Studies on the applicability of the mechanical advantage hypothesis of grasping

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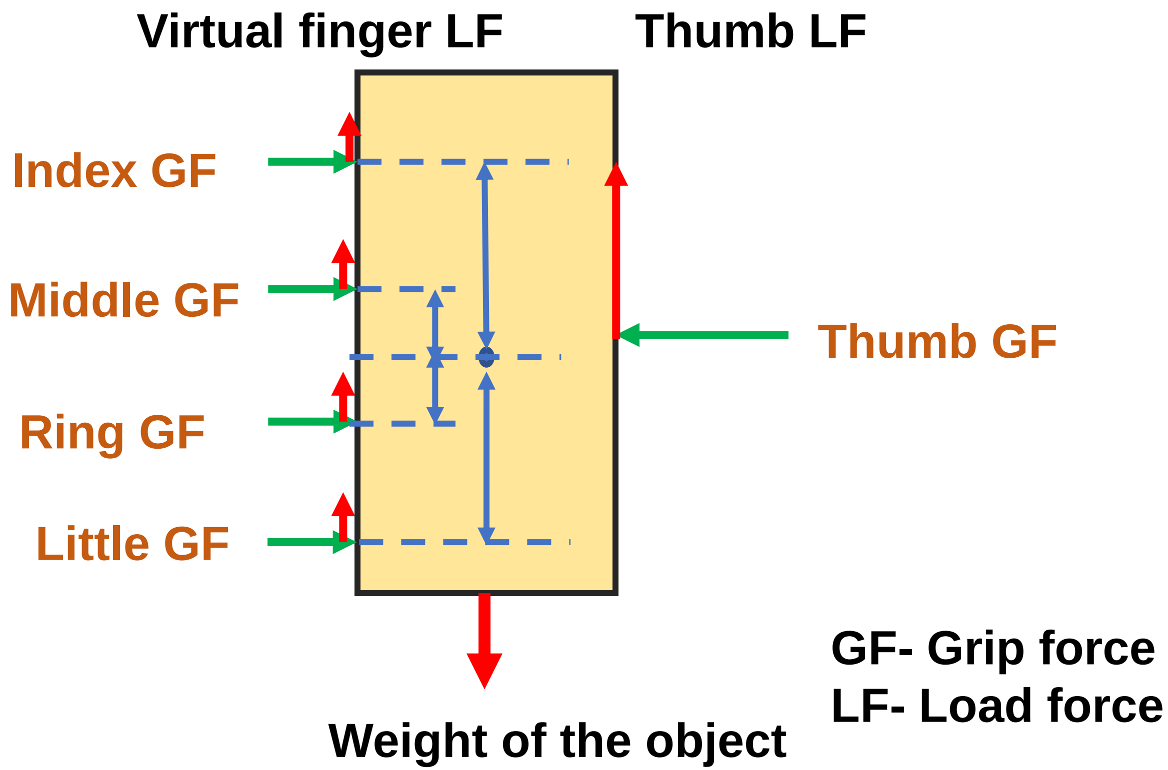
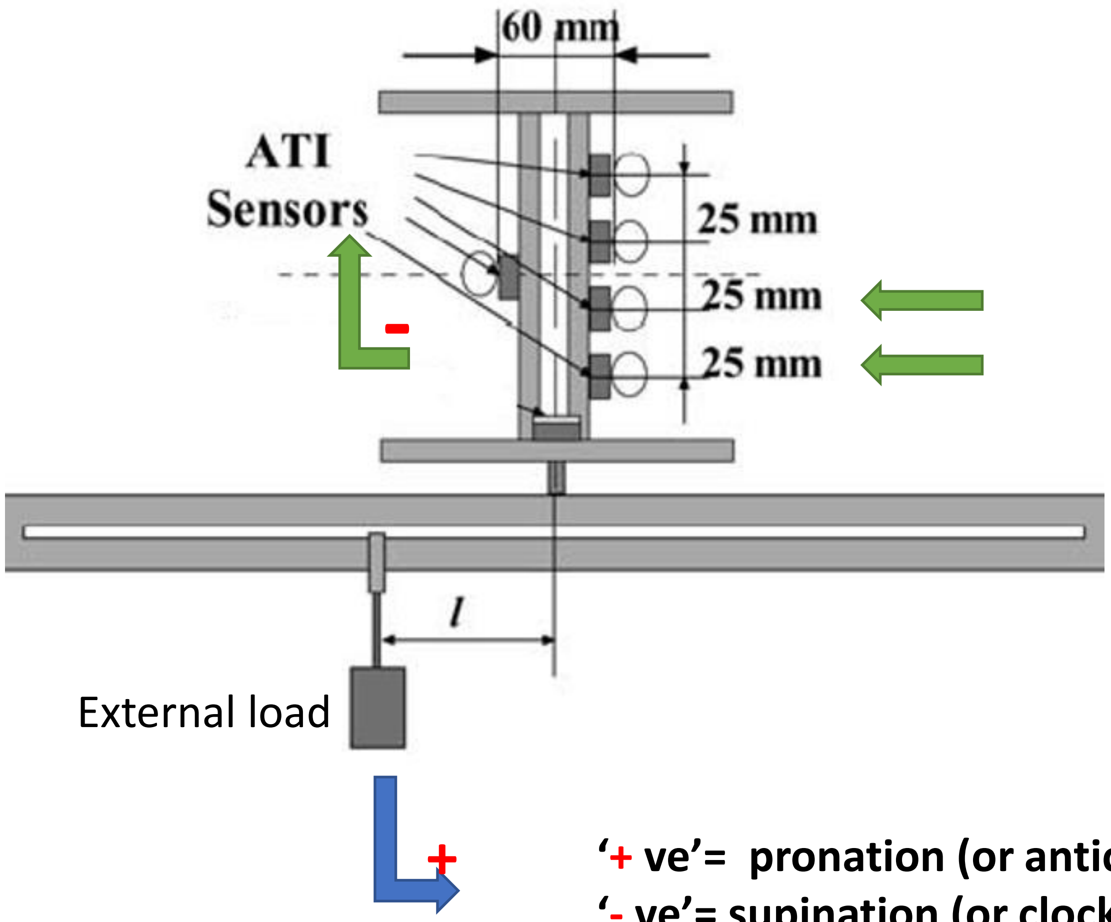
Introduction



