assessing blood, echocardiography and QOL



* = p<0.05
** = p<0.005

CUGUSI, L., et al, 2015. Effects of an aquatic-based exercise program to improve cardiometabolic profile, quality of life, and physical activity levels in men with type 2 diabetes mellitus. PM R, 7, 141-8

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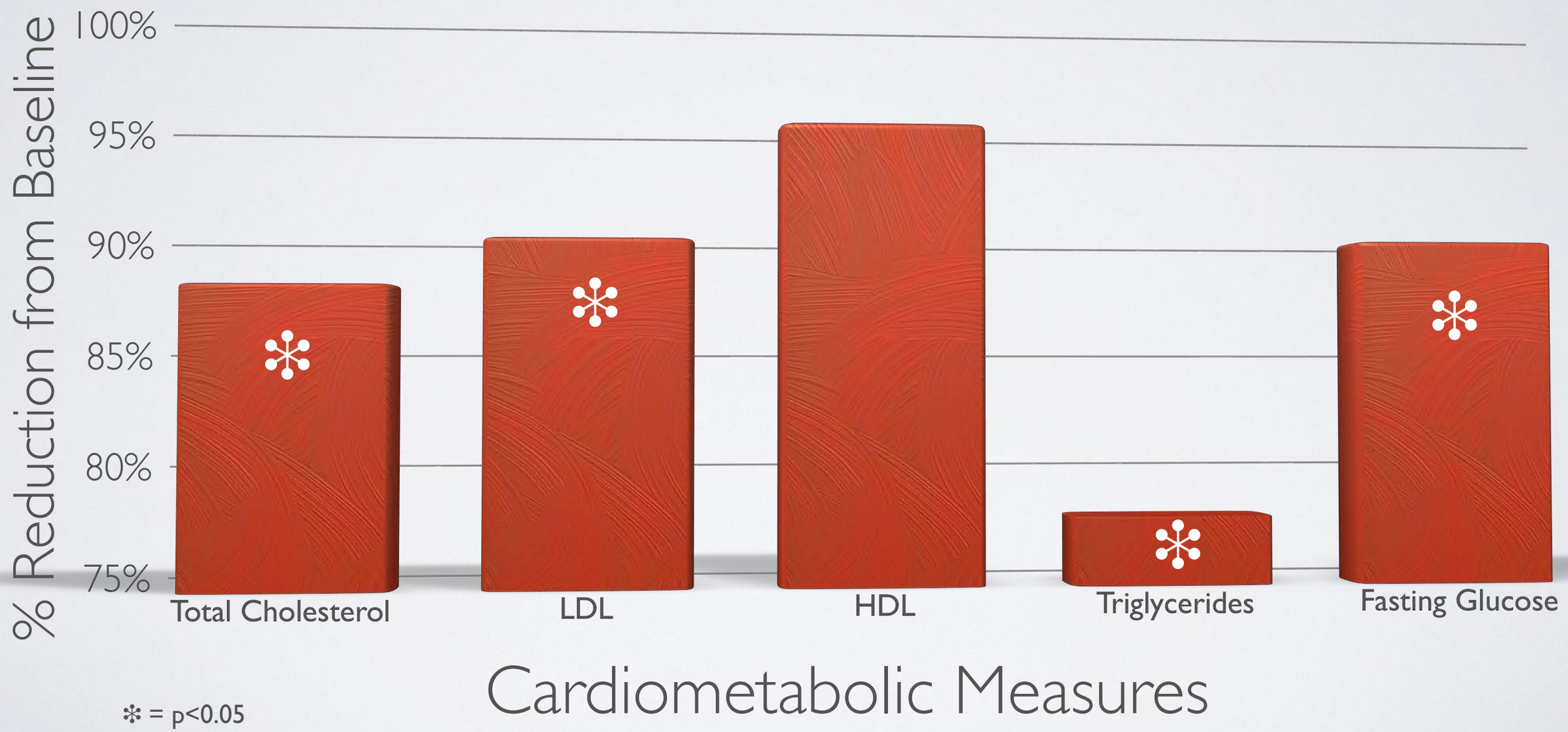

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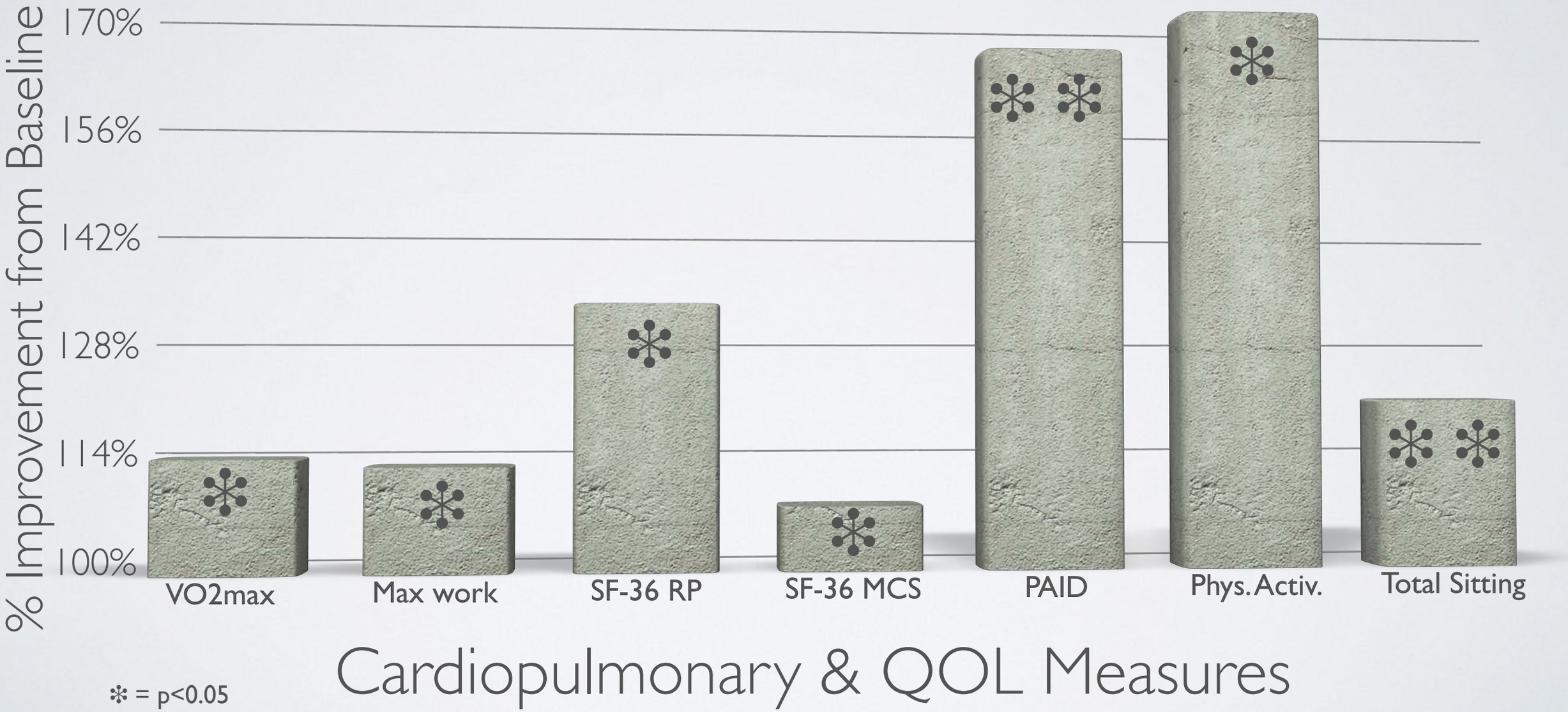

