King Saud University
LECTURE 1
(9-10:30am, 24th September)

Exercise-Induced Muscle Damage

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AUSTRALIA

1

Kazunori (Ken) Nosaka

- Sprinter (100m: 10.8, 200m: 22.0)
- Physical Education
- PE teacher, Athletics coach (Yokohama City University)
- Exercise Science (Physiology)
- University of Massachusetts (1989-1991) (Dr. Priscilla Clarkson)
- Sabbatical at ECU (2000)
- Edith Cowan University
  - Associate Professor (2004-2008)
  - Professor (2009-present)
  - Postgraduate course coordinator
  - Centre for Exercise and Sports Science Research (CESSR) director
- Muscle damage research: >20yr

How should I train muscles to sprint faster? Why do muscles become sore after training? No pain, No gain!

2

Type of Muscle Contraction

Isometric (Static) : Force = Load
Concentric (Shortening) : Force > Load
Eccentric (Lengthening) : Force < Load

Consciously: forced lengthening, controlled lengthening
Unconsciously: deceleration, shock absorption

3

Eccentric Exercises

4

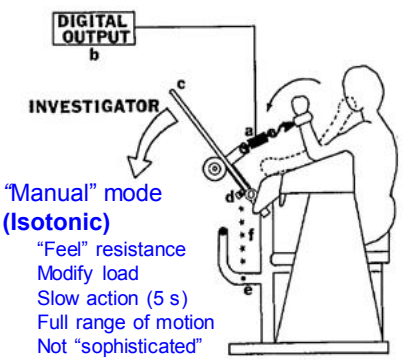
Exercise Models of Muscle Damage in Human Studies

- Downhill running, walking, backward walking
- Bench stepping exercise
- Sitting exercise
- Plyometric exercises (e.g. Drop Jumps)
- Eccentric cycling
- Submaximal / Maximal Eccentric Exercise
  Elbow Flexors / Extensors, Wrist Extensors
  Knee Extensors / Flexors, and others

The magnitude of damage is dependent on the models, subjects (gender, age, conditions etc)

5

Elbow Flexor "Torture" Machine

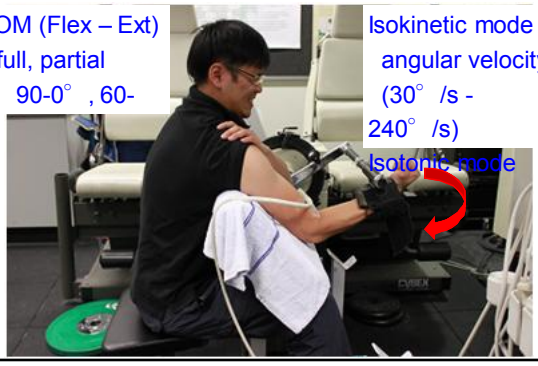


"Manual" mode
(Isotonic)
"Feel" resistance
Modify load
Slow action (5 s)
Full range of motion
Not "sophisticated"
But, worked well!

6

Maximal Eccentric Contractions of the Elbow Flexors

ROM (Flex – Ext)
full, partial
90-0°, 60-0°



Isokinetic mode
angular velocity
(30°/s - 240°/s)
Isotonic mode

7

Muscle Damage

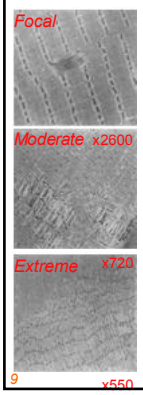
SYMPTOMS	MARKERS
Weakness	↓ Muscle function
Muscle Pain	Pain Scale (e.g. VAS, VRS)
↑ Stiffness	↓ Range of Motion
Swelling	↑Muscle Volume, Girth
	Abnormality in MR/US
	↑Muscle proteins in blood

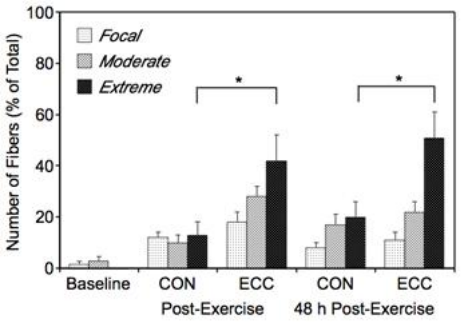
Histological changes

8

Ultrastructural Alterations

8 sets of 8 reps @80% 1RM Arm-curl exercise





Gibala et al., J Appl Physiol 1995.

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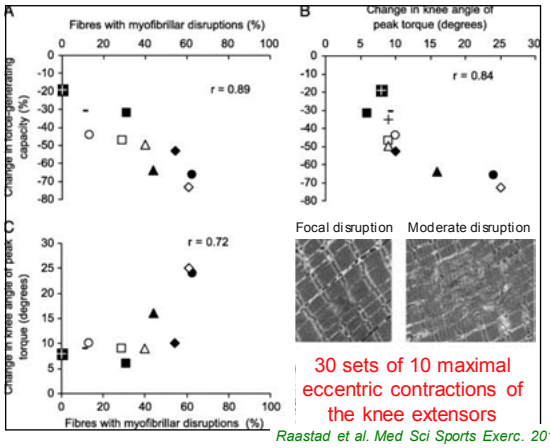

30 sets of 10 maximal eccentric contractions of the knee extensors

Raastad et al. Med Sci Sports Exerc. 2010.

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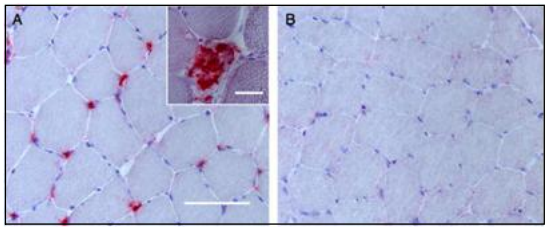

A: CD16+ cells (red stain) were observed in the interstitial spaces of the exercising leg (musculus vastus lateralis) shown here at 96h (4d) after exercise; the inserted picture shows CD68+ cells (red) inside a muscle cell (scale bar = 50 µm).
B: A small number of CD16+ cells were noted in the control leg. Blue stain (hematoxylin) shows nuclei. Scale bar = 100 µm.