Literature

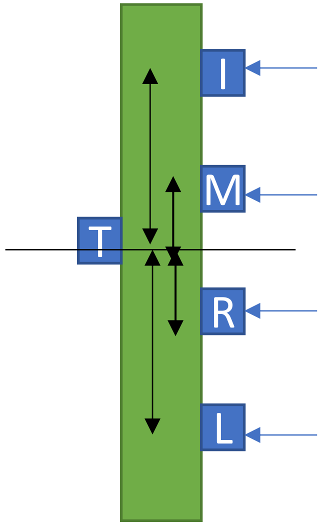
Zatsiorsky et.al (2002)



Mechanical Advantage hypothesis

During moment production task, peripheral fingers (Index and little) with longer moment arm for normal force produce greater normal force than the central fingers (middle and ring) with shorter moment arms

'+ ve'= pronation (or anticlockwise) torque
'- ve'= supination (or clockwise) torque



Motivation for the current research

Pocket radio

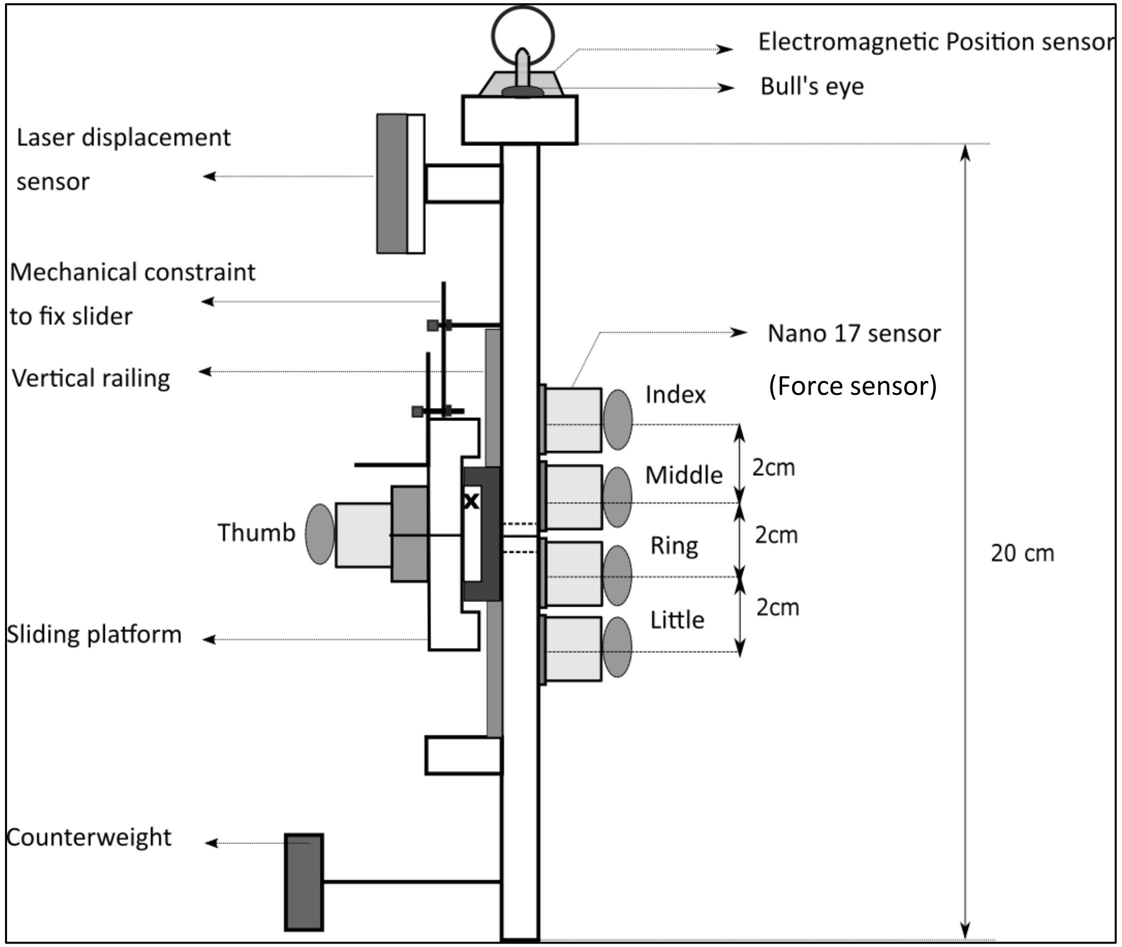
Image source: https://www.heathrowscientific.com/pipette-controller-i-120479

