Biochemical Adaptations to Training

Matt Van Dyke

University of Minnesota

Covered in this Presentation

- Basics of stress and adaptation
  - Homeostasis
- Requirements of sport
- Immediate adaptations
  - Stress response systems
- Stable adaptations
- Systematic training
- Testing for desired adaptations

Definition of "Adaptation"

- Goal is always maintain homeostasis
  - Any external influence to some extent, changes the organism
  - Body will increase survival odds by any means
    - Even though inefficiency may result when being exposed to new stimuli
- All stress leads to some adaptation within the athlete
    - Dependent on intensity, duration, and type
    - Must determine which stressors are optimal for desired adaptations

Homeostasis

- Regulation - cellular, autonomic, hormonal, and/or neural
- Rigid vs. plastic variables
  - Rigid
    - Great change means organism failure and death
    - Temperature, pH, water, PO_2
  - Plastic
    - change to a great extent to ensure rigid variable consistency
      - Heart rate, blood vessel constriction/dilation
- Allostasis is how the body responds to maintain homeostasis
- Can improve homeostasis level with training

“Biochemical Adaptations”

- The changes to the multiple functioning systems within the organism to improve the ability to maintain internal milieu
  - Multiple systems involved
  - Goal is to maintain homeostasis through changing environments

- What it is and how we look at it in athletics
  - How adaptations occur in the organism
    - Improvements in performance due to long-term, cumulative changes
    - Training completed leads to these net effects

Biochemical Adaptations to Training

- Every training session/exercise triggers an acute adaptation process
  - Body adjusts functions to corresponding level of elevated energy metabolism
- Systematic repetitions create long-term, sustainable adaptations
    - Achieved through training resulting in structural and metabolic enhancements
    - Long-term planning is crucial to ensure proper stable adaptations are created
- Nature of the chosen exercises determines long-term training adaptations
  - Specific training strategies for desired adaptations
    - Intensity and duration
      - Both determine energy systems used

Determine the Needs of Every Athlete

- Knowing each exercise causes specific adaptations, coaches must understand physiology and requirements of each competitive event

- Use 3 categories for simplicity – all require different parameters
  - Maximal effort – Weight lifting
    - Near-maximal recovery from every rep
    - High force output required
  - Repeat sprint effort – many team sports need to optimize this ability
    - Dependent on multiple qualities gained through training
  - Cyclic effort – distance running
    - Relies on cardiac output, aerobic ATP production and tolerance to energy metabolites

Repeat Sprint Ability

- Main focus
  - Mixture of multiple sport activities
  - Requires functional systems to adapt optimally for success
    - Rapid force production
    - Energy availability and capacity
    - High recovery rate
    - Cardiac output and blood flow
    - Metabolite production and clearance

Immediate Adaptations to Stress

- Organism survival is of upmost importance
- Muscles need energy to do work
- Rapid mobilization of energy for increased work output (glucose, protein, and fat)
  - Glucocorticoids, glucagon, epinephrine and norepinephrine
  - Glycogen to glucose
  - Triglycerides to free fatty acids and glycerol
  - Protein to amino acids (non-exercising muscles) to liver glucose
- Increased heart rate, blood pressure, and ventilation to get energy to the working muscles

Immediate Adaptations to Stress (cont.)

- Body halts long-term building processes (digestion, protein synthesis, and immune system)
  - If organism doesn't survive none of these matter
- Pain reception is blunted
- Improvements in sensory skills (senses and cognition sharpen)

Determinants of Immediate Adaptations

- Extent of response depends on multiple factors
  - Irritant's intensity
  - Athlete's current functional resources
    - Previous adaptations
      - Training age
      - Prior day's training
    - Nutritional status
    - Arousal level
    - Genetics
    - Fiber composition
- Represented by temporary reactions and transformations

