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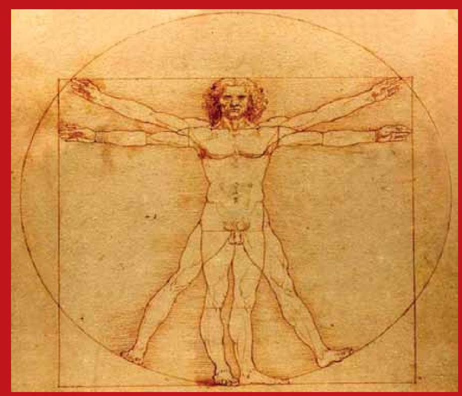

Motor Control Lab

HAND-WRIST ACTION
Control with Referent Configurations Implemented by Complex Anatomy

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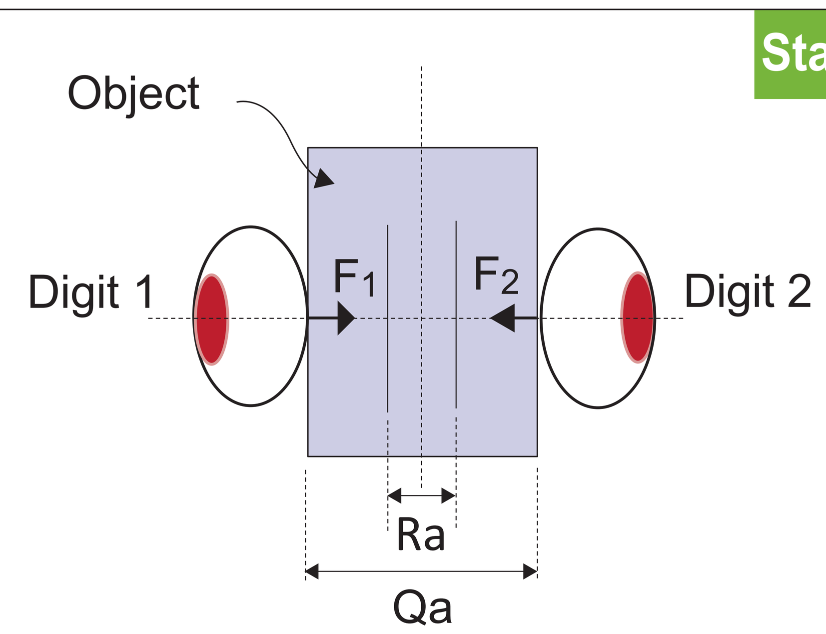
Introduction

Object manipulation in its fullest expression is the hallmark of humankind. We discuss the **control processes that lead to human prehensile dexterity** despite the complex anatomy of the hand.

The referent-configuration hypothesis: **Grip force emerges** from the difference between a system-defined referent aperture and the object-shape-defined actual aperture.

Static grasping



$F_{GRIP} := F_1 = F_2 = k(Qa - Ra)$

Qa = Actual aperture: constrained digit location
Ra = Referent aperture: desired digit location
k = Apparent stiffness

Apparent stiffness: A gross parameter of the grasp that depends on the mechanical properties, current lengths,and activations of all involved hand muscles.

The same muscles (FDP - Flexion, EDC - Extension) are the primary contributors to grip-force production at the fingertips and wrist flexion-extension **(FE)**. Gripping and wrist action are, therefore, coupled [1].

Flexor and extensor muscle lengths depend on wrist flexion-extension angle as well as the actual aperture. Therefore,

Hypothesis 1

Apparent stiffness (*k*) varies with wrist FE angle.

Hypothesis 2

Apparent stiffness (*k*) varies with (initial) actual aperture (Qa).

The force produced in isometric conditions drops if no visual force feedback is provided, even when subjects try to maintain its magnitude. Therefore,