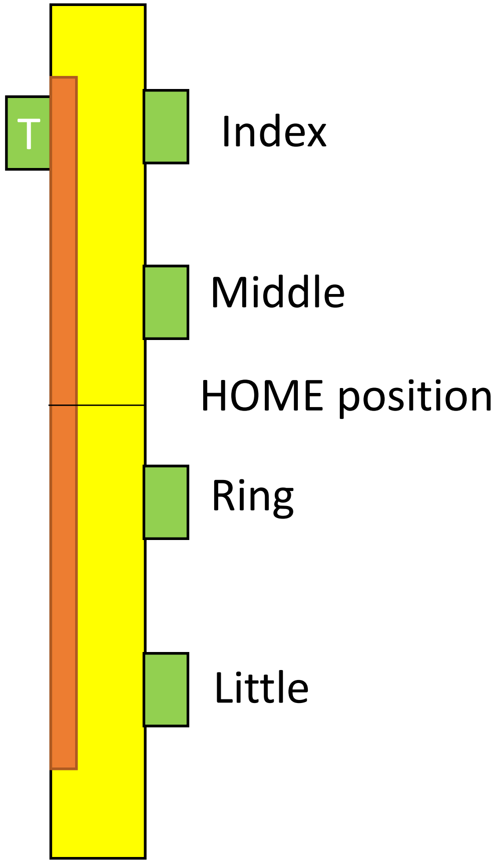
Pipette controller

Retractable ball point pen

How object stabilization is achieved while holding a handle that consists of unsteady thumb base?

Experimental handle with slider platform





Total mass of the handle (including slider platform) =0.535kg

T= Thumb

Objectives

1. **To study how the fingertip forces re-distribute for establishing object stabilization when the thumb was placed on an unsteady platform**. The force distribution was studied in the presence and absence of mechanical constraint to fix the unsteady thumb platform while grasping. In particular, the contribution of ulnar fingers in maintaining the static equilibrium was explored.

2. **To examine whether the applicability of the Mechanical advantage hypothesis is task-specific and to investigate the kind of task that lends support to the hypothesis.** This was done by systematically increasing the mass of the handle by suspending external loads of varying masses below the center of mass of the handle.

3. **To confirm on the kind of task that causes CNS to prefer the strategy of mechanical advantage principle** by restricting the normal force of the thumb while holding the thumb platform steady at the HOME position.