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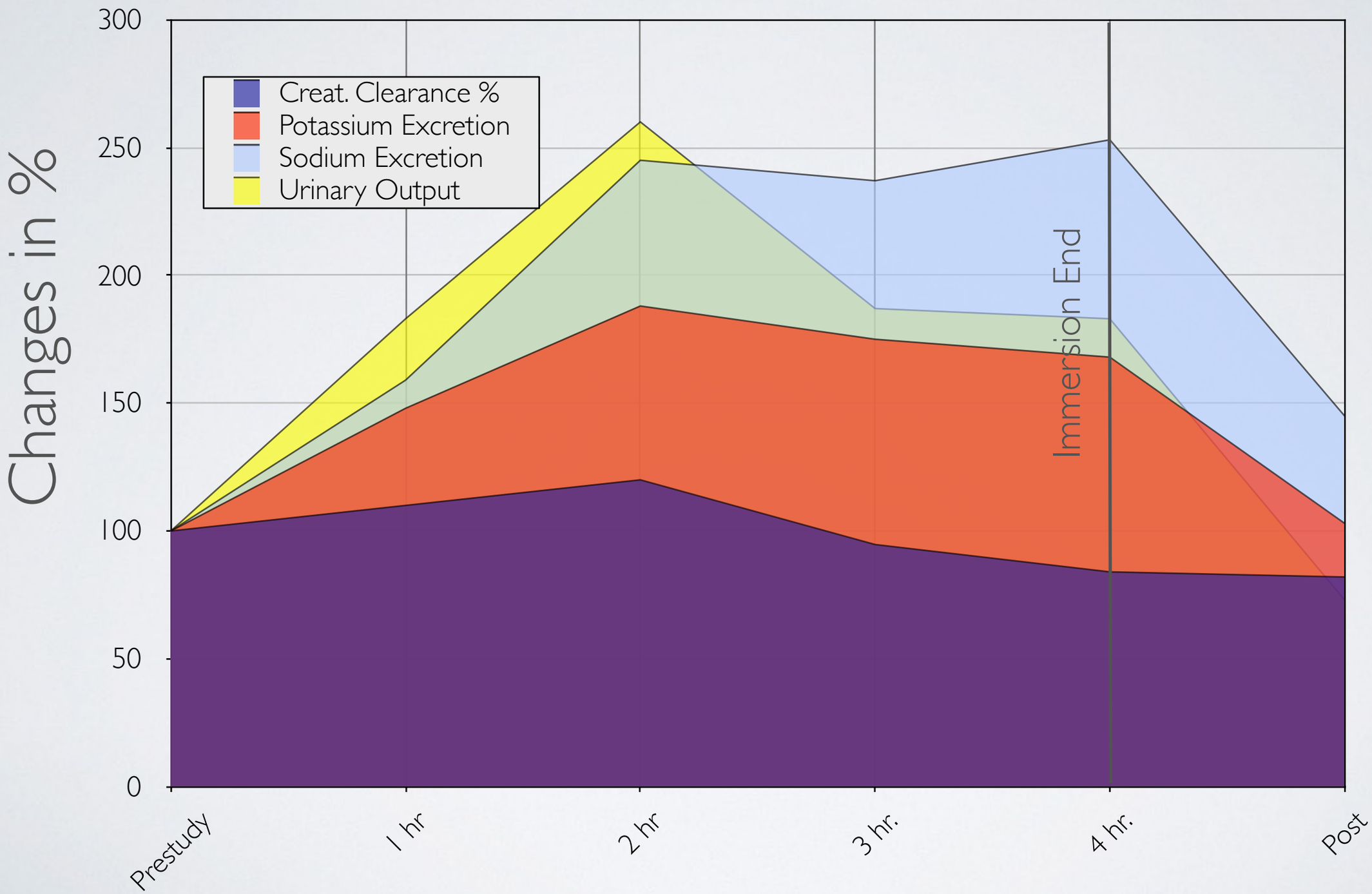
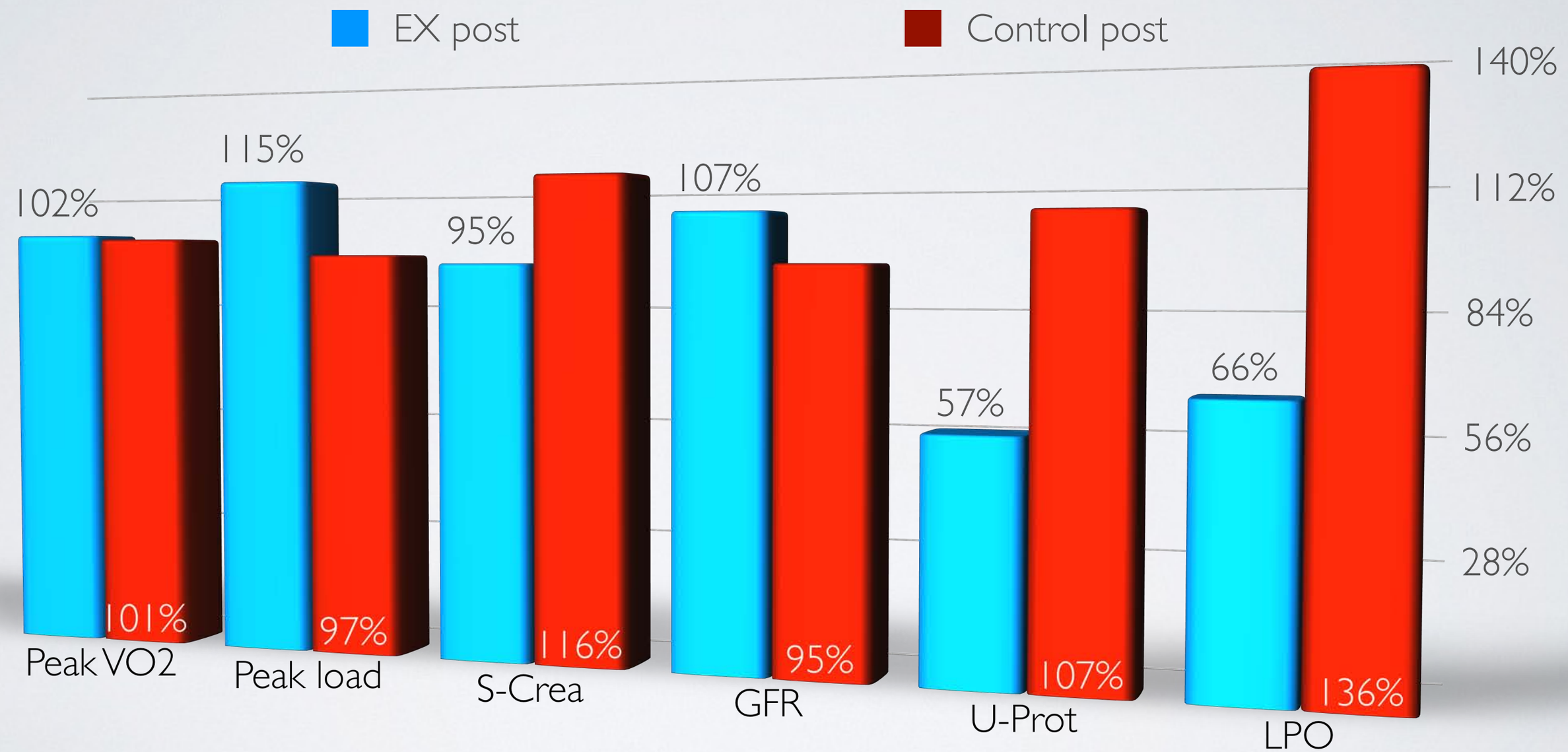
Renal Function during Immersion



Epstein, Physiol Rev 72:577, 1992

AQUATIC EXERCISE EFFECTS ON CHRONIC KIDNEY DISEASE

Vertical aquatic exercise 30 min/session twice weekly for 12 weeks in moderate CRF pts.



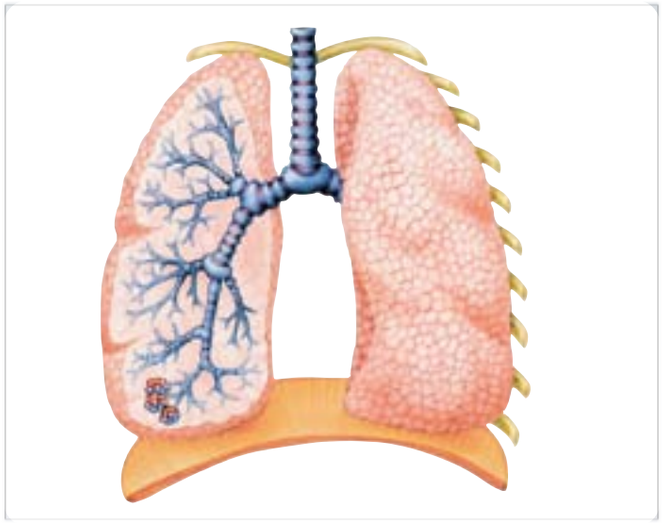
Pechter U, Ots M, Mesikepp S, et al. Beneficial effects of water-based exercise in patients with chronic kidney disease. Int J Rehabil Res. Jun 2003;26(2):153-156.

Aquatic Forces & Physiology

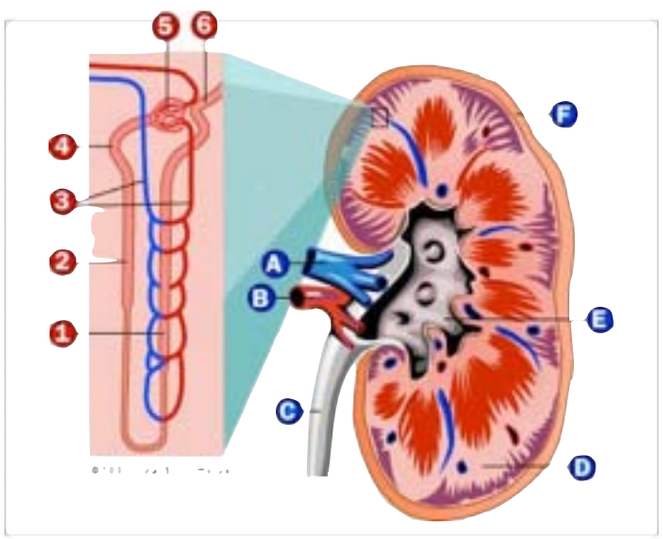
$$\Delta P = \rho g \Delta h$$
$$Q = mc\Delta T$$
$$Re = 2\tilde{v} r \rho / \eta$$
$$P_d = kv^3$$