Sympathetic Nervous System

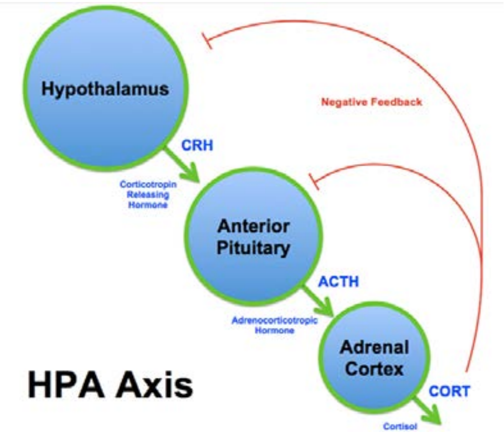
- Activated at onset of stress (pre-competition anxiety)
- Assists to complete the above stress responses
  - Stimulates secretion of epinephrine/norepenipherine
  - Dilate pupils
    - Improved vision capabilities
  - Increases concentration
  - Increases heart rate, blood pressure, peripheral muscular blood flow
  - Inhibits digestion
  - Inhibits immune system

Stress Response

- Stress response involves multiple systems
- Surviving in a changing environment depends on brain, endocrine, immune system, and their communication
- Understand all bodily systems function as one
- Communication is bi-directional
  - Immune system can influence release of hormones along with the activity of the nervous system and vice versa

HPA Axis

- Complex set of interactions among 3 endocrine glands
  - Major controller of stress reactions and bodily process regulation
    - Metabolic
    - Cardiovascular
    - CNS



- Responds to stress via sympathetic nervous system activation
  - Training, illness, cortisol levels, sleep

Hormones Involved in Stress Response

- Epinephrine/norepinephrine
  - Act within seconds of release
  - Generally stimulatory in nature
    - Mobilization of energy sources
- Glucocorticoids (Most well known is CORTISOL)
  - steroid hormone secreted by the adrenal gland
  - Often act similar to epinephrine
    - Regulation of metabolism of glucose
  - Take time for their effects to be realized
- These two account for a large percentage of stress response

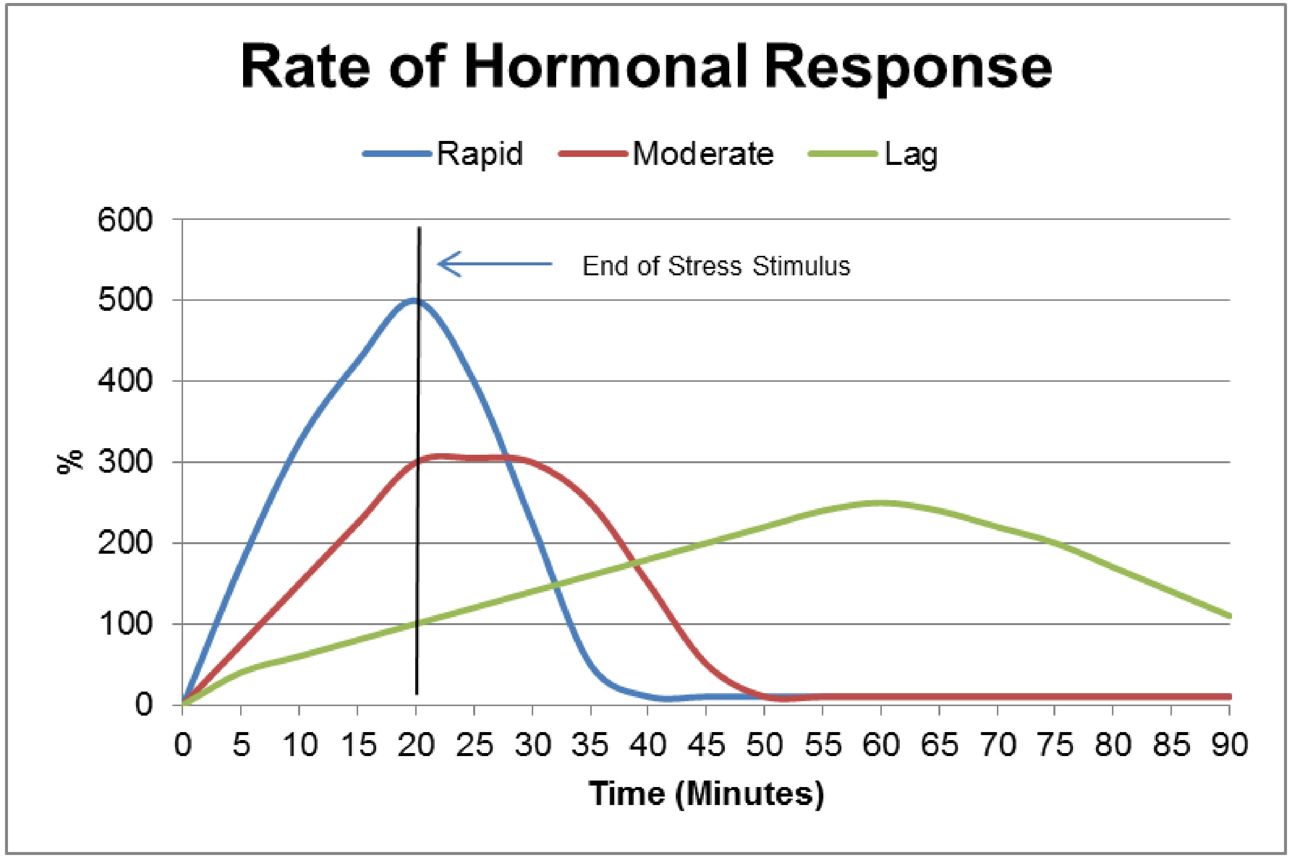
Other Hormones Involved in Stress Response