Hypothesis 3

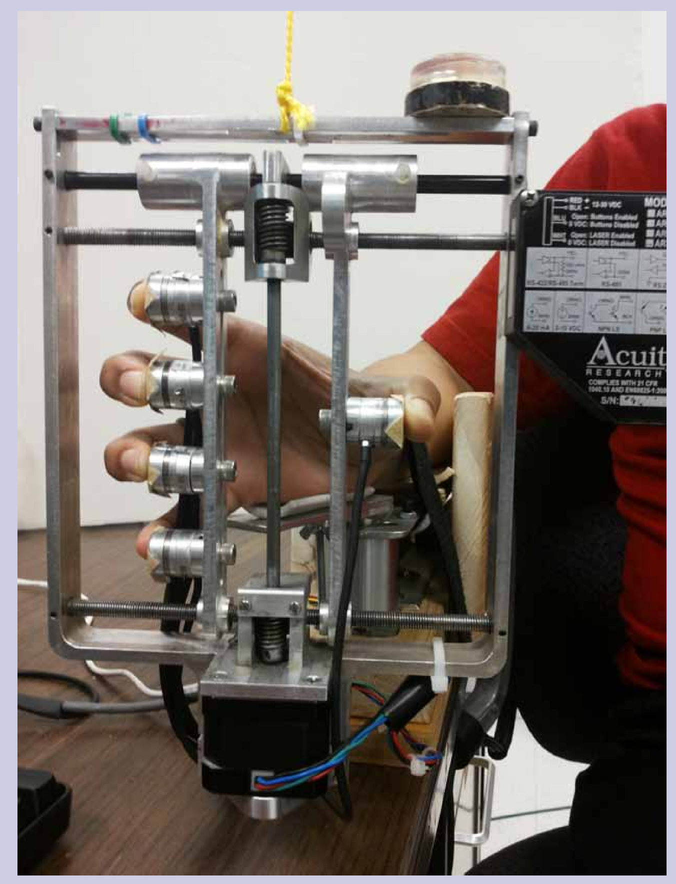
F_{GRIP} drops after a transient change in actual aperture (Qa).

Methods

Setup

The handle

- Handle held in prismatic grasp with wrist FE xis vertical
- Sensor under each fingertip measures force
- Motor-driven mechanism alters actual aperture
- Laser measures aperture width (Qa)



Supporting structure

- Prevents forearm movement and wrist ulnar-radial deviation
- Houses potentiometer that measures wrist FE angle