The Physics of H2O

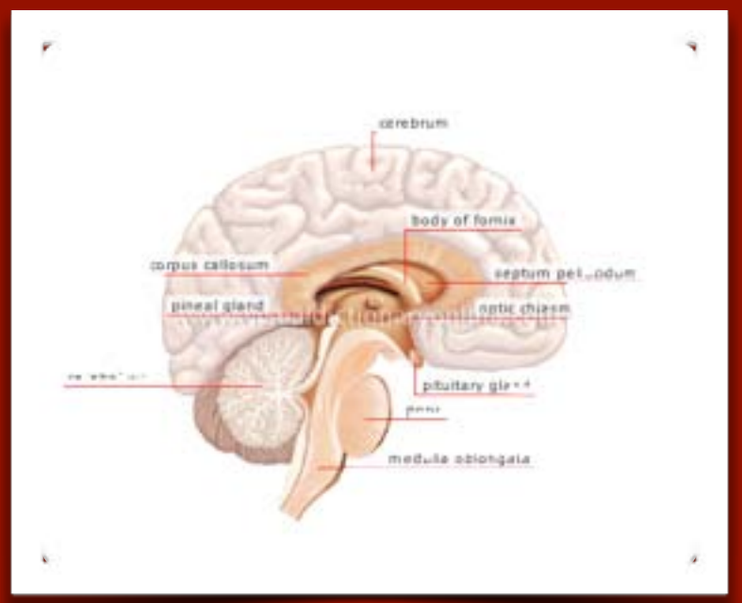
Cardiac Physiology



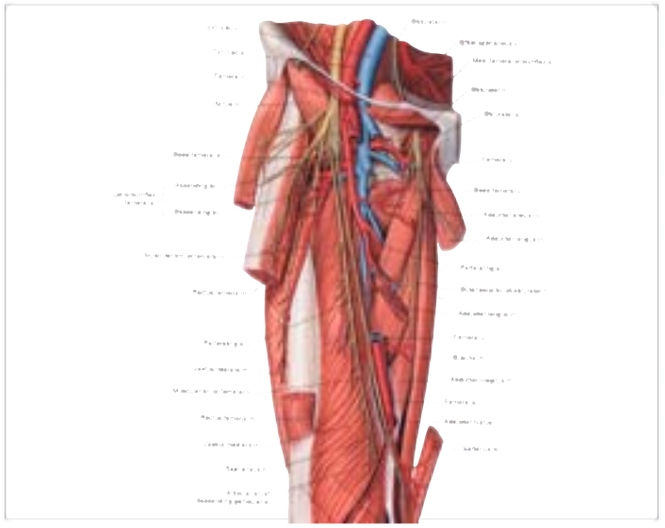
Pulmonary Physiology



Renal Physiology



Neurophysiology



MSK Physiology

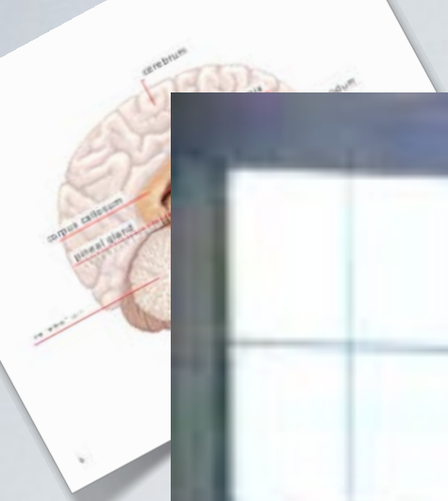
A Little Nervous System Anatomy

- The nervous system is comprised of 3 major components:

1. **The Central Nervous System**
   - The brain
   - The spinal cord

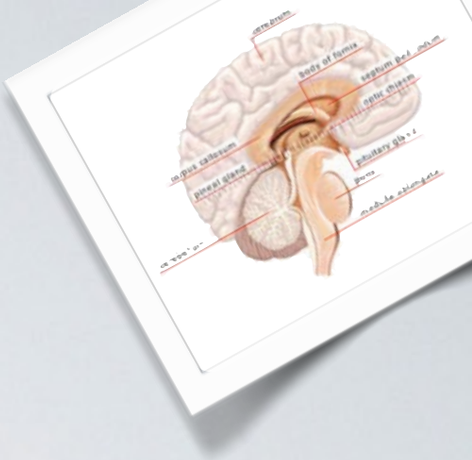
2. The Peripheral Nervous System
   - All of the major and minor nerves

3. The Autonomic Nervous System
   - The Sympathetic Nervous System
   - The Parasympathetic Nervous System
   - **The motherboard for most physiologic functions**



The Cocoon Effect

Probable Causes



- Autonomic Nervous System downregulation
  - Heart Rate Variability changes
  - Catacholamine changes
  - Blood Pressure changes
  - EEG changes
  - Muscle tone changes

THE AUTONOMIC SYSTEM

- Is the master control panel for homeostasis and responses to biologic threats
- Regulates essentially all major body functions
  - Cardiac and vascular systems
  - Respiratory
  - Digestive
  - Endocrine
- Functions mainly subconsciously

SYMPATHETIC SYSTEM FUNCTIONS

- Up-regulates the body for action
  - Increases heart rate and forcefulness
  - Constricts blood vessels in gut, but not in muscle, brain and heart
  - Increases blood pressure
  - Dilates pulmonary bronchioles
  - Slows gastric activity
  - Dilates pupils
  - Tightens sphincters
- Earliest neural regulatory system to emerge
- Chronic SNS activity increases inflammatory cytokines and catecholamines, decreases anti-inflammatory processes

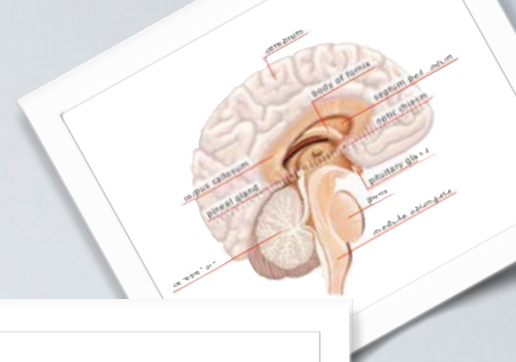
THE PARASYMPATHETIC SYSTEM

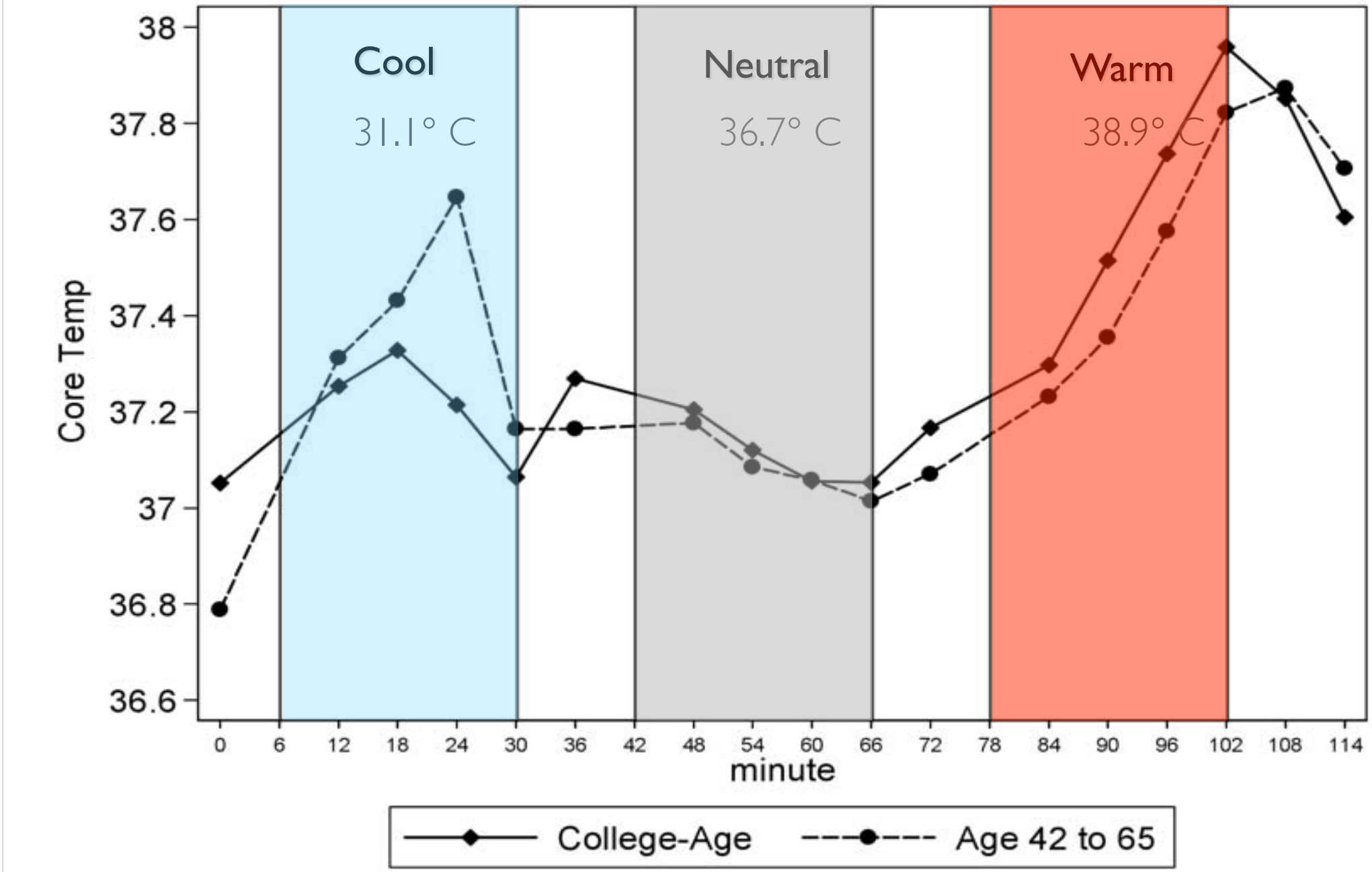
- Sometimes called the "rest & digest" or "feed and breed" component
- Slow response system functioning in opposition to the sympathetic system
- Nerve fibers flow from the sacral and cranial nerves (craniosacral outflow)
- Controls salivation, lacrimation, urination, defecation and sexual arousal, but also some brain functions
- Increases anti-inflammatory cytokines, suppresses pro-inflammatory processes

Autonomic function & Health

- Autonomic imbalance has been suggested to be the final common pathway in many diseases
- Highly correlated with cardiovascular health
- Associated with diabetes, inflammatory processes, and immune dysfunction
- An increase in parasympathetic tone decreases release of inflammatory cytokines, & increased sympathetic tone increases them