Intracellular infiltration was observed occasionally (0.2-1.35% of myofibres)

Paulsen et al. Med Sci Sports Exerc. 2010.

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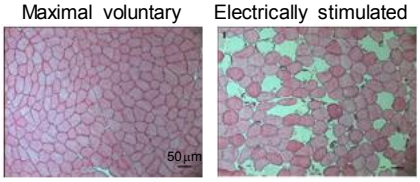
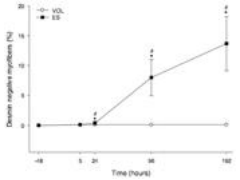
Voluntary Contraction vs Electrical Stimulation

210 lengthening contractions of the knee extensors (8 men)

Maximal voluntary | Electrically stimulated

Desmin stain
8 days post





- Disrupted Z-lines were greater for the stimulation
- No significant difference in muscle soreness
- Greater strength loss in the voluntary exercise

Crameri et al. J Physiol. 2007.

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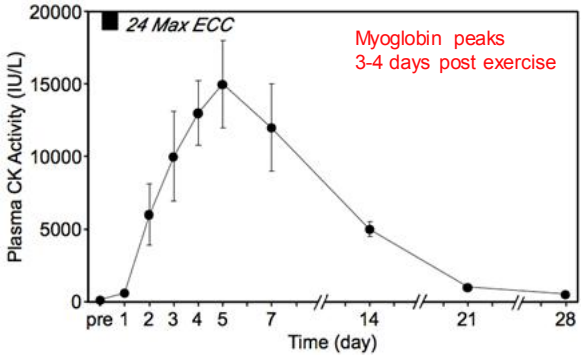
Changes in CK activity following Max ECC



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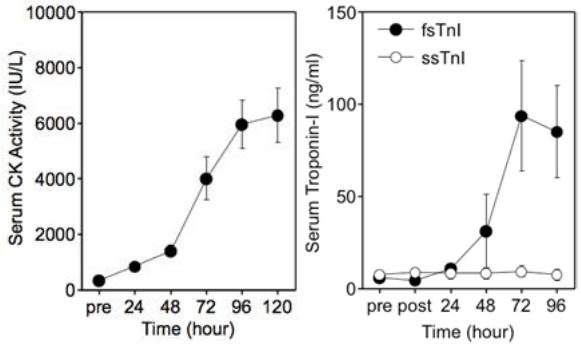
Nosaka & Clarkson, Med Sci Sports Exerc. 1996.

CK and TnI



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Chapan et al. J Sci Med Sport. 2012.

Inflammatory Markers after Mac ECC

No significant changes in CRP after Max ECC

Nosaka & Clarkson. Med Sci Sports Exerc. 1996.

No significant changes in the number of circulating lymphocytes, eosiophils, basophils, and small increases in neutrophils (12, 36, and 60 h post) and monocytes (8 h post)

Nosaka & Sakamoto. Adv Exerc Sports Physiol. 2000.

Little or no changes in inflammatory mediators

IL-1β, IL-1ra, IL-4, IL-6, IL-8, IL-10, IL-12p40, TNF-α G-CSF, MPO, PGE_2, HSP60, HSP70

Hirose et al. Exerc Immunol Rev. 2004.
Peake et al. Exerc Immunol Rev. 2006.

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Muscle Soreness

Visual Analogue Scale (VAS)

no pain **50 mm (100 mm)** **very painful**

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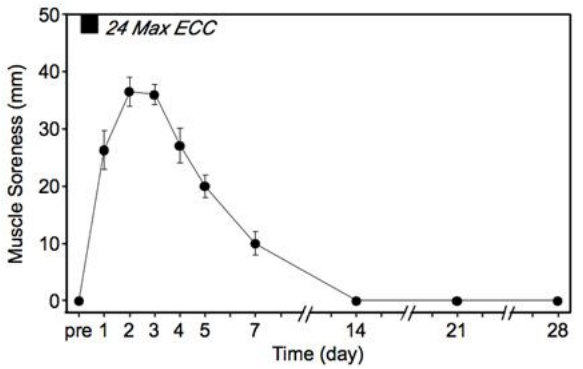
Muscle Soreness following Max ECC



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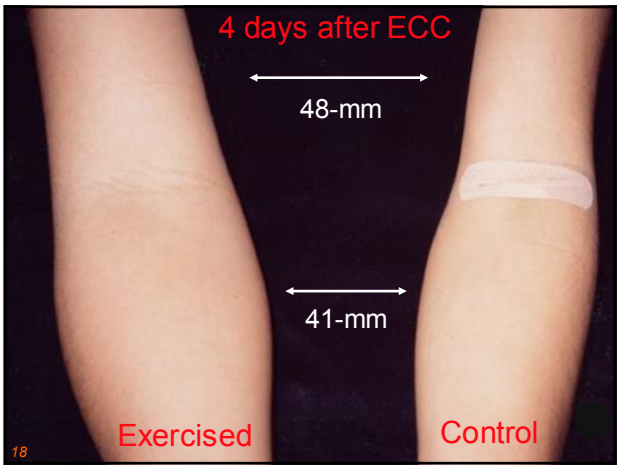
Nosaka & Clarkson, Med Sci Sports Exerc. 1996.



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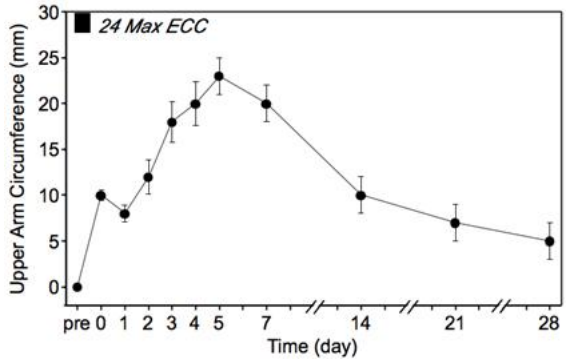
Muscle Swelling following Max ECC



Nosaka & Clarkson, Med Sci Sports Exerc. 1996.