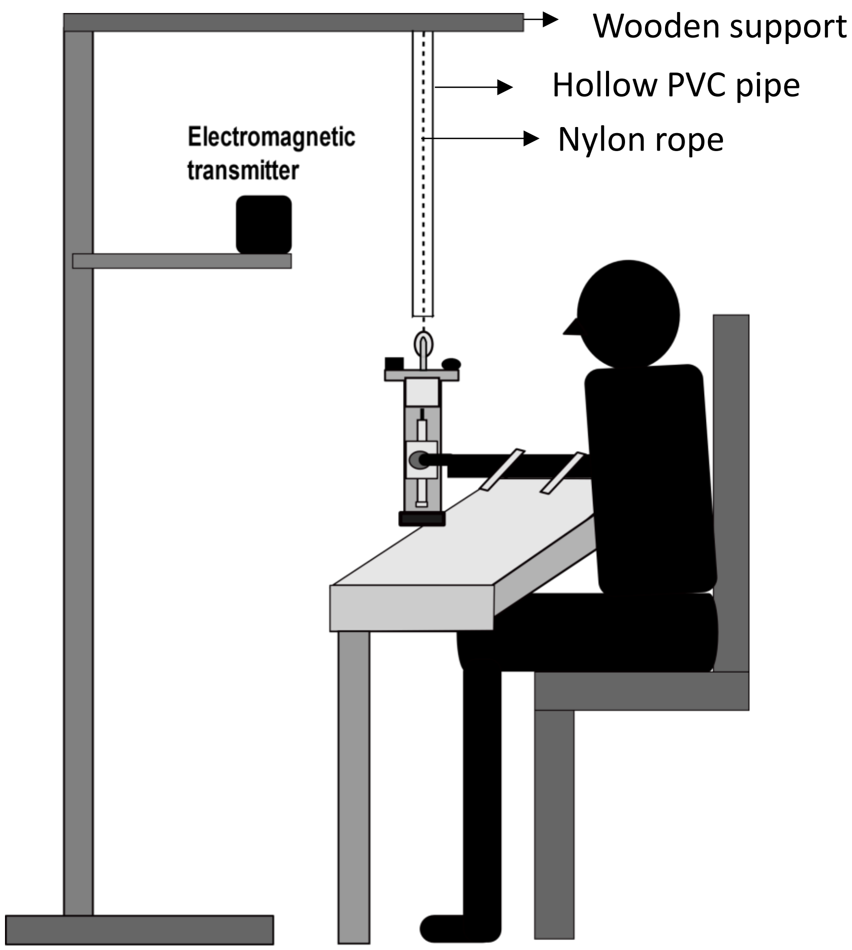
4. **To investigate the biomechanical relationship between the thumb and peripheral fingers** when the unsteady thumb platform was translated in the vertical direction while grasping.

Experiment 1

(Preliminary study)

Will the Mechanical advantage hypothesis (MAH) be supported by holding a handle of mass 0.535kg with slider platform held at HOME?

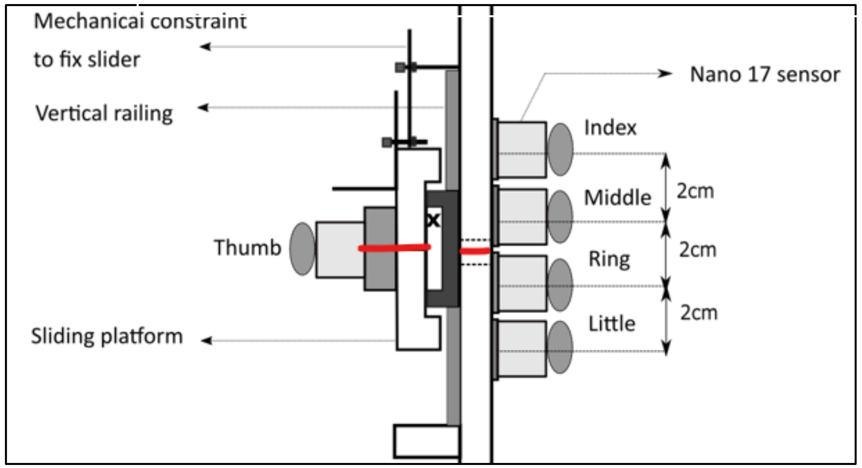
Experimental setup



CONDITIONS

Fixed (30 trials)	One hour rest	Free (30 trials)