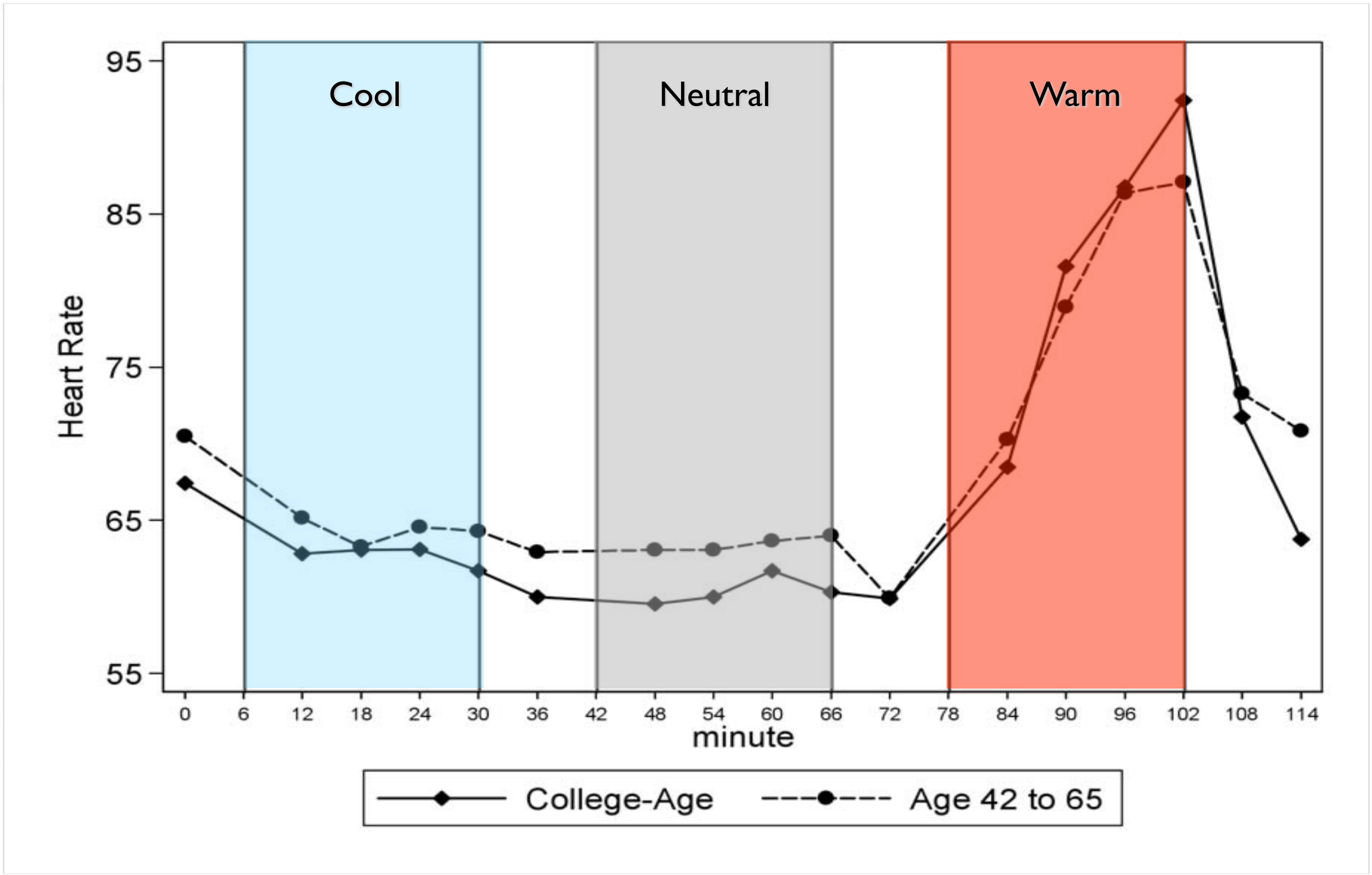
Core Temperature





Becker BE, Hildenbrand K, Whitcomb RK, Sanders JP. Biophysiologic Effects of Warm Water Immersion. International Journal of Aquatic Research & Education. 2009;3(1):24-37

Heart Rate Change



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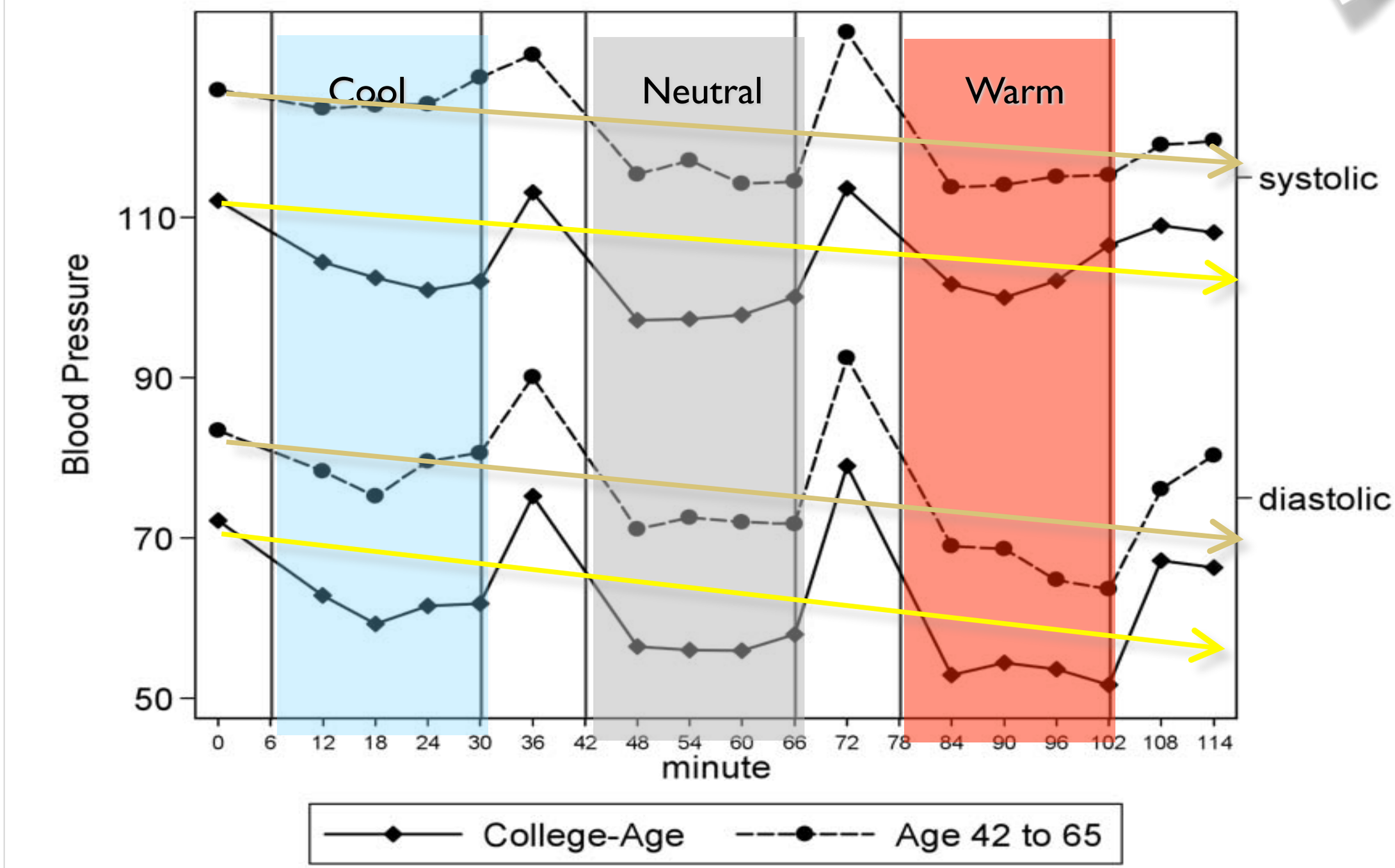
Blood Pressure Responses by Group