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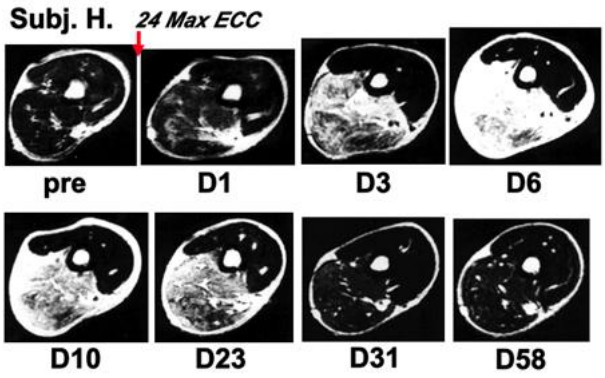
Changes in MRI (T2) following Max ECC



Nosaka & Clarkson, Med Sci Sports Exerc. 1996.

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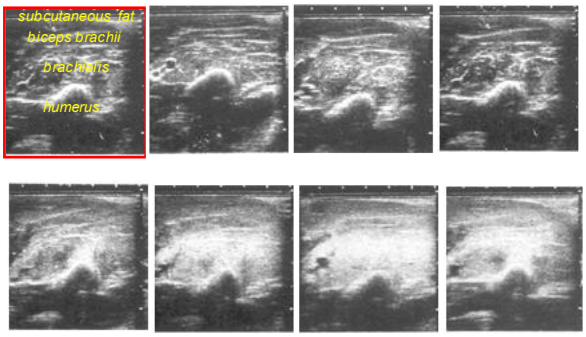
Changes in B-mode ultrasound images after elbow flexor eccentric exercise



Nosaka & Clarkson, Med Sci Sports Exerc. 1996.

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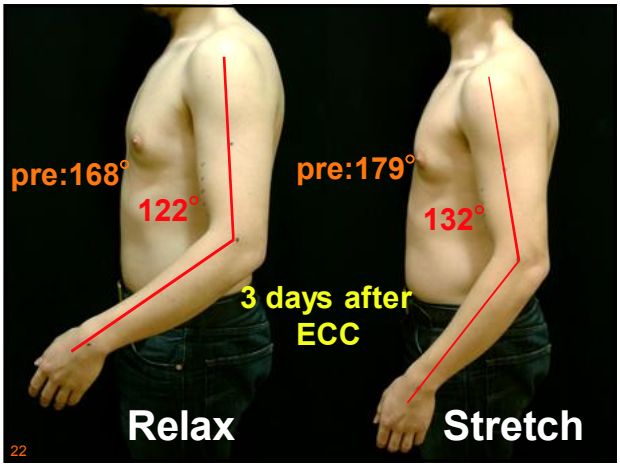

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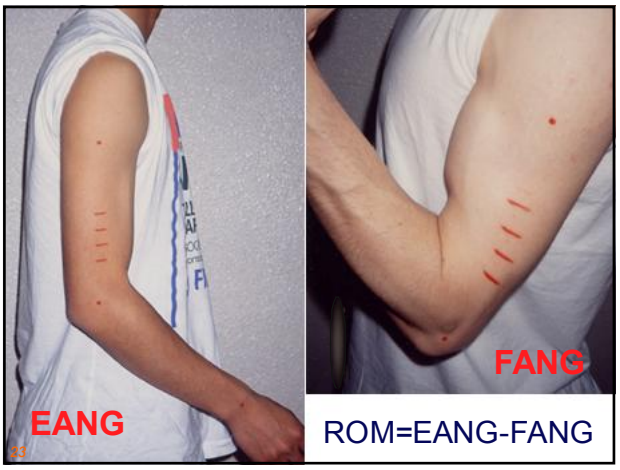

ROM=EANG-FANG

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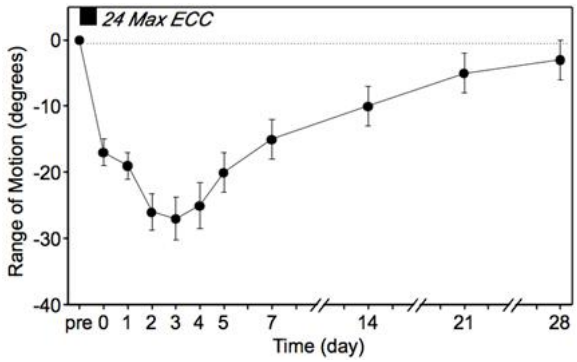
Changes in ROM following Max ECC



Nosaka & Clarkson, Med Sci Sports Exerc. 1996.

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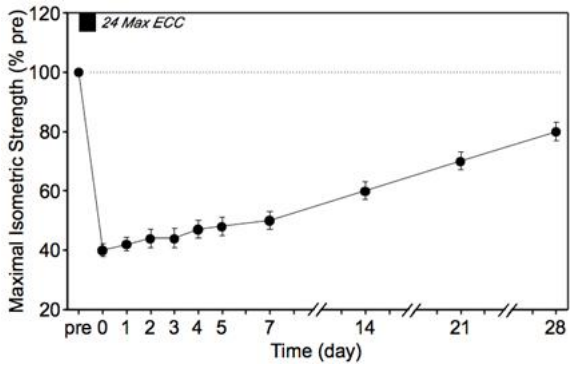
Changes in MVC following Max ECC



Nosaka & Clarkson, Med Sci Sports Exerc. 1996.