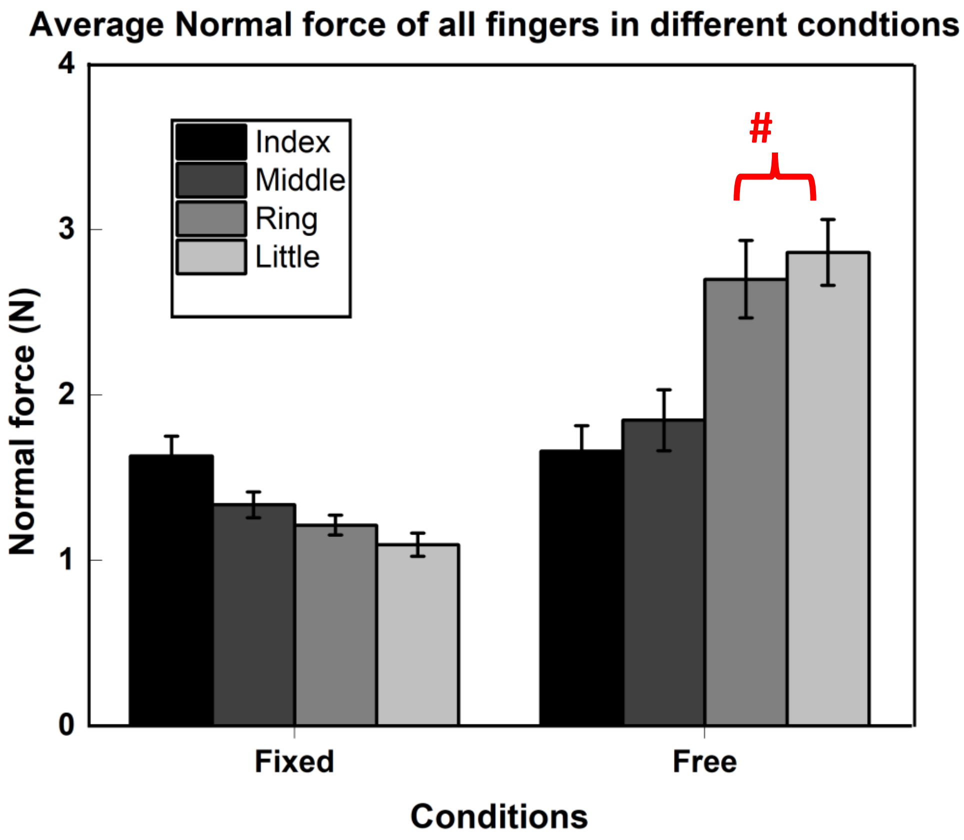
Participant side of the handle frame

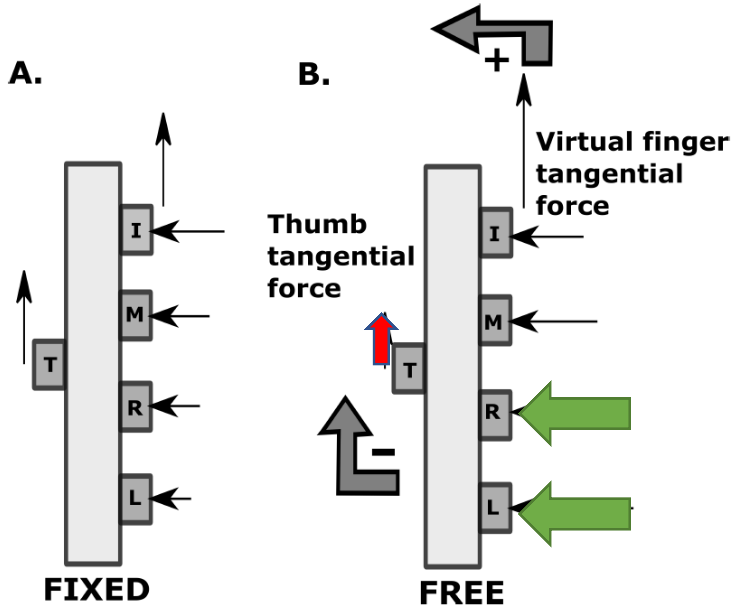


Thumb platform held at HOME position

Experiment 1 - Results

Average Normal force





+ Pronation torque / anticlockwise
- Supination torque/ clockwise

Note
Radial fingers: Index and middle
Ulnar fingers: Ring and little

statistically equivalent

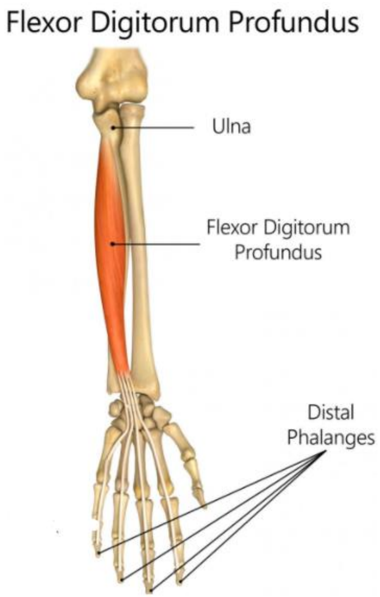
Conclusion from first experiment results

- Reason 1: lesser mass of the handle
- Reason 2: biomechanical constraint and neural interdependency

Reason

Biomechanical constraint | **Neural interdependency**

FDP: sole flexors of Distal Interphalangeal (DIP) Joint of index to little.