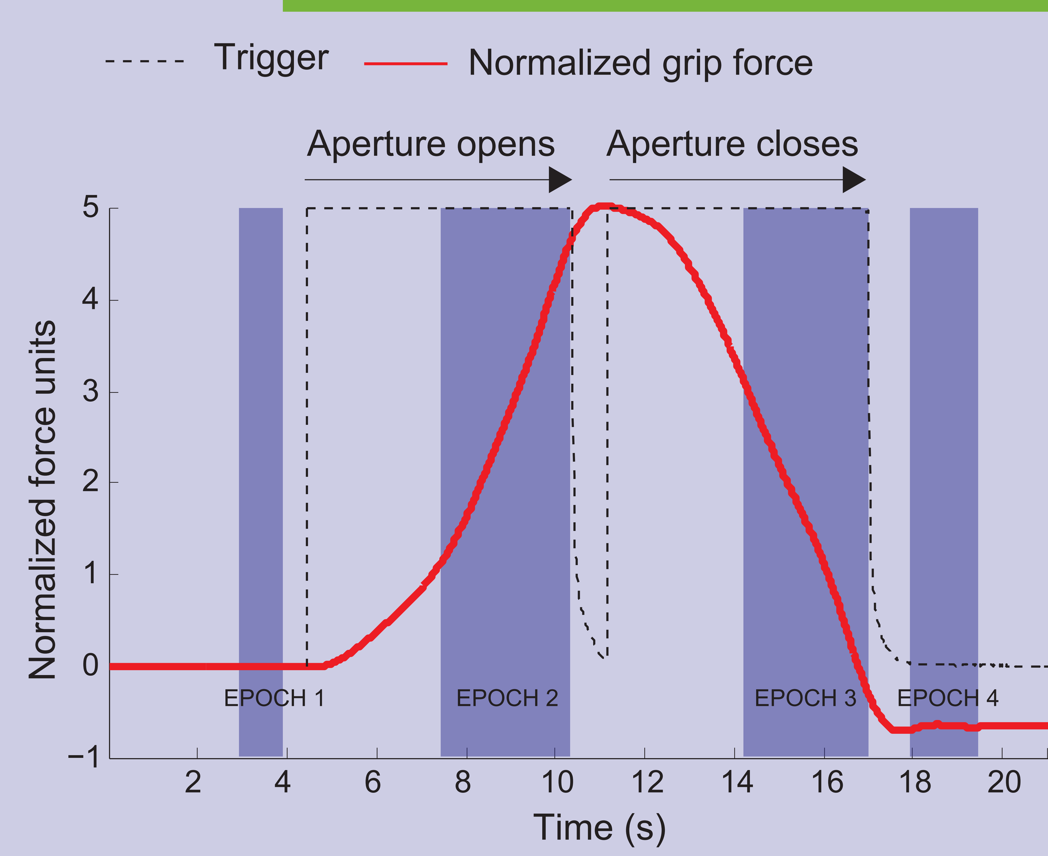
Experiment

10 Subjects (~ 26 yrs) :

Tasks

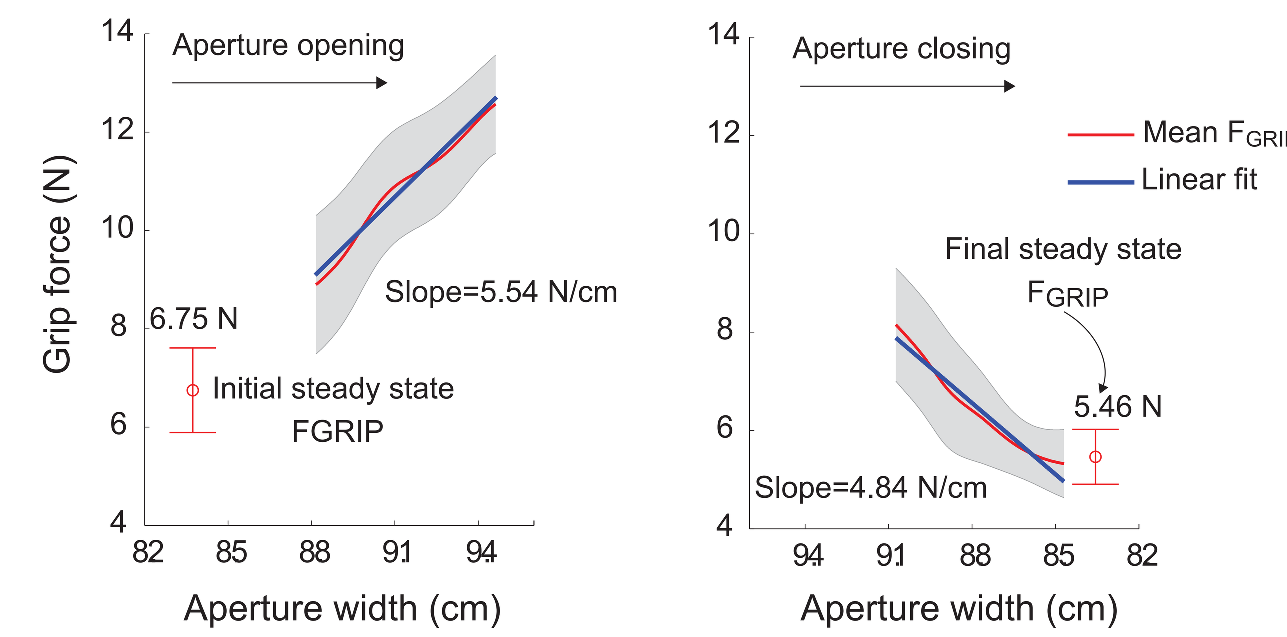
- Wrist FE range of motion
- Hold handle vertical at one of five discrete wrist locations
- Specified initial aperture width (8.5 cm or 9.5 cm)
- Actual aperture opens by 1 cm & returns to initial width
- Mean motor speed ~ 1.8 mm/s
- 'Do not intervene'

