PREHENSILE CAPABILITIES OF ROCK-CLIMBERS:
FROM FINGER FORCE EXERTION TO MUSCLE CAPACITIES

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Climbing

Multiple factors for performance: physiology, technique, psychology, cognition...

Main originality: upper limbs equilibrate and help the displacement of the entire body on walls which are vertical to fully overhanging
“Vertical quadrupedy”

Quaine et al., 1996, 1997
Noé et al., 2001
Fuss et al., 2008
generation of high intensities of forces on the fingertips which are sustained during up to several minutes

Static and intermitent exercise

Main causes of falls

Watts et al. 2000
Part 1: Hold performance
Fingertip forces?
Effect of fatigue?

Part 2: Influence of grip technique?
and hold characteristics?

Part 3: Muscle forces?
Muscle capacities?
→ Improve training methods and recommendations

→ Prevent injuries and pathologies (pulley ruptures, tendinitis... )
Objective: Determine grip performance of climbers
Hold performances: Effect of fatigue?

Pitcher et Miles (1997) showed by using an arrest of blood supply that a first plateau (2 minutes) is due to non-aerobically capacities and a second plateau is due to aerobically capacities.

40% MVC → ischémie: no blood flow

(80% MVC 6'/4’, handgrip)

Objective: determine fatigue evolution of climbers
First series of experimentations

Expert climbers (~20; french grade 7c+) vs. Non-climbers (~20)

3 Maximal voluntary contractions (MVC)

36 right hand finger flexions:
- 80% MVC
- 5 seconds of work
- 5 seconds of rest
Fingertip forces results

Three phases

- A first plateau (arrows)
- A fall of force
- A second plateau at a lower force level

Climbers: longer time for the first plateau; higher level of force during the 2\textsuperscript{nd} plateau

Quaine et al., 2003a IJSM; Vigouroux et al., 2006 J Sport Sci
EMG results

First phase:
- Metabolite accumulation
- Acidosis (H+ concentration)
- Slowdown of action potential velocity
  → Force intensity is too high and rest time are not sufficient to recover from the ischemy and effort in between contractions

Last phase (plateau):
Equilibrium of physiological parameters due to the lower level of force and the intermittent rest phase in between contractions

Philippe et al., 2012

Quaine et al., 2003a IJSM; Vigouroux et al., 2006 Sport Sci
Various profile of Experts:

- « endurance » climber
  MVC = 385.5N

- « force » climber
  MVC = 437.2N

→ Analysing the fingertip forces during such protocol allows to discriminate the climber qualities/characteristics
Part 1 conclusion’s : Fingertip forces capacities

• Climbers are able to generate more force at the fingertips than non-climbers (≠ results from whole hand grip exercises)

• Climbers are able to maintain high intensities of force during a longer period than non climbers

• Climbers are able to limit loss of force thanks to a better oxygenation in between contractions

• Using EMG and/or a fingertip dynamometer allows to characterize the profile of climbers (endurance/force) for training objectives
Influence factors: Grip technique and hold characteristics?
Second series of experiments

Half crimp/ Slope/ Full crimp

Size of the hold (1cm, 2cm, 3cm, 4cm)
The mean maximum fingertip forces are statistically not different between the two grips
→ Individual characteristics

(Schweizer 2001)

The force sharing among the fingers remain similar between the two grips

Quaine et al., 2003b IJSM; Quaine et al., 2004 Clin Biomech
No difference of fatigue index between the two grips
No difference of grip force for small holds but a different evolution of force according to the grip size

Amca et al., 2012 J Sport Sci
Part 2 conclusion’s: Grip techniques and hold characteristics

- The resultant fingertip force and the force sharing among the fingers remain similar between the crimp and slope grips.

- Fatigue evolves similarly between the two grips.

→ biomechanical and physiological factors generate no differences from grip performances point of view.

Performance of the grip technique is mainly dependant on the climbers history/training and on the characteristics of the hold.
Muscle forces - Muscle force-generating capacities
The direct in vivo measurement of such data requires the use of invasive force sensors and therefore remains unreasonable from both technical and ethical points of view.