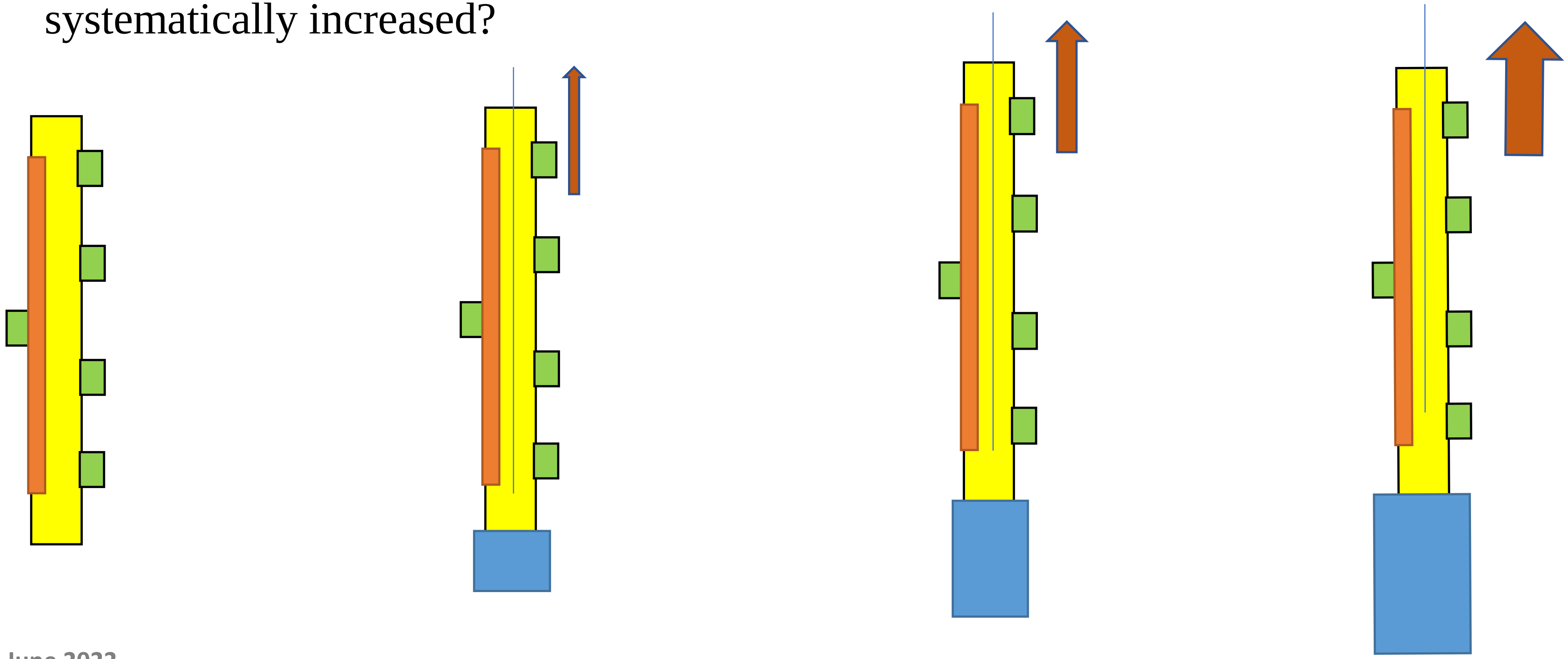
Overlap in the motor units territories of the ring and little fingers at the medial portion of the FDP muscle which is responsible for the flexion of ulnar fingers.

Experiment 2

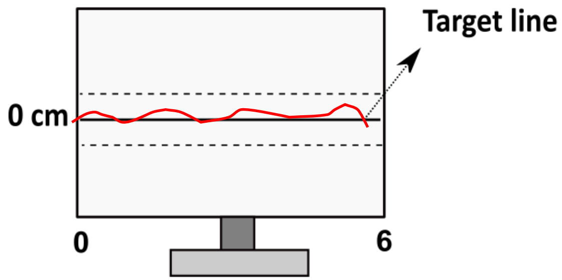
(Systematic mass increase study)