F_{GRIP} evolution with aperture modulation

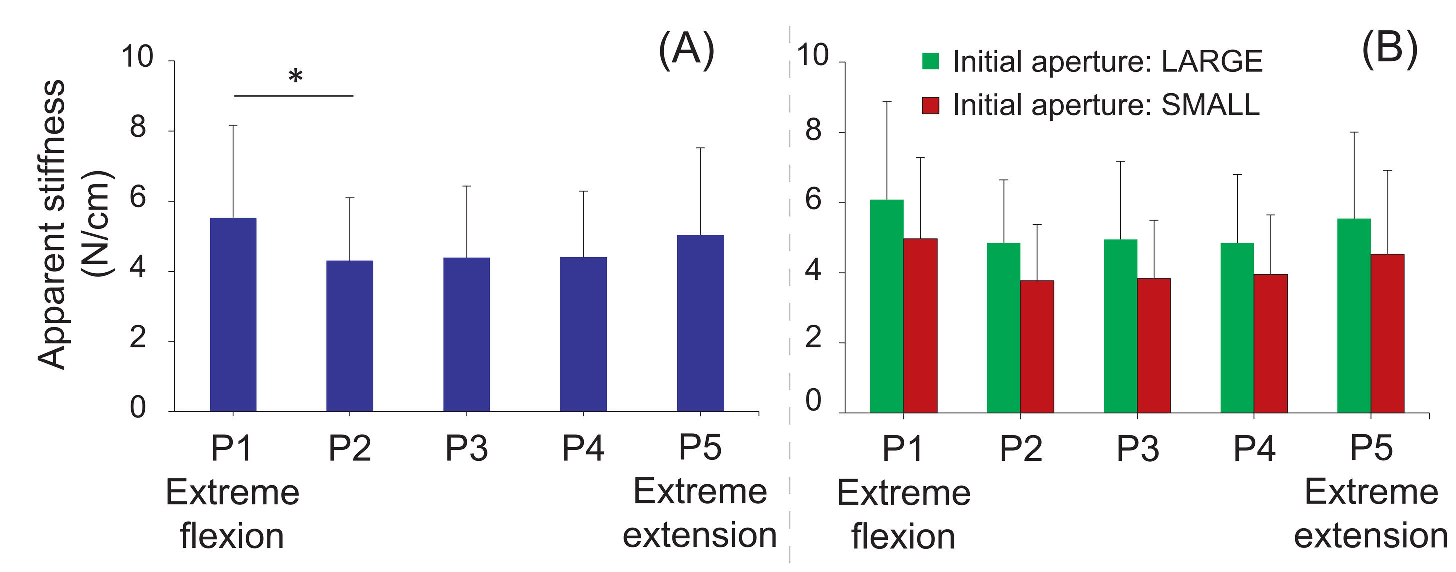


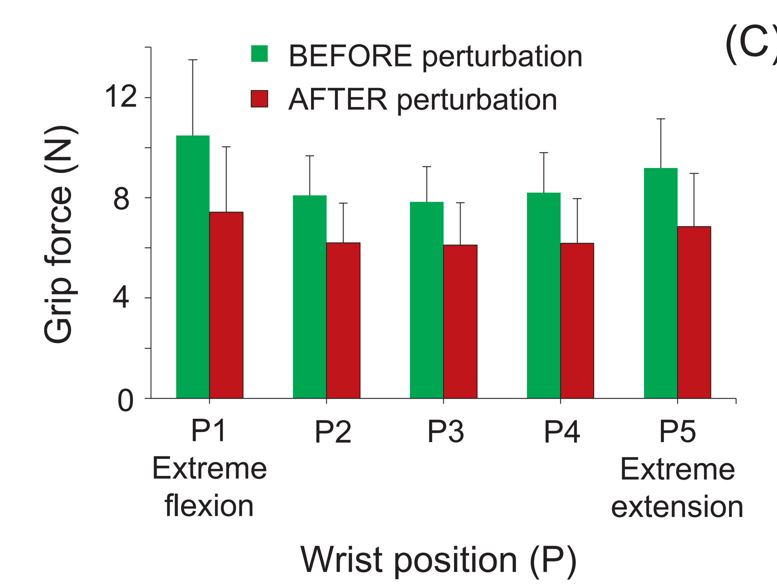
Computations

Slopes in Epochs 2 & 3 yield *k*.
Epochs 1 & 4 yield steady-state F_{GRIP}.



Results & Discussion





Hypothesis 1

Refuted: ***k* constant over wrist FE motion range (Fig. A)**

Hypotheses 2 & 3

Validated: *k* greater for larger initial aperture width (Fig. B)
F_{GRIP} after perturbation is lower (Fig. C)

- **Specifying referent aperture (Ra) in an object-fixed frame may simplify prehension control [2].**
- ***k* is constant during handle expansion and contraction (data not shown). Therefore, the drop in F_{GRIP} results from a drift of Ra towards Qa over the aperture perturbation cycle.**
- **We call this phenomenon 'RC-back-coupling'.**

[1] Ambike et al., *Exp Brain Res*, 232, 2014
[2] Ambike at al., *Exp Brain Res*, 227, 2013