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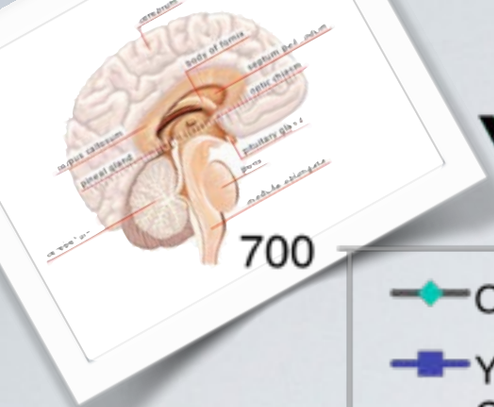
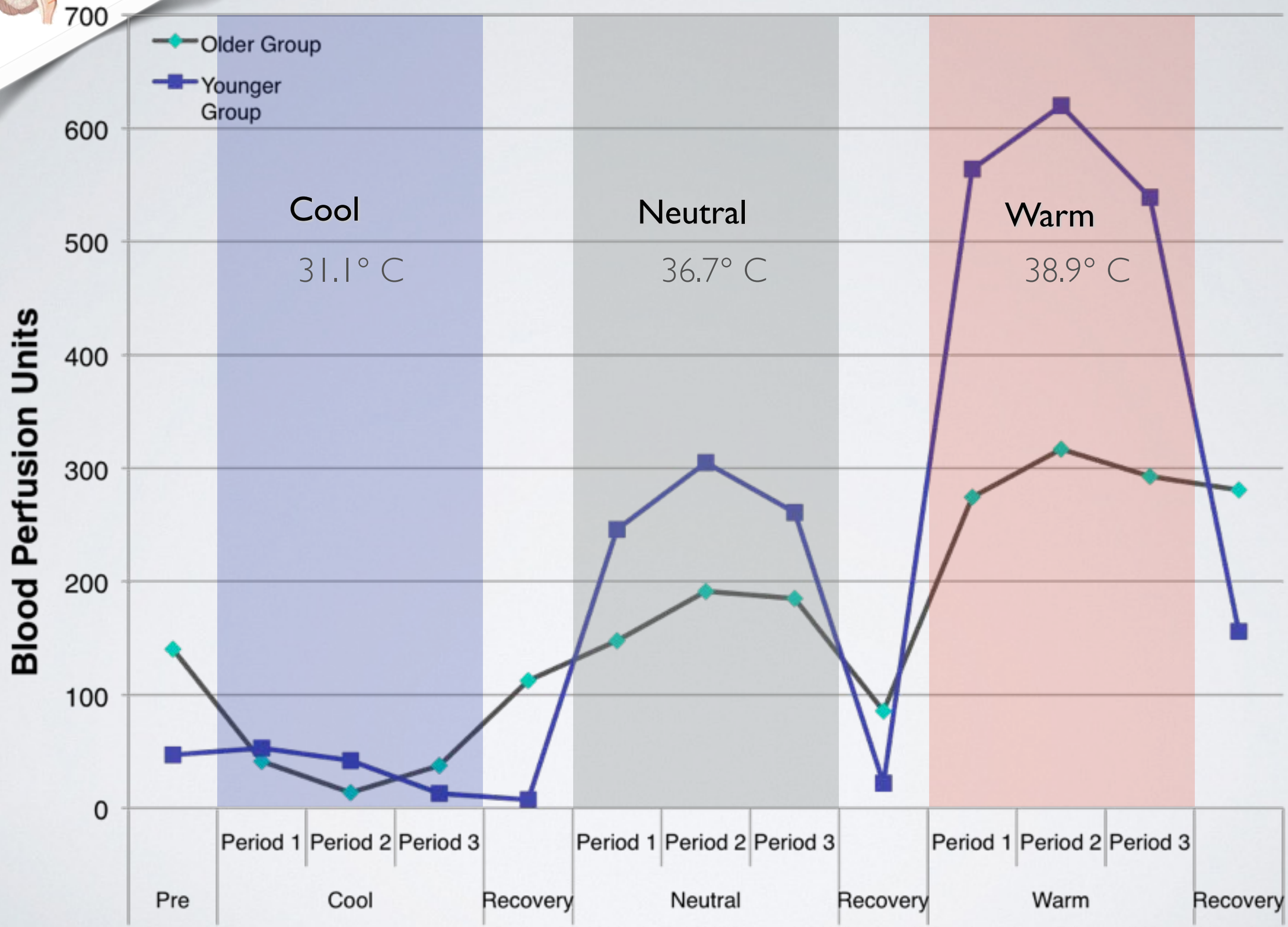
Young vs Older Circulatory Changes





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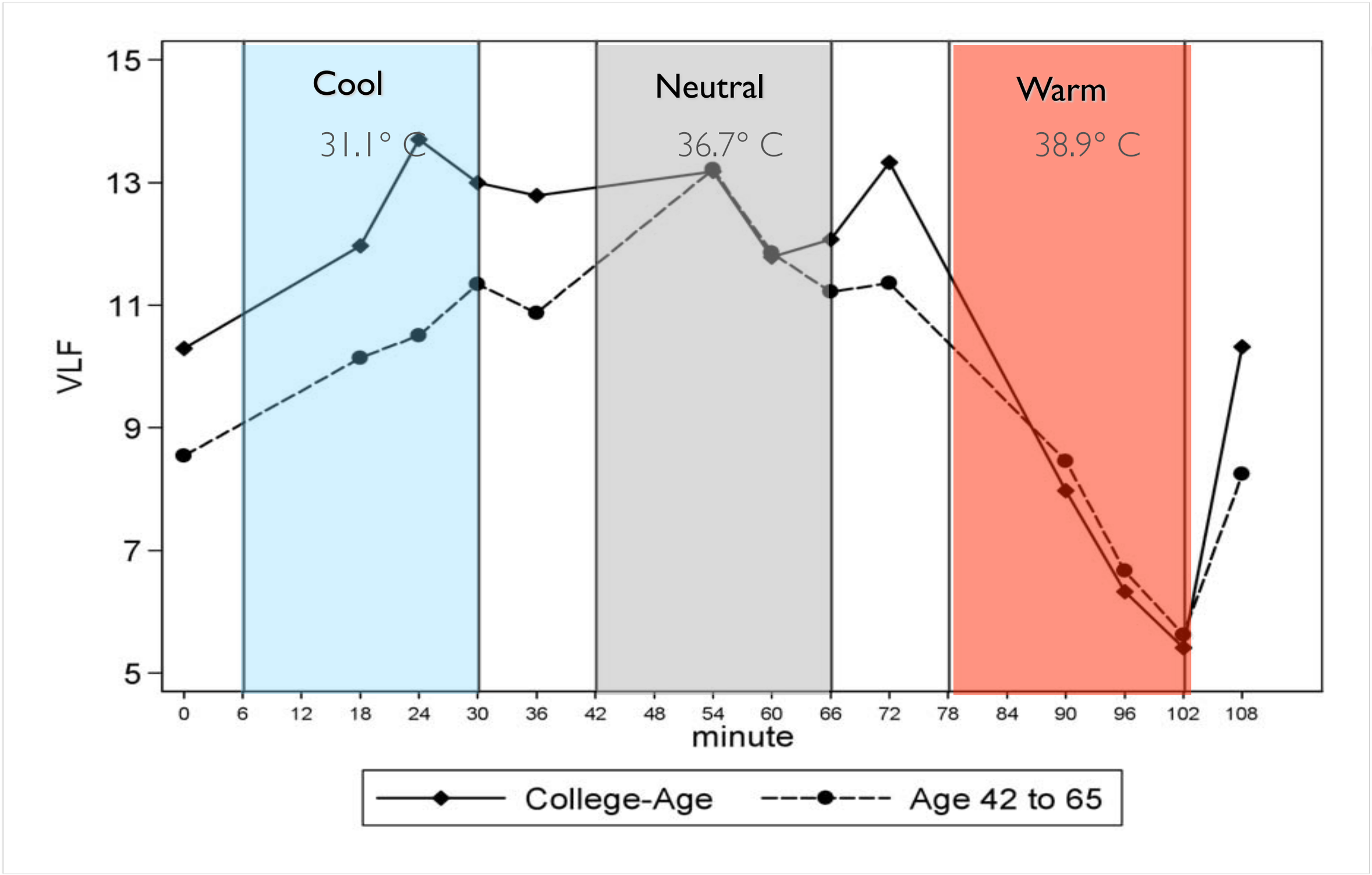
VLF Change by Age Group



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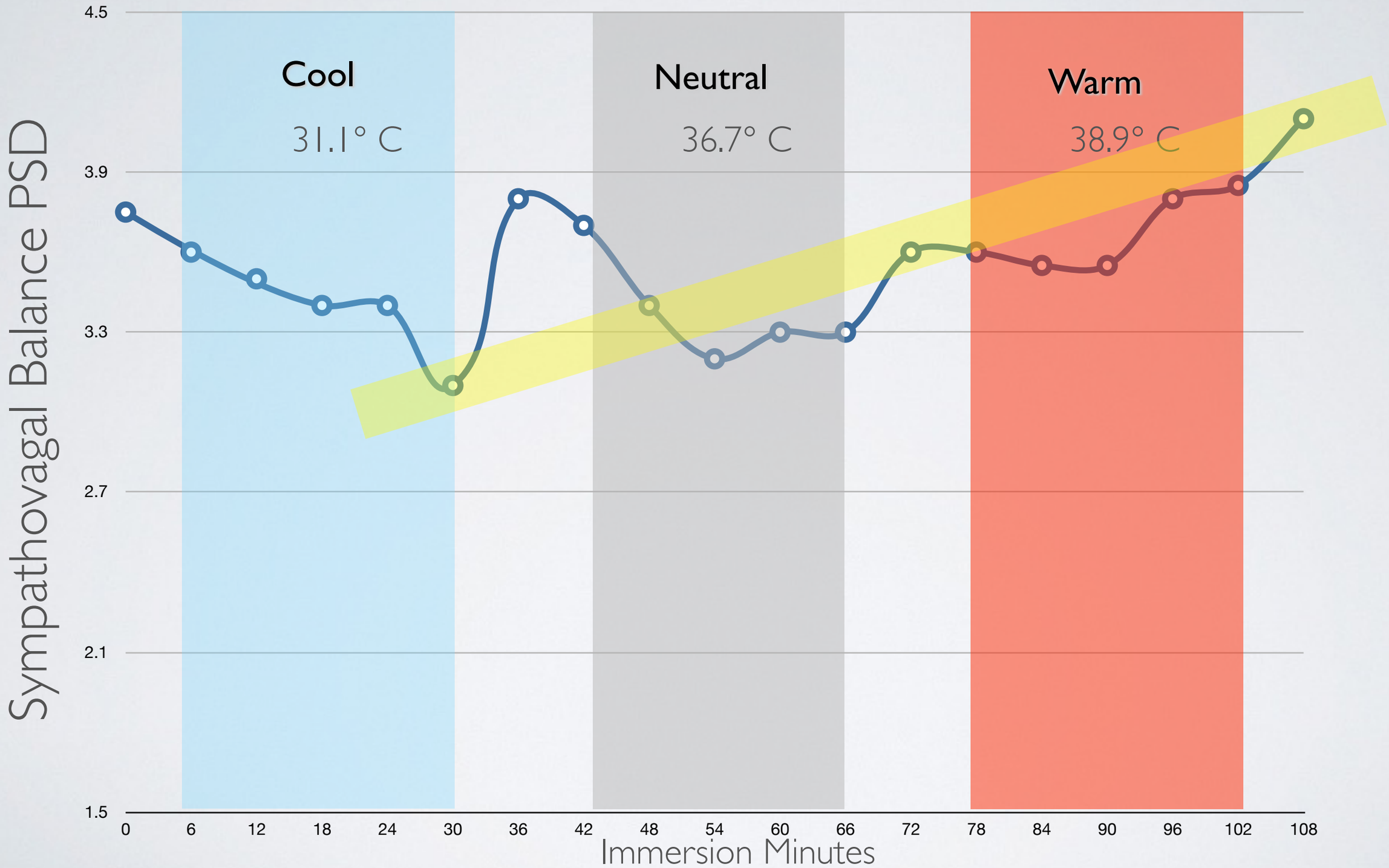
Sympathovagal Balance