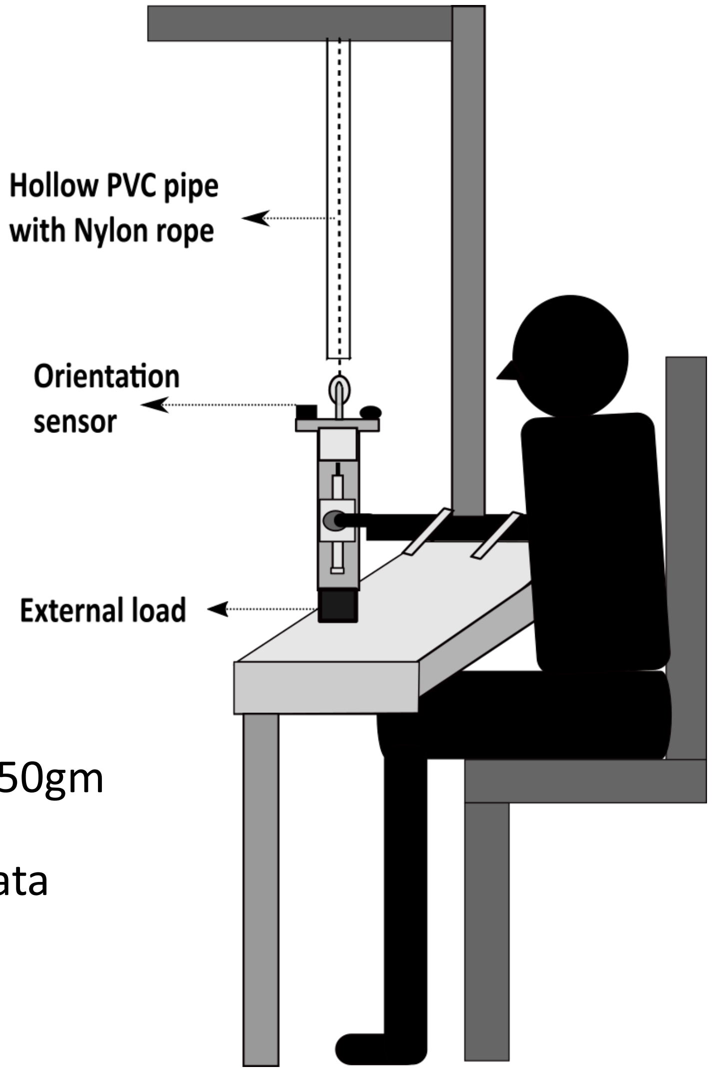
Research question

- Will the mechanical advantage hypothesis be supported when the mass of the handle is systematically increased?