- Glucagon
  - Assists epinephrine and glucocorticoids in increasing glucose circulation
- Insulin
  - Inhibited
  - Responsible for increasing storage
- Growth Hormone
  - Released to improve mobilization of energy
  - Building function blocked
    - Decreased sensitivity

Hormonal Response

- 3 Responses
  - Rapid
    - Increase seen in first few min of exercise
    - Epinephrine and norepinephrine increases seen in 6 sec. of max effort
    - Due to higher nervous centers (HPA axis)
  - Moderate
    - Gradual increase in production
    - May continue beyond exercise time
  - Lagged
    - Delayed response in hormone increase
    - Dependent upon cumulative effects of exercise
    - Determines final blood hormone concentrations

Rate of Hormonal Response



Rate of Hormonal Responses			
Rate of Response	Rapid	Moderate	Lagged
Hormone	Catecholamines	Aldosterone	Somatotropin
	Corticotropin	Renin	Insulin
	Cortisol	Angiotensin II	Glucagon
			Calcitonin

Determinants of Hormonal Response

- Training age
- Nutritional status
  - Glucose availability
- Temperature
  - Hydration regulation
- Hormonal threshold
  - Closely related to the anaerobic threshold
    - close relationship between lactate levels and cortisol
- Exercise Stimulus
  - Increased recruitment enables greater hormone-tissue interaction
- Duration is a greater determinant than intensity
  - Limitations of athlete to maintain high intensities

Other/Metabolic Responses

- Increase glycogen phosphorylase (increase glycogen breakdown)
  - calcium and sodium ions, along with acetylcholine all increase glycogen phosphorylase activity
    - all involved in muscle contraction (neural or ion channels)

- PFK also increases with increased ADP and AMP
  - also responsible for glucose use

- Lactate inhibits a number of enzymes responsible for creating glycogen
  - want to keep resources mobilized

Stable adaptations

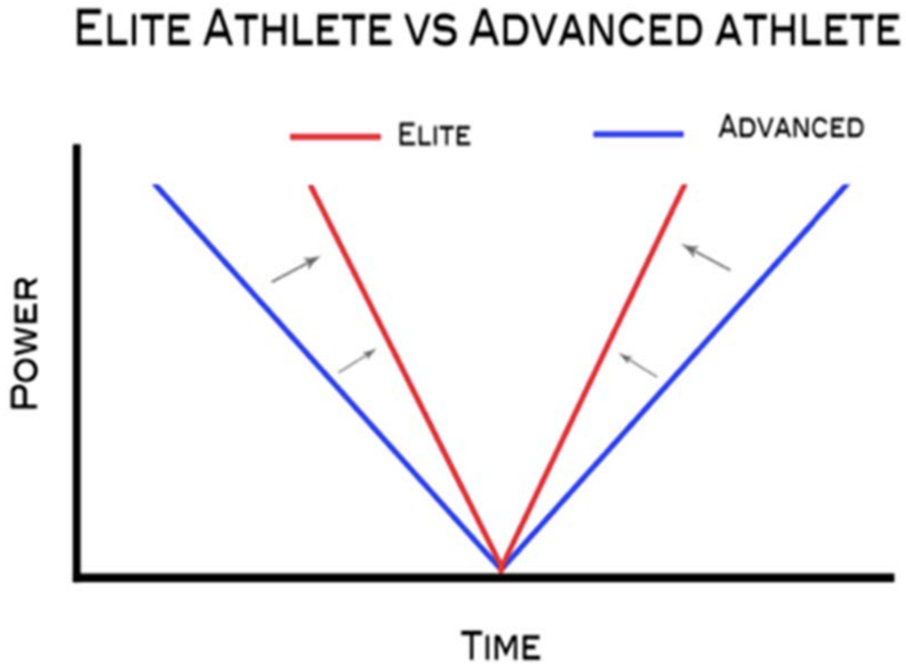
- Reflects the net cumulative training effect
  - Adaptation is specific to training executed
    - Max speed vs. conditioning example
- Potential stable adaptations
  - Cardiac
  - Muscular/CT
  - Metabolic
  - Endocrine
  - Nervous system
- Quantitatively measured by athletic condition and top form
  - Testing to determine adaptations