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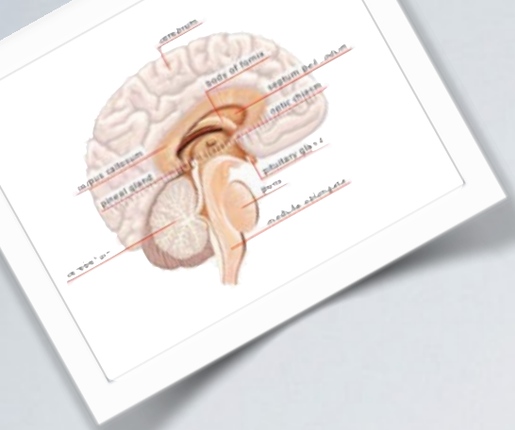
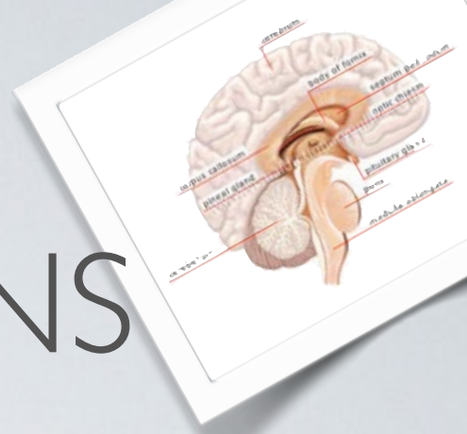


ANS Study Findings

- Systolic pressures remained quite constant through all 3 immersion phases, with age group differences
- Diastolic pressures declined through the 3 phases, also with age-group differences
- Heart rates remained stable until climbing during the mid-point of warm water immersion
- Core temperatures also rose during this latter cycle, but only by less than 1°C on average

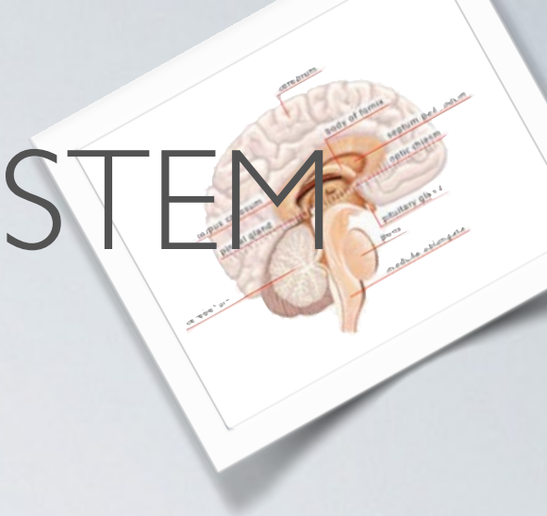
ANS Study Conclusions



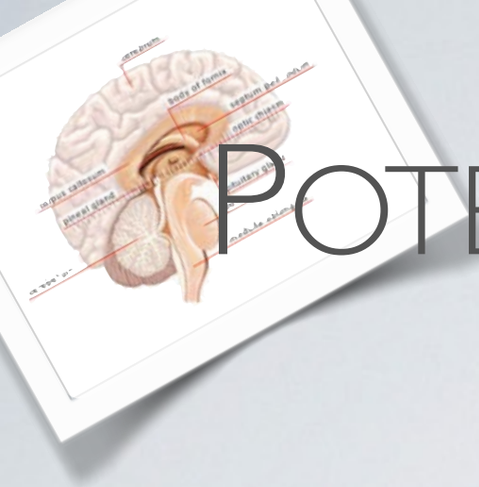
- There seems to be a very significant effect of warm water immersion upon the autonomic nervous system
- That effect seems to enhance the balance between parasympathetic and sympathetic components, and is likely one of the major changes that create the feeling of relaxation in warm water.
- The increase in autonomic balance did not happen in cooler water temperatures
- Sympathetic activation occurred in both cool and neutral temperatures, but not in warm
- The changes noted were quite consistent across all of the subjects

Becker BE, Hildenbrand K, Whitcomb RK, Sanders JP. Biophysiologic Effects of Warm Water Immersion. International Journal of Aquatic Research & Education. 2009;3(1):24-37

Autonomic Nervous System Associations



- **Warm water immersion produces a balancing of the 2 components of the autonomic nervous system.**
- This autonomic effect has been associated with
  - Reduction in cardiac irritability
  - Reduction in blood pressure, both systolic & diastolic
  - A decrease in inflammatory processes
  - Anxiety reduction & mental relaxation
  - Improvement in mood state & reduction in mood state disorders
  - Improvement in working memory
  - Increase in cognitive task-performance, creative problem-solving & cognitive flexibility

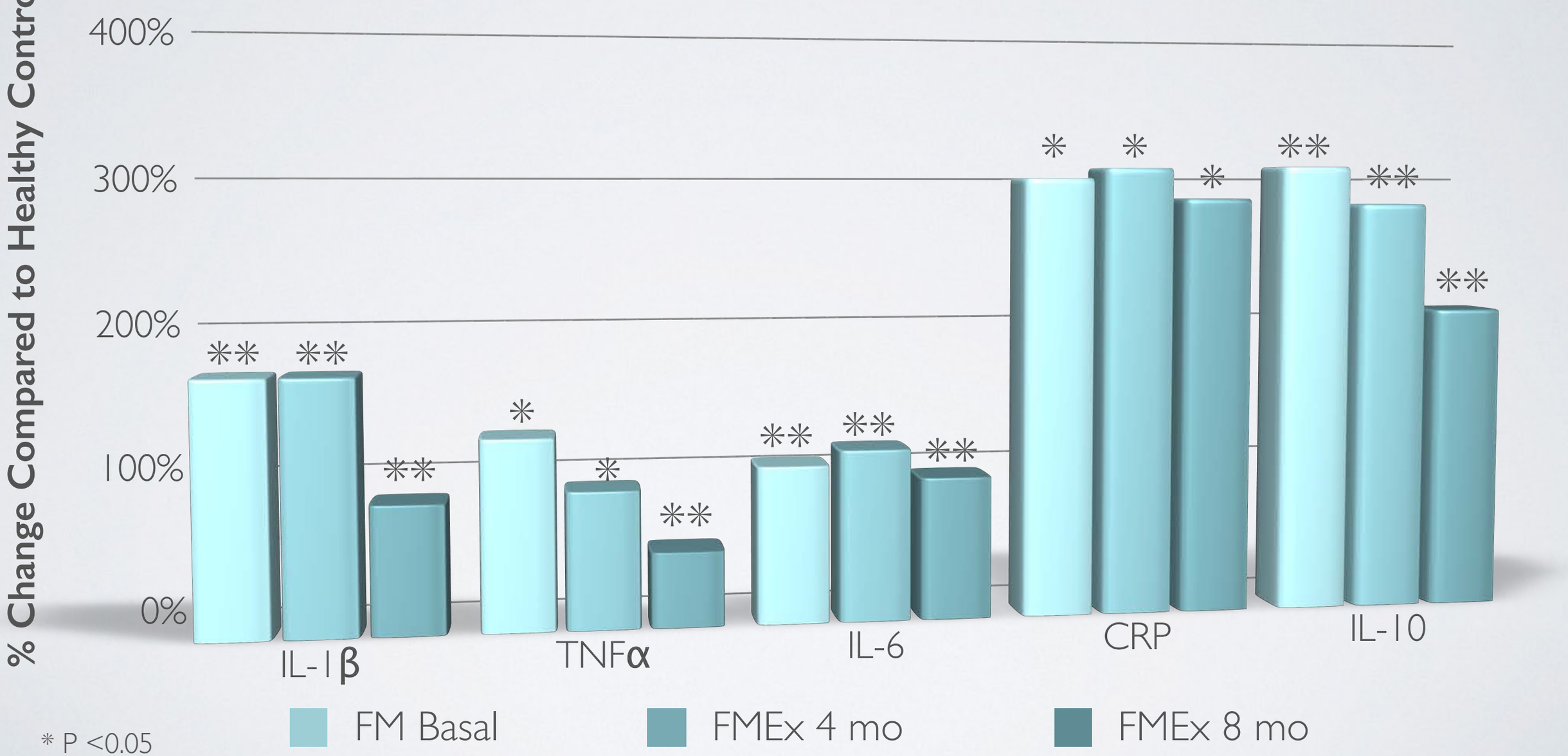


Potential Clinical Applications with ANS Dysfunction

- Cardiac Rehabilitation
- Diabetes, both Types I & II
- Mood State Disorders
  - Depression
  - Anxiety and panic disorders
- Attention Deficit Disorder
- Autism
- Fibromyalgia

Aquatic Exercise Effects on Pro- & Anti-inflammatory Monocytic Cytokine Production in Fibromyalgia

Nonrandomized study of 2x/wk 60 min. aquatic exercise sessions in 9 women with ACR-criteria fibromyalgia, compared to 9 age-matched healthy sedentary female controls, with blood draws pre-, 4 months and 8 mo.