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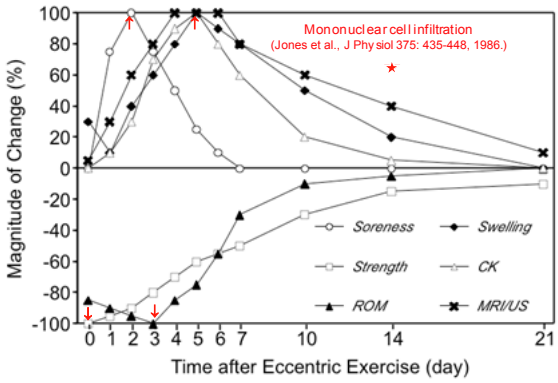
Changes in Markers following Max ECC



Nosaka et al. Int J Sport Health Sci. 2003.

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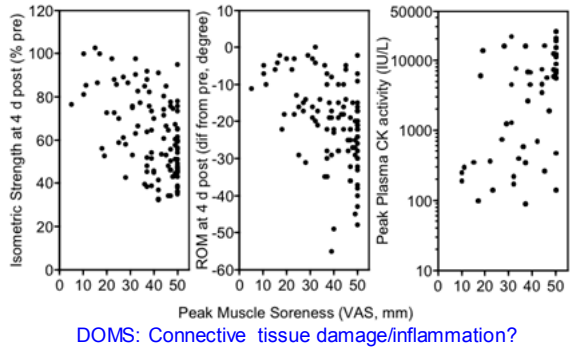
DOMS and Other Markers

No significant correlation



DOMS: Connective tissue damage/inflammation?

Nosaka et al. Scan J Med Sci Sports. 2002.

27

Muscle Damage by Non-ECC

- Isometric contractions at a long muscle length (e.g. elbow joint angle: >160°)
- Concentric contractions with fatigue
- Electrical stimulation
- Stretching
- Muscle cramp

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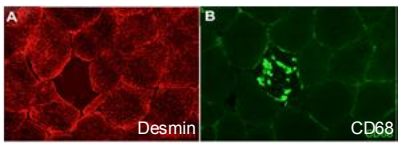
Structural Damage by EMS

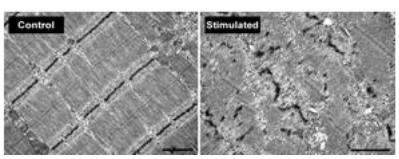
180 isometric contractions of the plantar flexors

EMS: 60 Hz, 300 μs, on-off 4–6 s

Lack of desmin fibres:12%
CD68+ fibres: 13.6%



48 h post EMS, gastrocnemius



Mackey et al. J Appl Physiol. 2008.

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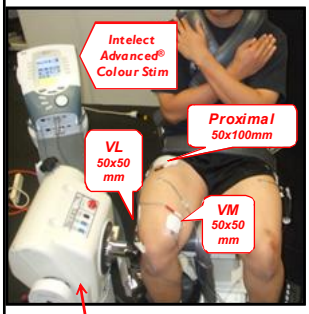
EMS Protocol



Biodex isokinetic dynamometer

Intelect Advanced Colour Stim (Chattanooga Group, USA)

2 positive electrodes over motor point of the VL and VM

2 negative electrodes over the proximal portion of the QF

75 Hz pulsed current, pulse duration: 400 μs, duty cycle: 5 s / 15 s

40 isometric contractions

Knee joint angle: 100°

Trunk angle: 110°

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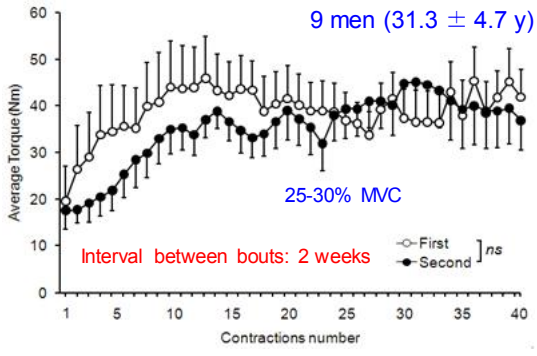
Torque during Exercise



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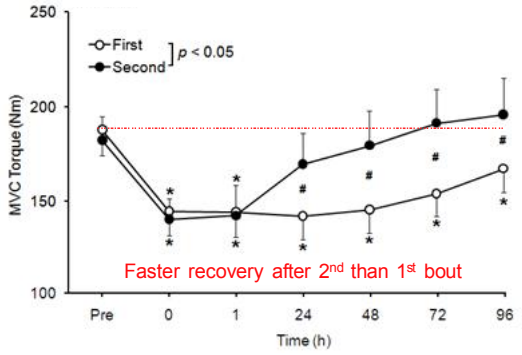
Aldayel et al. Eur J Appl Physiol. 2010.

Maximal Voluntary Isometric Contraction Strength @100°



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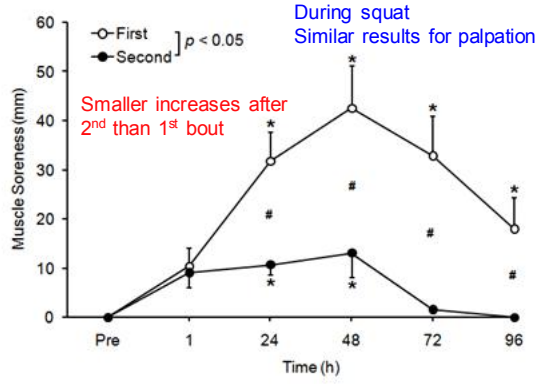
Muscle Soreness



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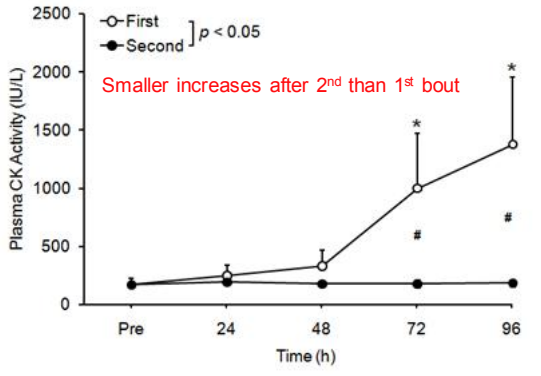
Plasma CK Activity