Cardiac adaptations

- Foundation for all performance parameters
- Improved efficiency through training
  - Central
    - Increased stroke volume
    - Improved contraction force/velocity
  - Peripheral
    - Improved oxygen kinetics
      - Increased hemoglobin concentration
      - Increased capillary density
      - Improved O_2 extraction
- Fick Equation
  - VO_2 = SV + HR –aVO_{2diff}
    - VO_2 still not perfect predictor of RSA

Muscular/CT adaptations

- Tissue Remodeling
  - Improved myosin-attachment
    - Increased titin activity?
- Muscle contractile steps
- Muscle action occurs at a higher rate
- Stretch shortening cycle

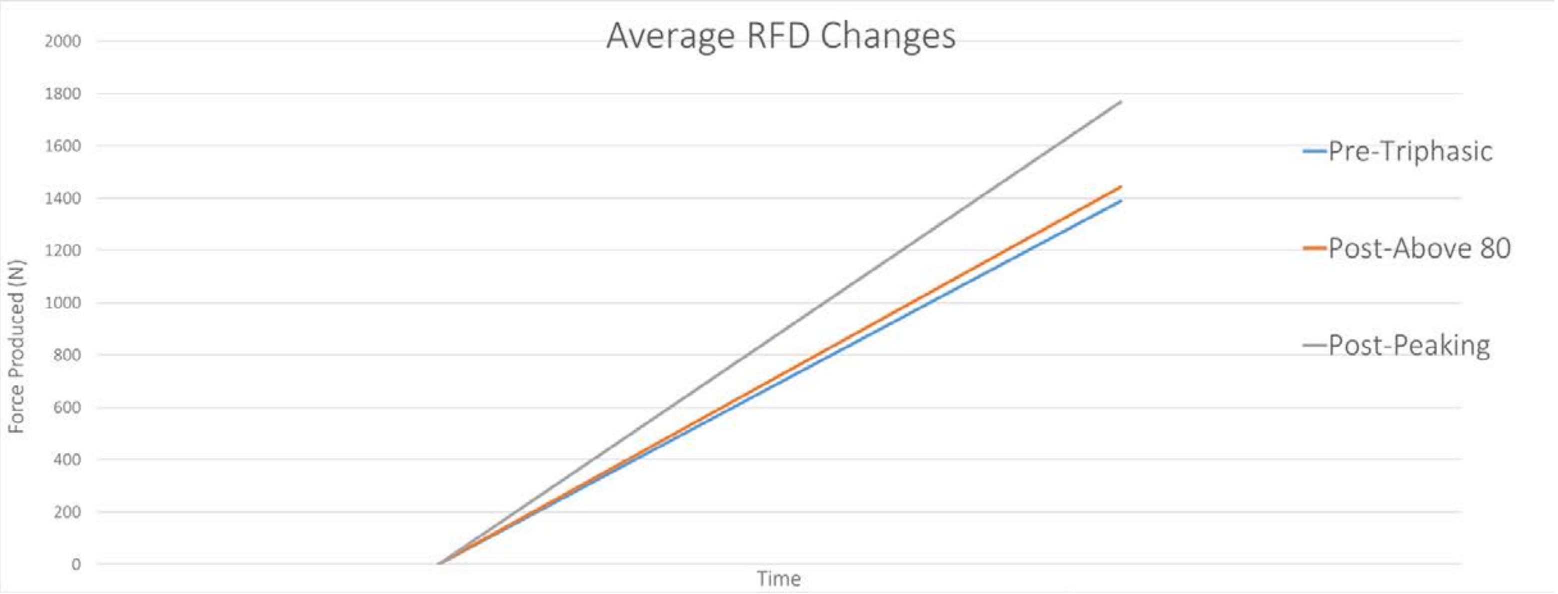


Metabolic adaptations

- Increase cellular resources due to training reduces need for increased systemic mobilization of resources during vigorous exercise
  - Body becomes "better prepared" to a stimulus
  - Homeostatic reactions may also diminish to some extent
  - Potential decrease in exercise-induced hormonal responses or avoid them altogether
- Oxidative
- Glycolytic
- Cr-P

Nervous system adaptations

- Rate of force development
  - Crucial in high-velocity movements
- Two phases
  - Early – neural
    - Recruitment
      - Selective in learned skill
    - Rate coding
      - Doublet occurrence
    - Synchronization
  - Late – muscular
    - Already covered



Stable endocrine adaptations

- Related to change in threshold intensity
  - Threshold intensity of exercise is shifted to a higher level
    - Need higher intensities to achieve hormonal response
  - In maximal intensity cases hormonal responses are magnified in athletes
    - Actual training-induced changes in the hormone response to exercise depend on a combination of various alterations in the organism

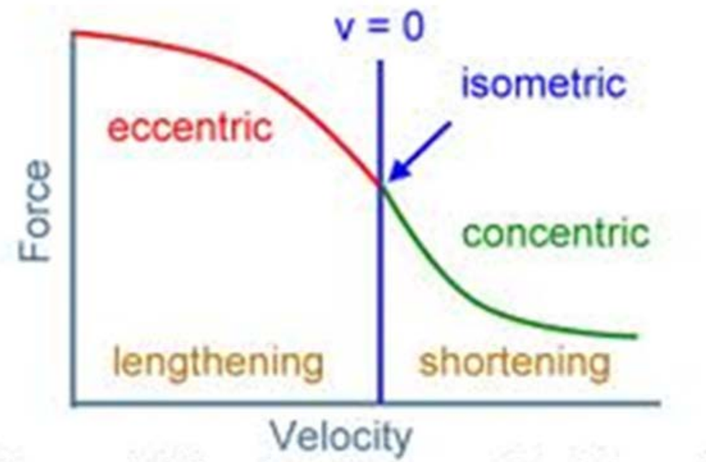