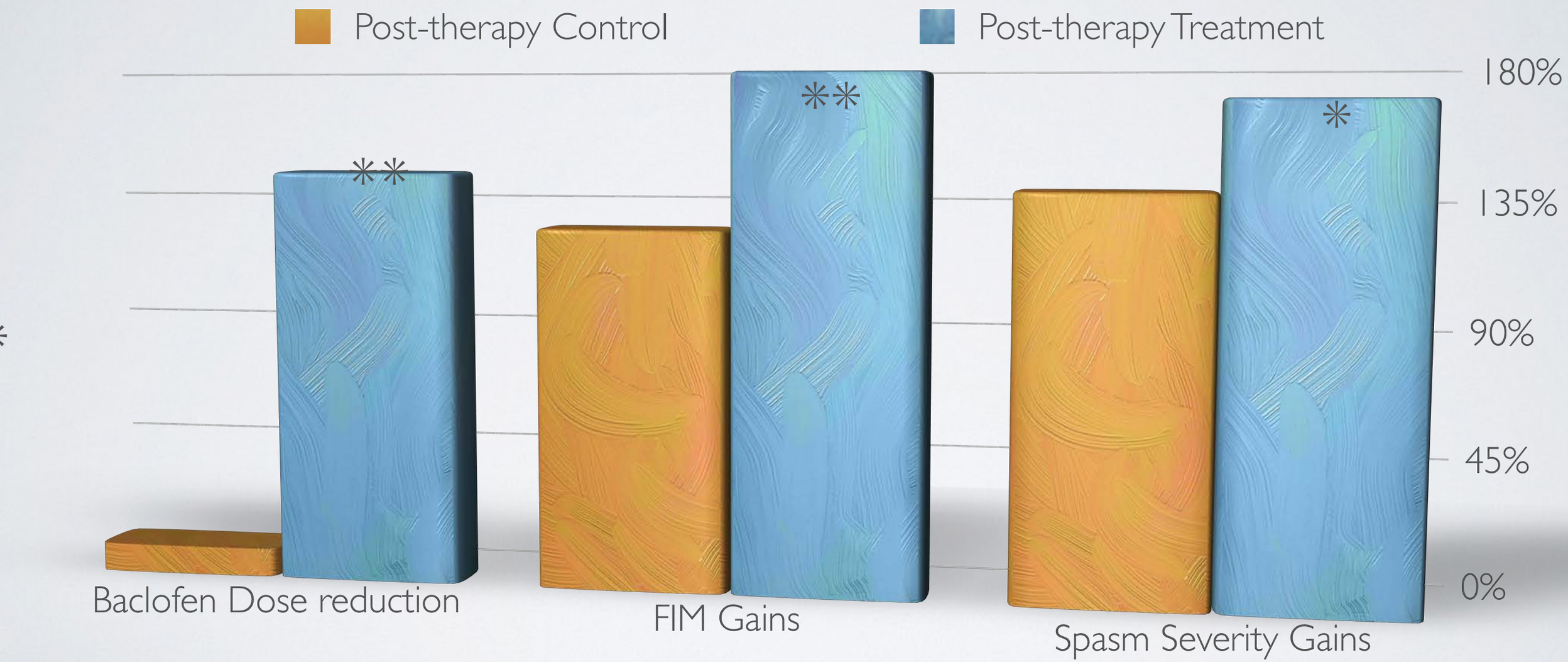


* P <0.05
** P <0.001

ORTEGA, E., BOTE, M. E., GIRALDO, E. & GARCIA, J. J. 2012. Aquatic exercise improves the monocyte pro- and anti-inflammatory cytokine production balance in fibromyalgia patients. Scand J Med Sci Sports, 22, 104-12.

Aquatic Therapy and SCI Spasticity

20 SCI patients, age, gender, Ashworth, baclofen and FIM matched. Control group received standard therapy and treated group received additional 20 min of aquatic therapy 3x/wk for 10 weeks.



* P <0.05
** P <0.001

Kesiktas N, Paker N, Erdogan N, Gulsen G, Bicki D, Yilmaz H. The use of hydrotherapy for the management of spasticity. Neurorehabilitation and neural repair. Dec 2004;18(4):268-273.

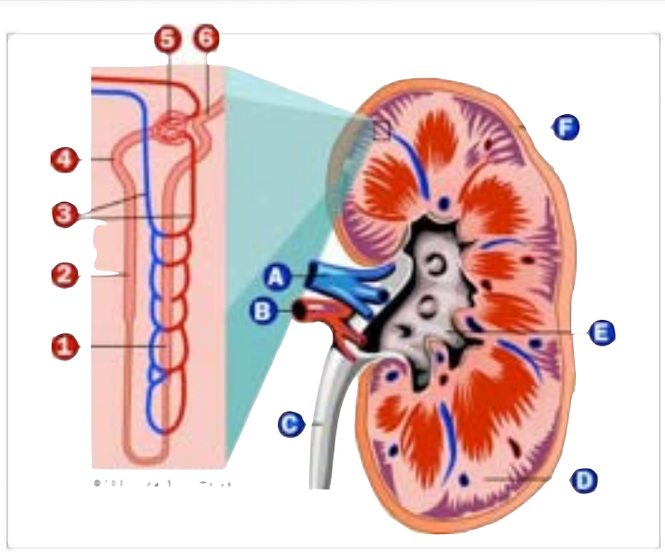
Aquatic Forces & Physiology

$$\Delta P = \rho g \Delta h$$
$$Q = mc\Delta T$$
$$Re = 2\tilde{v} r \rho / \eta$$
$$P_d = kv^3$$