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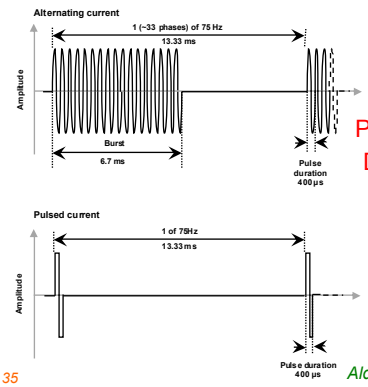
Alternating Current vs Pulsed Current



2.5 kHz @75 Hz
Sinudoidal

Pulse duration: 400 µs
Duty cycle: 5 s / 15 s
Maximal tolerance

75 Hz
Biphasic, rectangular

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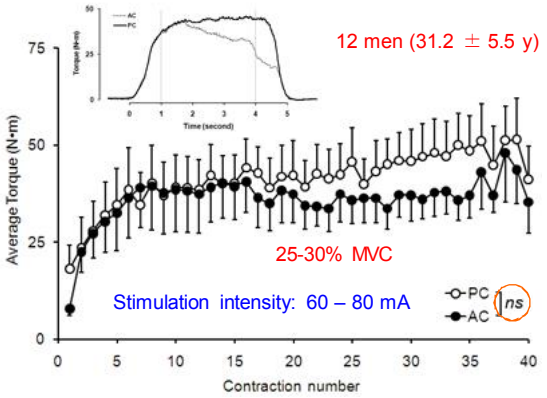
Aldayel et al. J Appl Physiol. 2011

Torque during EMS



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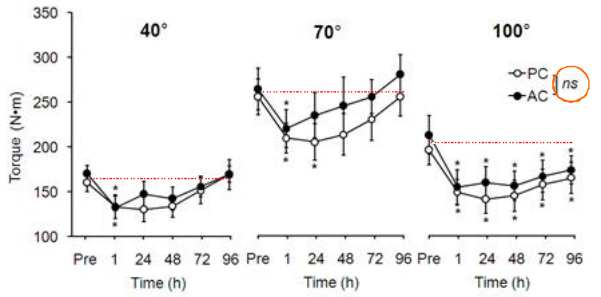
Maximal Voluntary Isometric Contraction Strength



Strength loss: 100° > 70° > 40°

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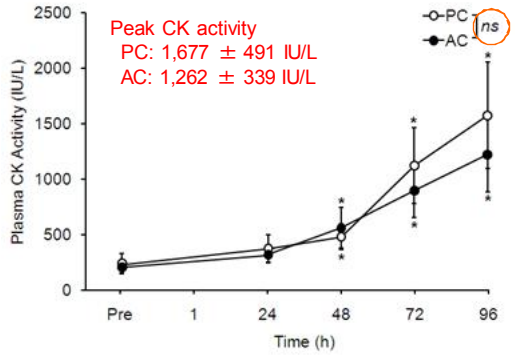
Plasma CK Activity



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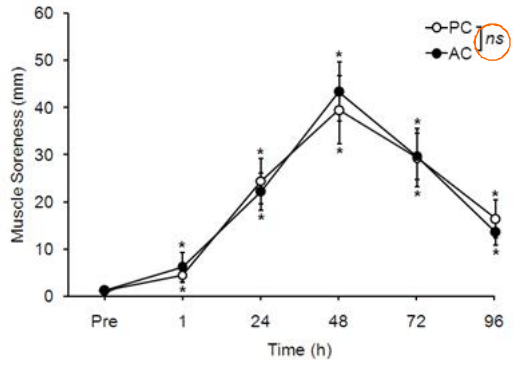
Muscle Soreness



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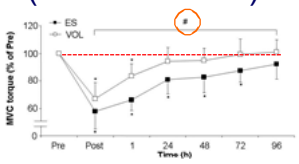
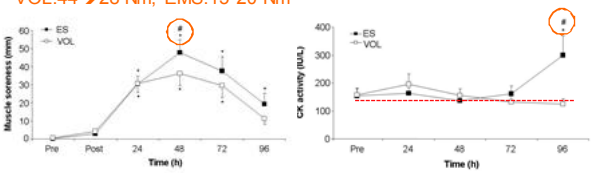
Voluntary vs EMS (Elbow Flexors)

12 men
Arm1: Voluntary Max isometric
Arm2: EMS-induced isometric
50 intermittent (5s /15s rest) contractions@160°
EMS: 75 Hz, 200µs
Peak torque over 50 contractions
VOL:44➔28 Nm, EMS:15-20 Nm



Greater changes after EMS than VOL



Greater increases after EMS than VOL

Jubeau et al. Eur J Appl Physiol. 2012.

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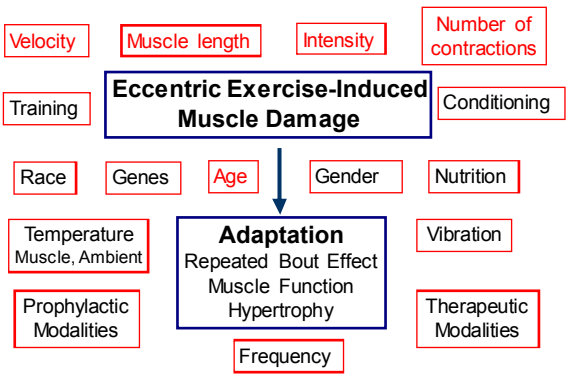
Factors influencing muscle damage



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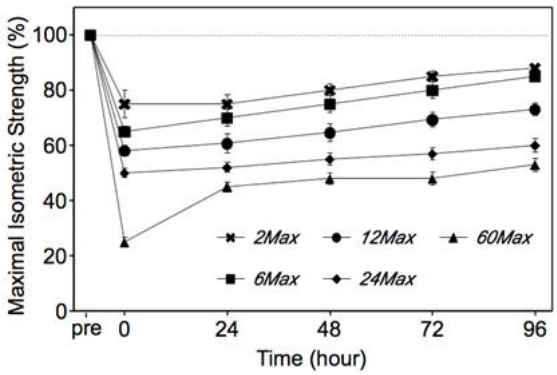
Effect of Number of Eccentric Actions



Nosaka et al., Int J Sport Health Sci. 2003.