- Training induced adrenal hypertrophy is associated with an increased number of mitochondria
  - Duration plays major role in hormonal response
    - mitochondria and endoplasmic reticulum are the main sites of biosynthesis of glucocorticoids

Stable endocrine adaptations

- Acute responses more critical to tissue remodeling
- Many studies have not shown a significant change during resistance training despite adaptations
  - Other factors play a large role in stable adaptations
    - Non-training stress factors
    - Nutrition
    - Overtraining and detraining
    - Circadian patterns of hormone secretion

Stable training program

- Systematic, specific stress model
  - Block periodization
    - Residual effects
- Modified undulated training
- Specific muscle action training
  - Eccentric and Isometric stronger



Force-Velocity Curve of a Muscle

Testing Protocols

- Transfer of training
  - Test for adaptations related to qualities used in competition

- Tests must be specific for desired adaptation
  - HR recovery
  - Repeat sprint ability
  - Lactate tolerability/clearance

Heart rate recovery

- Efficiency of cardiac/circulatory components
- Adaptations over specific training cycles
- Vital role in recovery aspect

Repeat sprint ability

- Maximal intensity and Recovery rate
  - Similar to team sports
- Percent change in sprints
- 10 – 30 yard sprints
- Visual for athlete

Lactate tolerability/clearance

- 2 – 300 yard shuttles
- 3-5 min recovery between
- Current lactate system status

Conclusion

- Body adapts specifically to stressors applied
- Determine needs of each sport
- Acute endocrine response to stress is more important for stable adaptations
- Stable adaptations are the net effects of training
- Maximize adaptations using the specific stress training model
- Test athletes appropriately based on needs