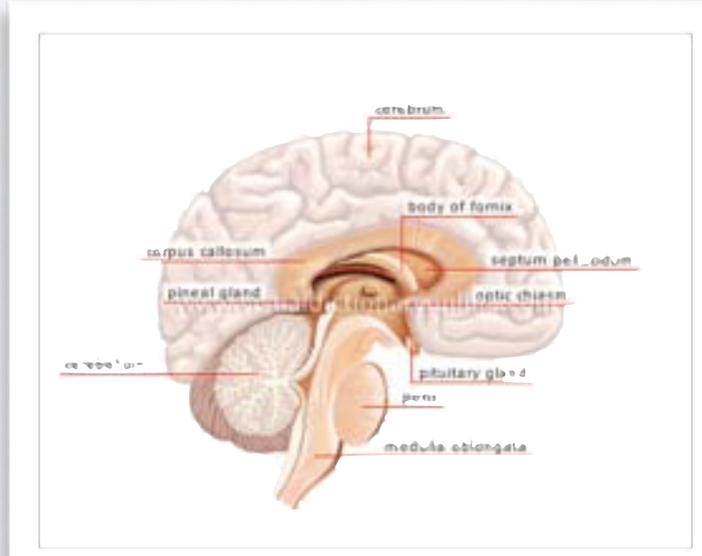
The Physics of H2O

Cardiac Physiology

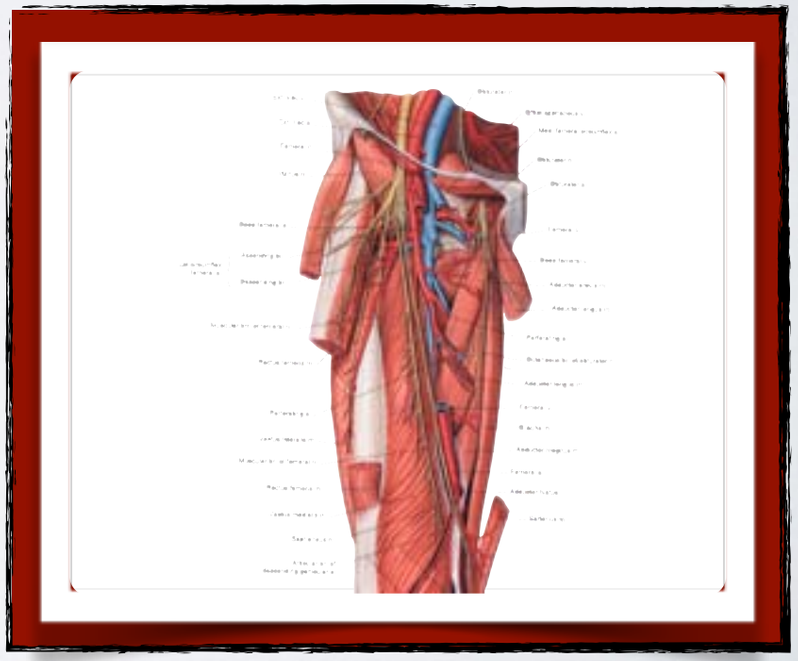
Pulmonary Physiology



Renal Physiology

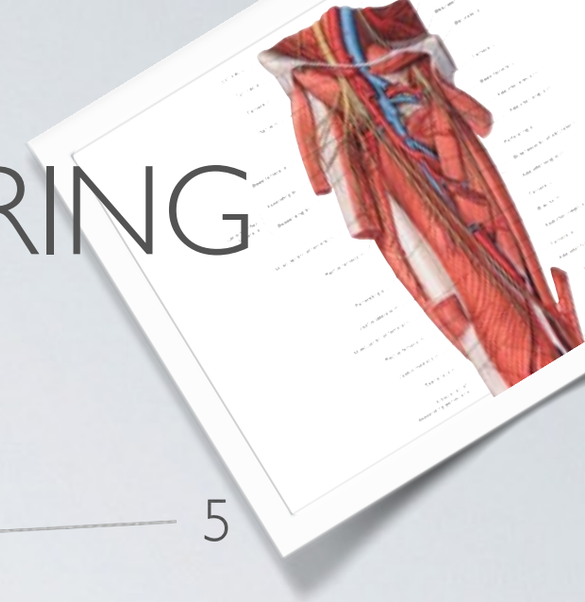


Neurophysiology



MSK Physiology

Muscle Blood Flow during Immersion



Tib. Ant. blood flow, Xe washout, thermoneutral

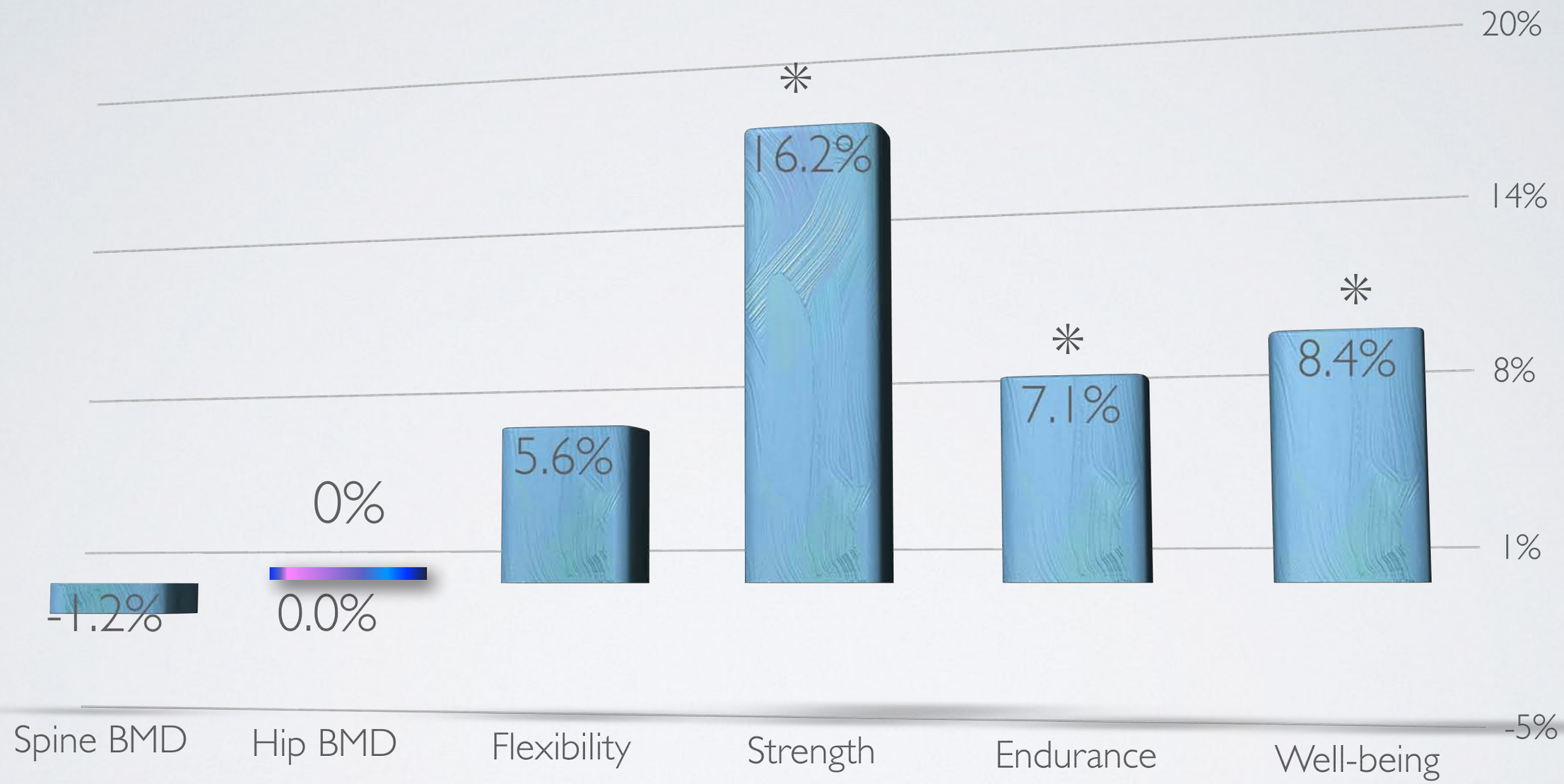
Balldin, Aerospace Med 42:489-493, 1971

AQUATICS & BONE DENSITY

- In older male Masters swimmers, increased bone density has been found.
- In older female Masters swimmers, no effect has been noted.
- In younger individuals, swimming did not add bone mineral content as effectively as weight-bearing exercise.

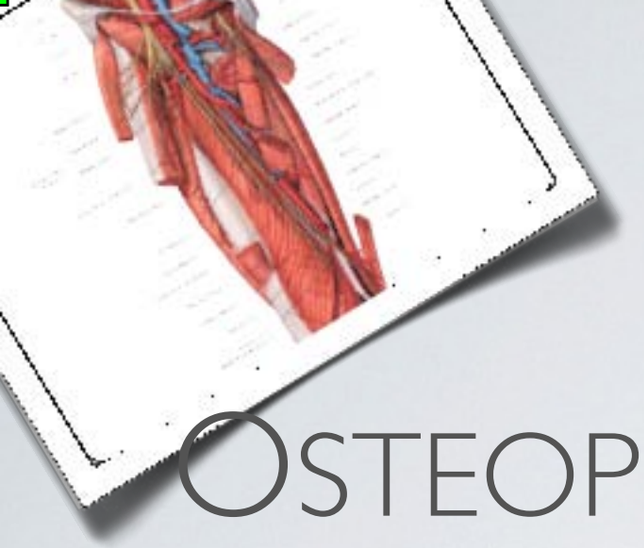
Aquarobic Effect on BMD, Fitness & Well-being @1 year

77 females, ages 50-70, 1 hour/day, 3 days per week, 12 months



* $p<0.05$

Bravo, Gauthier et al, Arch PMR, 78, 1375-80,1997



Osteoporosis and Aquatic Therapy

- The aquatic environment is a very appropriate place to begin a strengthening and endurance program and to improve balance for persons with osteoporosis and it may increase serum osteocalcin, an osteoblastic protein
- The pool probably does not provide a major bone-deposition stimulus, or reverse loss of bone mineralization in critical areas including the hip and spine
- Transitioning to land-based impact activities remains the goal for therapy in osteoporosis

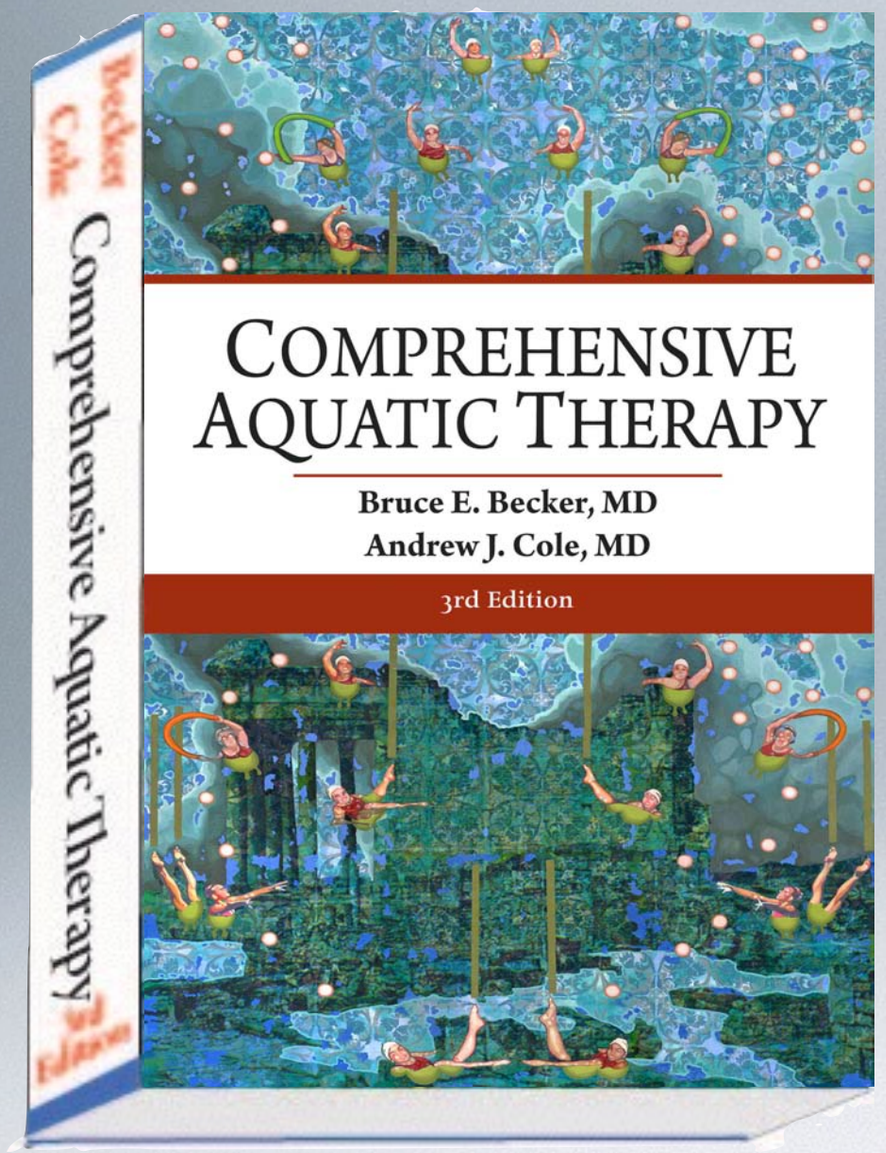
Aquatic Therapy Utility

- Arthritis, both rheumatoid and osteoarthritis
- Spine Pain
- Post-operative pain
- Parkinsonism
- TBI
- SCI
- Fibromyalgia
- Complex Regional Pain Syndrome
- Post-polio Syndrome
- Neuropathy
- Cerebral Palsy
- Polio and Post-polio Syndrome
- Neuropathy
- Stroke (embolic and hemorrhagic)
- Multiple Sclerosis
- Balance Dysfunction

THE UNIQUE EFFECTS OF IMMERSION

- Usually lowers blood pressure
- Reduces autonomic arousal
- Strengthens respiratory musculature
- Enhances cardiovascular efficiency
- Improves kidney function
- Increases muscle perfusion
- Offloads joints, and probably increases circulation to joints
- **And all this with essentially no side effects!**

Comprehensive Aquatic Therapy



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