A: finger flexor measurements (Dennerlein et al., 1998)
B and C: measurement of Achille tendon force (Komi et al., 1996; Komi et al., 1987)
D: Measurement of ACL ligament force (Fleming & Beynnon, 2004)

→ Use of a biomechanical model of the hand
Biomechanical modeling: function

Musculo-skeletal model

- Kinematics
  - Force
  - EMG

Inputs

Muscle Forces
Joint Forces
Ligaments and soft tissues forces

Variables of interest

\[ \overline{M_{\text{ext}}} + \sum_{m} B_{\text{dl}} L_{m} \cdot F_{m} = 0 \]

Vigouroux, et al. 2011, JAB
Domalain, Vigouroux et al., 2010, JoB
Muscles and tendons of the fingers

Vigouroux, et al., 2007, JoB
Rollof, Vigouroux, et al. 2006, JoB
Musculo-skeletal model of the hand

-16 articulations - 23 DoFs
-42 muscles

\[ \overrightarrow{M}_{ext} + \sum_{m} \overrightarrow{BdL}_m \cdot F_m = \overrightarrow{0} \]

Optimization process

\[ \min \sum_{m} \left( \frac{F_m}{PCSA_m} \right)^4 \]

Goislard, Vigouroux, et al. 2012, MSSE
Goislard, Vigouroux, et al. 2014, MEP
• 1024 Hz,
• 3D force sensor

• 5000 Hz,
• Butterworth filter, bandpass (20-600), 4th order
Experimentations

Crimp

Slope
Tendon force results

Vigouroux et al., 2006 JoB; Vigouroux et al., 2008 clin biomech

Crimp

$F_{A4} = 178,4 \text{ N}$

$t_{EDC} = 18,0 \text{ N}$
$t_{FDS} = 113,2 \text{ N}$
$t_{FDP} = 256,4 \text{ N}$

$F_{externe} = 95,7 \text{ N}$

Slope

$F_{A2} = 6,5 \text{ N}^*$

$t_{EDC} = 35,2 \text{ N}^*$
$t_{FDS} = 166,5 \text{ N}^*$
$t_{FDP} = 188,9 \text{ N}^*$

$F_{externe} = 99,1 \text{ N}$

$F_{A4} = 56,8 \text{ N}^*$

$F_{A4} = 178,4 \text{ N}$

$F_{A2} = 209,2 \text{ N}$

* $p<0.05$ in between crimp and slope
Muscle force-generating capacities of climbers?

What are the muscle adaptations resulting from several years of climbing practice?
Muscle-generating capacities: methods

<table>
<thead>
<tr>
<th>N</th>
<th>Type</th>
<th>Age (years)</th>
<th>Hand size (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>Healthy non-climbers</td>
<td>27.6±4.0</td>
<td>18.8±1.0</td>
</tr>
<tr>
<td>9</td>
<td>Male climbers (french-grade 8)</td>
<td>25.5±10.2</td>
<td>19.5±0.5</td>
</tr>
</tbody>
</table>

Electromyographic activities

- Biopac MP150
- ECRL
- EDC
- FCR
- FDS

Wrist and finger net joint moments

Bio2M ergometer

- Measurement axis
- MVC modules

Schweizer et al. 2003
Methods: tasks

Wrist task
Wrist-Finger task
Finger task
Intrinsic task

7 maximal net moments

MCP
Wrist

Finger Extensors
Finger Flexors
Intrinsic
Wrist Extensors
Wrist Flexors
Methods: maximal muscle moment estimation

Optimisation-Hand biomechanical model

Find

\[ M_{max|g} \quad a_{g|t} \]

which minimize

\[ \sum_t \left( \overline{M_{ergo|t}} - M_{ergo|t} \right)^2 \]

\[ \overline{M_{ergo|t}} = \sum M_{max|g} \times a_{g|t} \]

Adapted muscle parameters

Imbalance = \[ \frac{M_{max|extensor\ group}}{M_{max|flexor\ group}} \]

Wrist and MCP joints
Results: Muscle moment generating capacities

Vigouroux et al., EJAP, submitted
Results: Muscle moment generating capacities

Finger MCP moment (Nm)

Climbers
Non-Climbers

Finger Extensors
Finger Flexors
Intrinsic

* indicates significant difference (p < 0.05)

n.s indicates no significant difference

Vigouroux et al., EJAP, submitted
Injury can occur when ratios of MCP and Wrist are weak.
Part 3 conclusion’s:

• Different muscles force coordinations between crimp and slope techniques.

• Strong improvement of the only finger flexors muscles but this improvement generates desequilibrirums in forearm muscle harmony.
Main Conclusions

In 2014:
knowledge and well known protocols to evaluate the climber’s profiles

Slope/Crimp/Full crimp
Endurance/Force
Muscle Groups

→ Ready for using these knowledges and these protocols for training

FUTUR:
How the grip is controlled during climbing?
→ SECURITY MARGIN
→ FINGER COORDINATION
→ GRIP-MOVEMENT INTERACTION
Thank you for your attention