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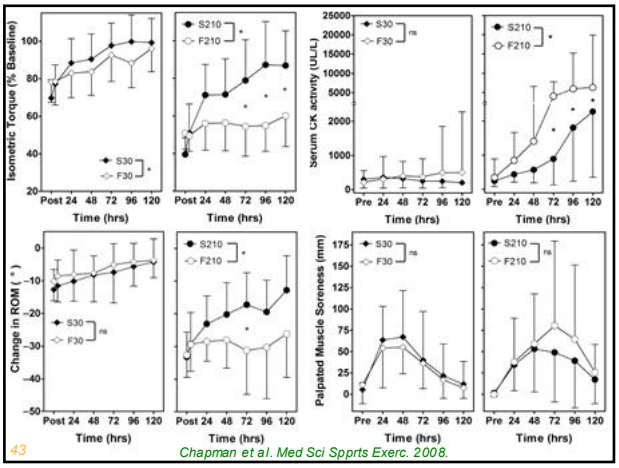

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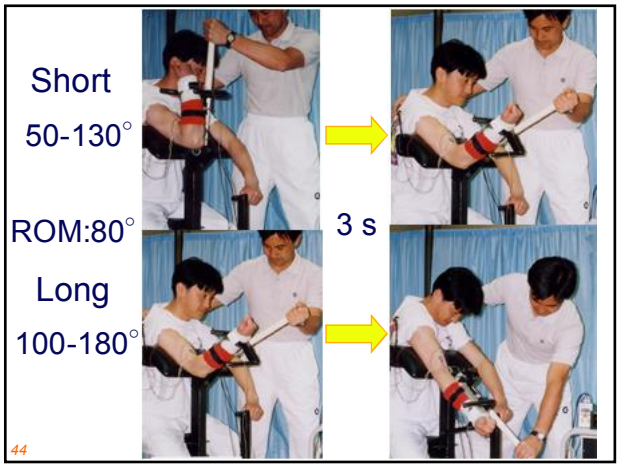
Chapman et al. Med Sci Sports Exerc. 2008.



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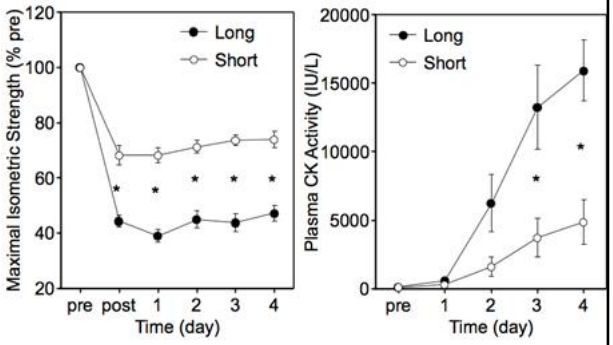
Short vs Long Muscle Length



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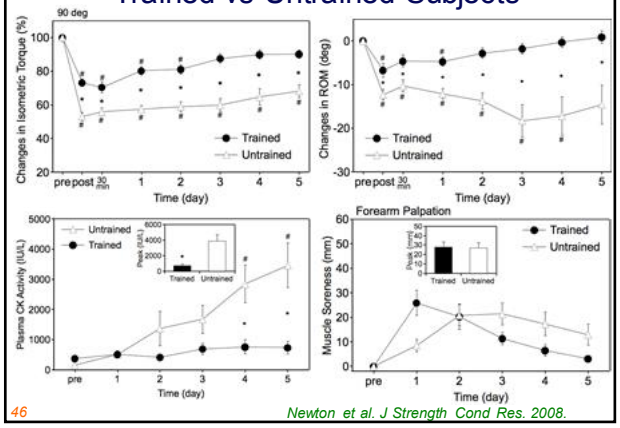
Nosaka & Sakamoto, Med Sci Sports Exerc. 2001.

Trained vs Untrained Subjects



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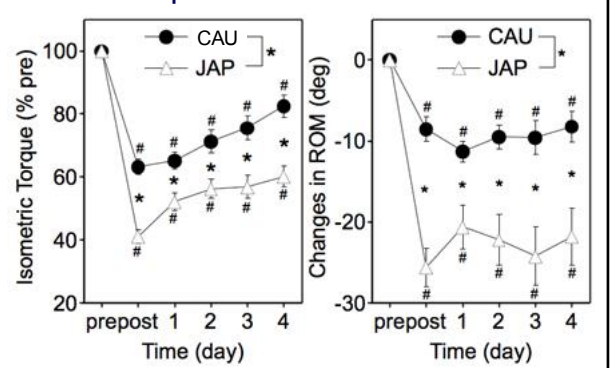
Newton et al. J Strength Cond Res. 2008.

