Residual Force Enhancement in humans
Moving beyond purely mechanical properties

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Residual Force Enhancement (RFE)…

…as mechanical property of voluntarily activated human muscle:

\[ \Delta F = \text{RFE} \approx 10\% \]

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Residual Force Enhancement (RFE)...

...as activation reduction (AR) at a given level of force/torque:

- 60s torque-control contractions at 50% knee extensor MVC

\[ \Delta VL = -14.2\% \]
\[ \Delta RF = -20.6\% \]
\[ \Delta VM = +0.9\% \]
Residual Force Enhancement (RFE)…

…as higher force/torque at a given level of EMG activity or
…as activation reduction (AR) at a given level of force/torque

1. **Modulation of neural control?**

   *Altenburg et al. (2008), Appl Physiol Nutr Metab 33(6), 1086-1095*

   → reduced sEMG but **no reduction** in discharge rate of single motor units (MU)

   → potential derecruitment of MU during AR

   *Hahn et al. (2012), PLoS One 7(11), e49907*

   → Cortical and spinal excitability during the presence of RFE
Modulation of neural control during RFE

Methods & Experimental Protocol

- calf muscles of n = 10 subjects
  (29.1 ± 6.6 yr, 1.77 ± 0.08 m and 73.4 ± 11.8 kg)

- EMG of soleus (SOL), medial gastroc. (MG) and tibialis anterior muscles (TA)

- 2 different plantar flexor contractions:
  isometric MVC at 20° dorsiflexion
  active lengthening MVC, 0-20° DF, ω = 30°s⁻¹

- 3 different superimposed stimulations:
  electrical nerve stimulation (n. tibialis)
  electrical stimulation of the cervicomedullary junction → spinal excitability (CMEP)
  transcranial magnetic stimulation of the motor cortex → cortical & spinal excitability (MEP)
Modulation of neural control during RFE

Results

→ 9±8% RFE 2.5-3 seconds following active lengthening
Modulation of neural control during RFE

**Results**

- increased MEPs during RFE
Modulation of neural control during RFE

Results

- increased MEPs during RFE
- unchanged CMEPs
Modulation of neural control during RFE

**Results**

- greater MEPs during RFE
  → **cortical & spinal excitability**

- unchanged CMEPs
  → **spinal excitability**

- unchanged M-wave, enlarged V-wave

→ **increased cortical excitability during the presence of RFE**

Do these changes in neural control contribute to RFE?
Residual Force Enhancement (RFE)…
…as higher force/torque at a given level of EMG activity or
…as activation reduction (AR) at a given level of force/torque

1. **Modulation of neural control?**
   → Yes, but unclear how this modulation underlies RFE

2. **Reduction in metabolic cost?**
   
   Joumaa & Herzog. (2013), J Biomech 46, 1135-1139
   → 17.2±4.1% reduced ATPase activity per unit of force in skinned fibres following active lengthening.
   → Does this also apply for an in vivo human muscle?
Reduction in metabolic cost

Methods & Experimental Protocol

- QF, 60% MVC torque control, 60s
- stretch 80-100°, \( \omega = 60°\text{s}^{-1} \)
- 4h rest between contractions
- EMG of VL, RF, VM
- near-infrared spectroscopy (NIRS) over VL, VM
  - oxy- \((O_2\text{HB})\), deoxygenated hemoglobin (HHB); total hemoglobin (tHB)
  - arterial occlusion allows indirect analysis of energetic cost
    (de Ruiter et al. 2005 *JAP*, 2007 *MSSE*)
Reduction in metabolic cost - Raw Data NIRS

- $O_2$Hb (oxyhemoglobin)
- HHb (deoxyhemoglobin)
- tHb (total hemoglobin)

delta concentration [$\mu$M] vs. Time [s]
Reduction in metabolic cost - Raw Data NIRS

deoxyhemoglobin (HHb)

O$_2$HB (O$_2$Hb)

HHB

tHb

Time [s]

delta concentration [µM]
Reduction in metabolic cost - *exemplar Result*

\[ \text{oxygen consumption} = \text{slope } r \left[ \% \text{ of } \Delta \text{max HHB} \right] \]

(de Ruiter et al. 2005)

→ reduced slopes for HHb and O\(_2\)Hb during stretch contractions
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2. **Reduction in metabolic cost?**
   → 17.2±4.1% reduced ATPase activity per unit of force in skinned fibres following active lengthening.
   → Preliminary results point towards potential benefits in oxygen consumption during RFE in humans

3. **Relevance of RFE for human locomotion?**
RFE & human locomotion...

...like walking, running, hopping, [...]

- involvement of multiple lower extremity joints synergistic muscles
- joints slightly flexed, i.e. main muscles (*triceps surae, quadriceps femoris*) acting on their ascending limbs of the *force-length relation*
- submaximal muscle activation
- contractions represent *stretch-shortening cycles (SSC)*

→ *Does RFE occur during these kind of contraction conditions?*
→ *Do RFE mechanisms contribute to enhanced force production during SSC?*
RFE during submaximal multi-joint contractions

- n = 14 subjects, ROM = 30-50° knee flexion, ω = 60°s⁻¹
- submaximal activation at 30% of maximum VM EMG
- EMG, 3D-force plates, kinematics, inverse dynamics

(for methods refer to Hahn et al. 2010, Seiberl et al. 2013)
RFE during submaximal multi-joint contractions

→ no difference between contractions

→ residual force enhancement

EMG activity [%MVA]

Force [N]
RFE during submaximal multi-joint contractions

→ phenomenon of responders and non-responders reported earlier
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→ Preliminary results point towards potential benefits in oxygen consumption

3. Relevance of RFE for human locomotion and SSC?

→ not finally confirmed and/or not investigated
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Thank you for your attention!