References

- Ahtiainen JP, Pakarinen A, Alen M, et al. Muscle hypertrophy, hormonal adaptations and strength development during strength training in strength-trained and untrained men. Eur J Appl Physiol 2003; 89: 555-563
- Ahtiainen JP, Pakarinen A, Kraemer WJ, et al. Acute hormonal and neuromuscular responses and recovery to forced vs maximum repetions multiple resistance exercises. Int J Sports Med 2003; 24: 410-418
- Bengt, S. Hemodynamic adaptations to exercise. The American Journal of Cardiology 2004; 55: D42-D47
- Chandler RM, Byrne HK, Patterson JG, et al. Dietary supplements affect the anabolic hormones after weight-training exercise. J Appl Physiol 1994; 76: 839 – 845.
- Fry AC, Kraemer WJ. Resistance exercise overtraining and overreaching: neuroendocrine responses. Sports Med 1997; 23: 106-129
- Guezennec Y, Leger L, Lhoste F, et al. Hormone and metabolite response to weight-lifting training sessions. Int J Sports Med 1986; 7: 100-5
- Hakkinen K, Pakarinen A, Alen M, et al. Relationships between training volume, physical performance capacity, and serum hormone concentrations during prolonged training in elite weight lifters. Int J Sports Med 1987; 8 Suppl.: 61-65
- Hakkinen K, Pakarinen A, Kraemer WJ, et al. Basal concentrations and acute responses of serum hormones and strength development during heavy resistance training in middle-aged and elderly men and women. J Gerontol A Biol Sci Med Sci 2000; 55: B95-105
- Hakkinen K, Pakarinen A. Acute hormonal responses to heavy resistance exercise in men and women at different ages. Int J Sports Med 1995; 16: 507-13
- Hickson RC, Hidaka K, Foster C, et al. Successive time courses of strength development and steroid hormone responses to heavy-resistance training. J Appl Physiol 1994; 76: 663-670
- Kahn SM, Hryb DJ, Nakhla AM, et al. Sex hormone-binding globulin is synthesized in target cells. J Endocrinol 2002; 175: 113-120
- Kraemer WJ, Fleck SJ, Maresh CM, et al. Acute hormonal responses to a single bout of heavy resistance exercise in trained power lifters and untrained men. Can J Appl Physiol 1999; 24: 524-537
- Kraemer WJ, Hakkinen K, Newton RU, et al. Effects of heavy-resistance training on hormonal response patterns in younger vs older men. J Appl Physiol 1999; 87: 982-992

References

- Kraemer WJ, Marchitelli L, Gordon SE, et al. Hormonal and growth factor responses to heavy resistance exercise protocols. J Appl Physiol 1990; 69: 1442-1450
- Kraemer WJ, Noble BJ, Clark MJ, et al. Physiologic responses to heavy-resistance exercise with very short rest periods. Int J Sports Med 1987; 8: 247-252
- Kraemer WJ, Staron RS, Hagerman FC, et al. The effects of short-term resistance training on endocrine function in men and women. Eur J Appl Physiol 1998; 78: 69-76
- Kraemer WJ, Volek JS, Bush JA, et al. Hormonal responses to consecutive days of heavy-resistance exercise with or without nutritional supplementation. J Appl Physiol 1998: 85: 1544-55
- Kraemer, W., & Ratamess, N. (2003). Endocrine responses and adaptations to strength and power training. In *Strength and power in sport* (2nd ed., pp. 361-386). Malden, MA: Blackwell Scientific Publications.
- Kraemer, W., Ratamess, N., & Rubin, M. (2000). Basic principles of resistance exercise. In*Nutrition and the strength athlete*. Boca Raton: CRC Press.
- Scheuer, J, Tipton, CM. Cardiovascular Adaptations to Physical Training. J Appl Physiol 1977; 39: 221-251
- Tremblay MS, Copeland JL, Van Helder W. Effect of training status and exercise mode on endogenous steroid hormones in men. J Appl Physiol 2003; 96: 531-539
- Volek JS, Kraemer WJ, Bush JA, et al. Testosterone and cortisol in relationship to dietary nutrients and resistance exercise. J Appl Physiol 1997; 8: 49-54
- Weiss LW, Cureton KJ, Thompson FN. Comparison of serum testosterone and androstenedione responses to weight lifting in men and women. Eur J Appl Physiol 1983; 50: 413-9
- Willoughby DS, Taylor M, Taylor L. Glucocorticoid receptor and ubiquitin expression after repeated eccentric exercise. Med Sci Sports Exerc 2003; 35: 2023-2031