Japanese vs Caucasian



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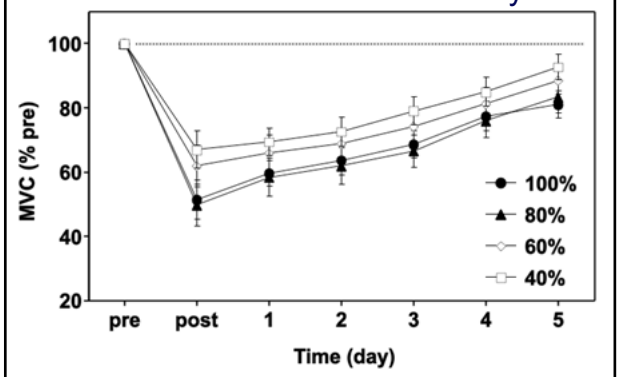
Newton et al. in preparation

Effect of Exercise Intensity



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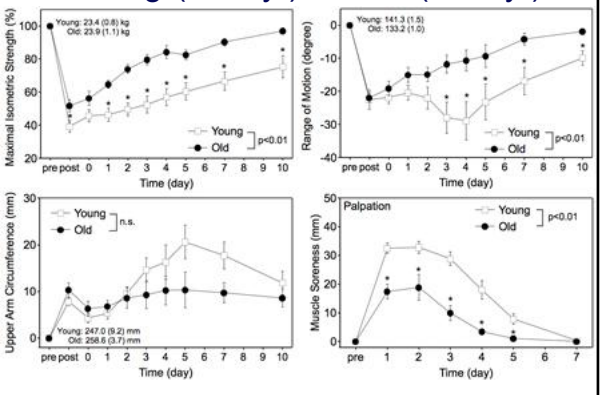
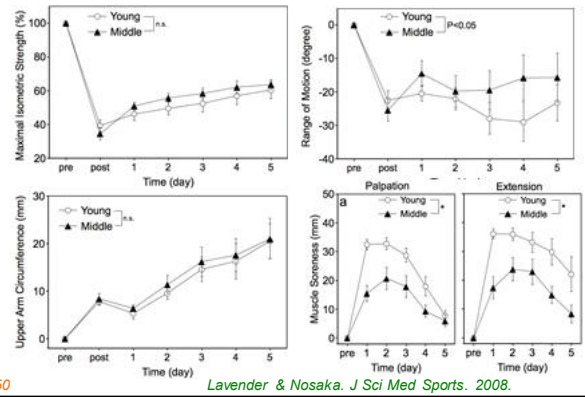
Chen et al. J Appl Physiol. 2007.

Young (19.4 yr) vs Old (70.5 yr)



49 *Lavender & Nosaka. Appl Physiol Nutr Metab. 2006.*

Young (19.5 yr) vs Middle-age (48.0 yr)



50 *Lavender & Nosaka. J Sci Med Sports. 2008.*

Muscle Damage / DOMS in Children

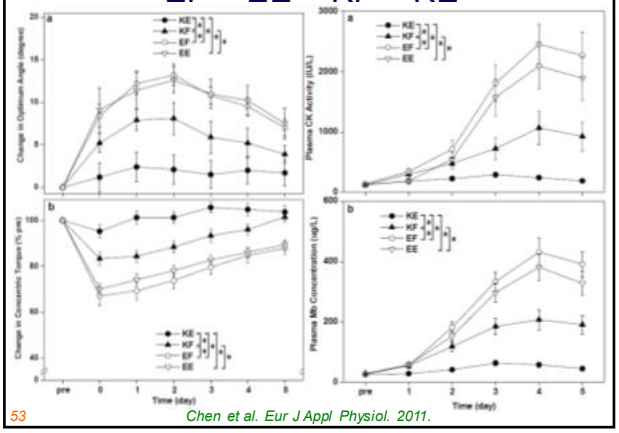
- Limited information is available
- No DOMS for infants?
  - no DOMS for 3-5 yr (parents' observation)
- Little DOMS before 10 yrs?
  - little DOMS for 6-7 yr (questionnaire)
  - no DOMS after eccentric exercise (Exp)
  - 1/3 of 11-12 yr had DOMS (questionnaire)
  - less DOMS and muscle damage for 9-10 yr

51

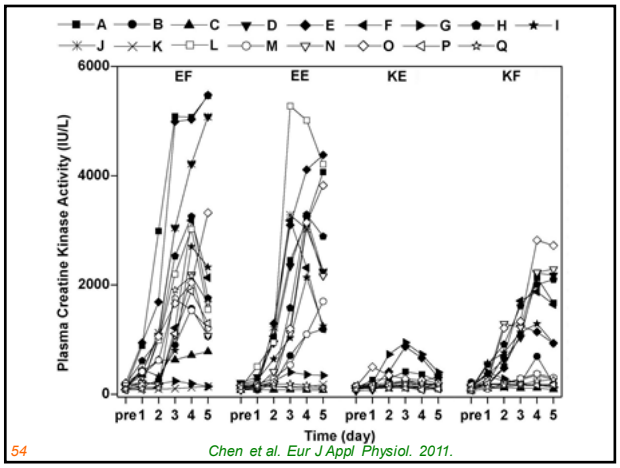
Eccentric Exercise of 4 Different Limbs

52

EF = EE > KF > KE

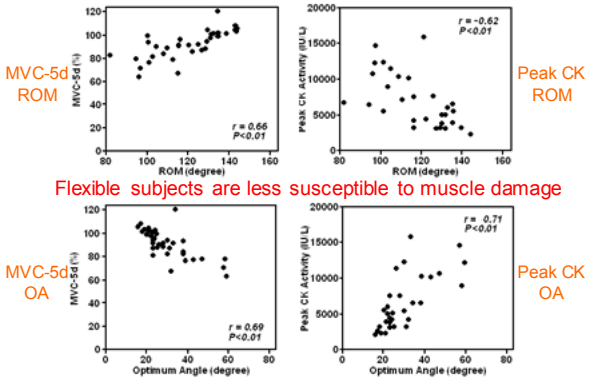


53 *Chen et al. Eur J Appl Physiol. 2011.*



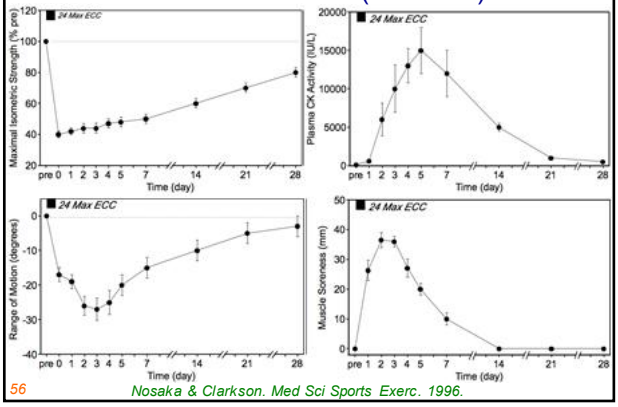
54 *Chen et al. Eur J Appl Physiol. 2011.*

Flexibility and Muscle Damage



55 *Chen et al. Med Sci Sports Exerc. 2011.*

24 Maximal Eccentric Contractions of the Elbow Flexors (untrained)



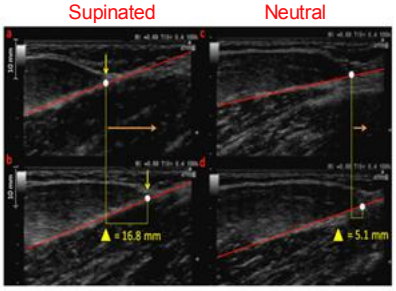
56 *Nosaka & Clarkson. Med Sci Sports Exerc. 1996.*

Effect of Wrist Position

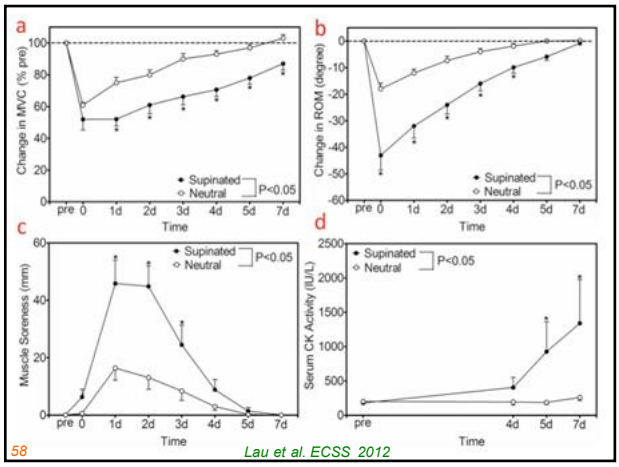
Supinated

Neutral

Supinated Neutral



57



58 *Lau et al. ECSS 2012*

Factors influencing Muscle Damage

Contraction type	*shortening*	*isometric*	*lengthening*
Intensity	*low*		*high*
Velocity	*slow*		*fast*
Number of contractions	*small*		*large*
Muscle length	*short*		*long*
Muscle temperature		*high*	*low*
Pre-conditioning/training	*yes*		*no*
Age		*young*	*old*
Gender		*female*	*male*
Factors	minor	**Magnitude of Muscle Damage**	severe

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Muscle Damage after Downhill Running

	pre	1 h	1 d	2 d	3 d	4 d	5 d
MVC	496.7	391.2*	423.9*	436.0*	443.2*	461.0*	486.5
(N)	± 21.2	± 40.6	± 36.1	± 33.8	± 31.1	± 27.7	± 22.5
Muscle	0.0	2.1	4.9*	7.6*	3.1	1.0	0.8
Soreness	± 0.0	± 0.9	± 1.6	± 2.1	± 0.8	± 0.4	± 0.2
CK	104.5	226.6	420.2*	461.5*	420.1*	420.0*	418.3*
($IU \cdot L^{-1}$)	± 28.5	± 46.3	± 70.7	± 96.9	± 89.7	± 88.5	± 87.8
Mb	19.8	100.6*	127.3*	122.7*	94.2*	72.0*	67.0
($\mu g \cdot L^{-1}$)	± 5.1	± 20.2	± 27.9	± 21.3	± 19.2	± 16.2	± 10.9

60 *Chen et al. J Sports Sci. 2007.*

Ironman Triathlon

Muscle function (pre-1d) pre-post-12h-1d-2d-3d-5d-8d

- MVC (KE): -30% -38, -32, -23, -5, 0, 0, 0%
- MVC (KF): -9% -52, -46, -30, -19, -5, 0, 0%
- SJ: -29% -48, -50, -42, -18, -9, -8, 0%
- CMJ: -20% -54, -47, -39, -30, -29, -24, -18%

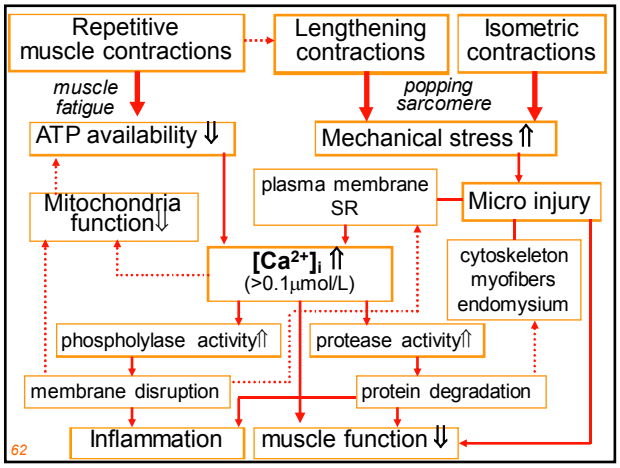
Muscle soreness (pre, post, 1d) pre-2h-12h-1d-2d-3d-5d-8d

- KE: 0 - 6.1 - 6.0 0, 7, 8, 8, 8, 7, 2, 1
- KF: 0 - 3.0 - 3.4 0, 5, 4, 3, 2, 1, 0, 0
- AF: 0 - 4.3 - 3.9 0, 6, 4, 4, 1, 1, 1, 0

Blood markers (pre, post, 1d) 36yr man (67 ml/kg/min)

- CK: 218, 2780, 5700 IU/L S: 1:07:03
- Mb: 21, 2998, 487 ng/ml C: 5:25:06 11:38:41
- Interleukins: large increases R: 5:06:32

61 *Suzuki et al. Eur J Appl Physiol. 2006.* *Nosaka et al. Eur J Sport Sci. 2009.*



Thank you very much

Questions?
Comments?
Suggestions?
Collaborations?
Supervisions?

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