Experimental setup





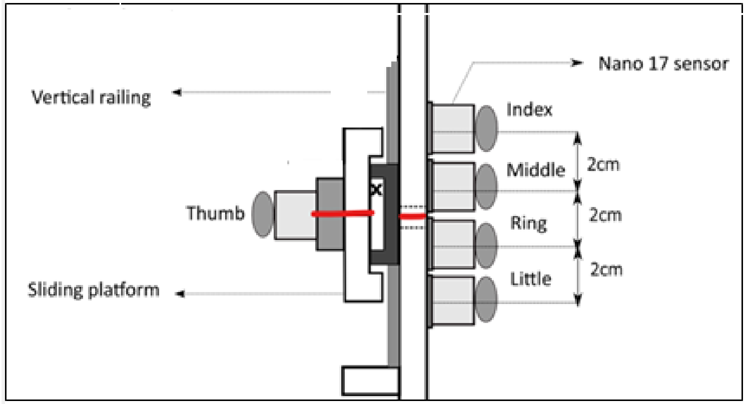
Mass of the handle=450gm

Thumb position data

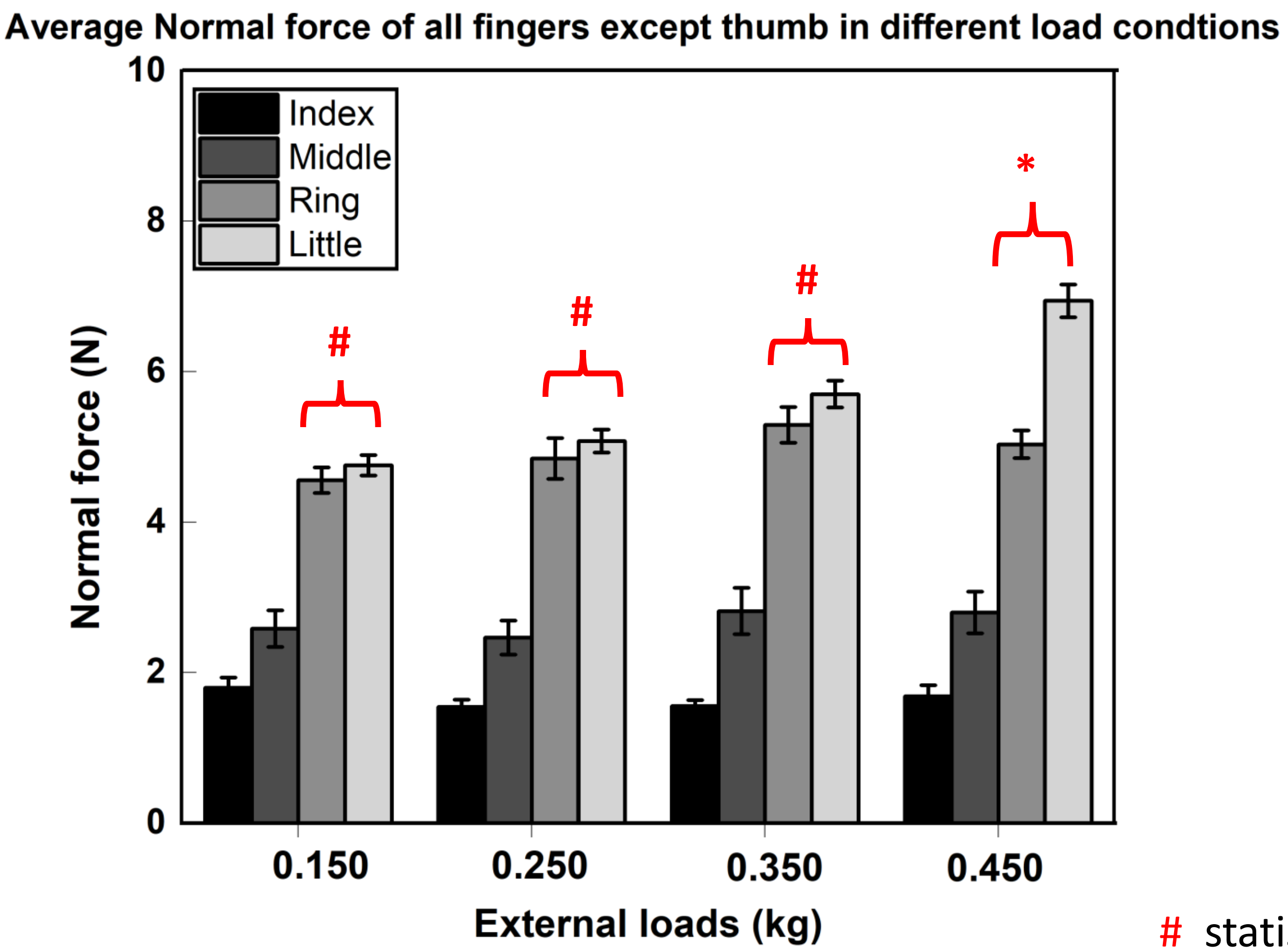
CONDITIONS

- **Session 1**
  - 0.150kg (25 trials)
  - 30mins
  - 0.350kg (25 trials)
- **One hour rest**
- **Session 2**
  - 0.450kg (25 trials)
  - 30mins
  - 0.250kg (25 trials)

Participant side of the handle frame



Experiment 2 - Results



statistically equivalent

* statistically different

Conclusion from second experiment results

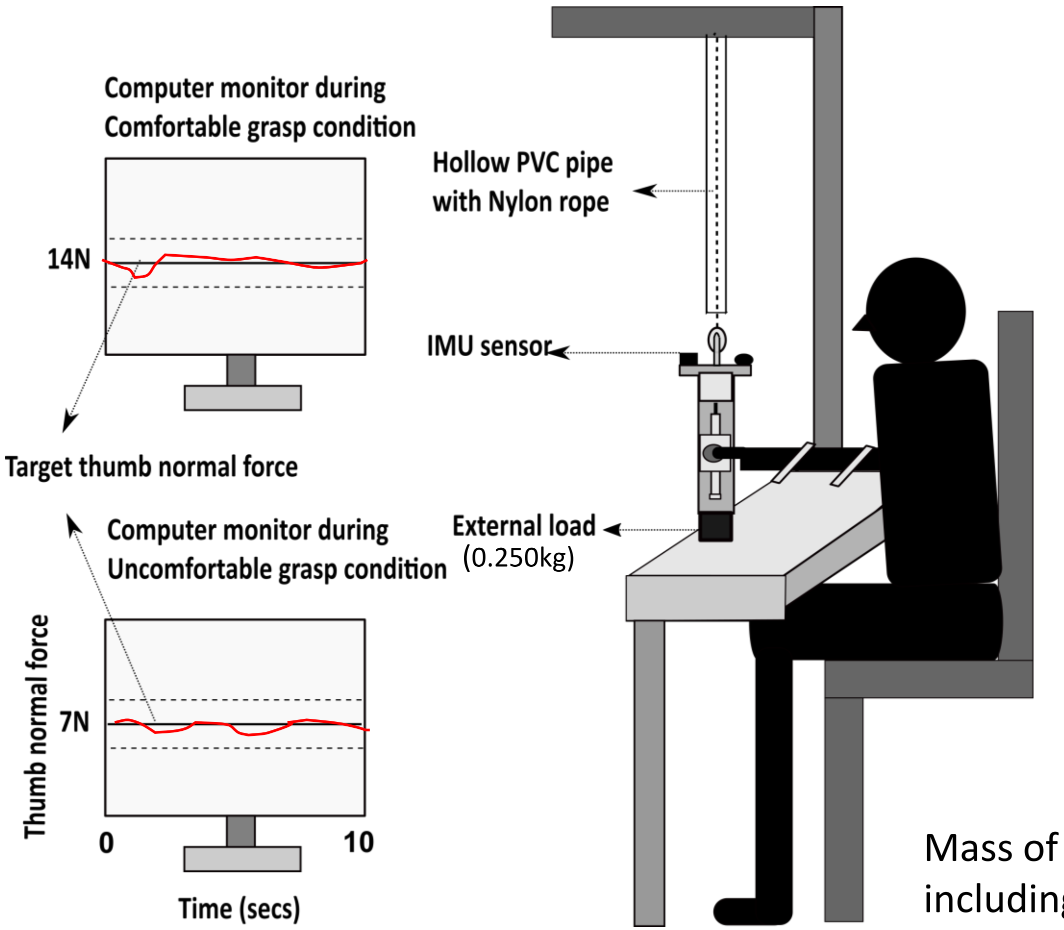
- It was suspected that it could be due to the **challenge associated with the task** could be the reason for supporting MAH.

Experiment 3

(Uncomfortable grasp study)

Whether support for MAH depends on the challenge associated with the task?

Experimental setup



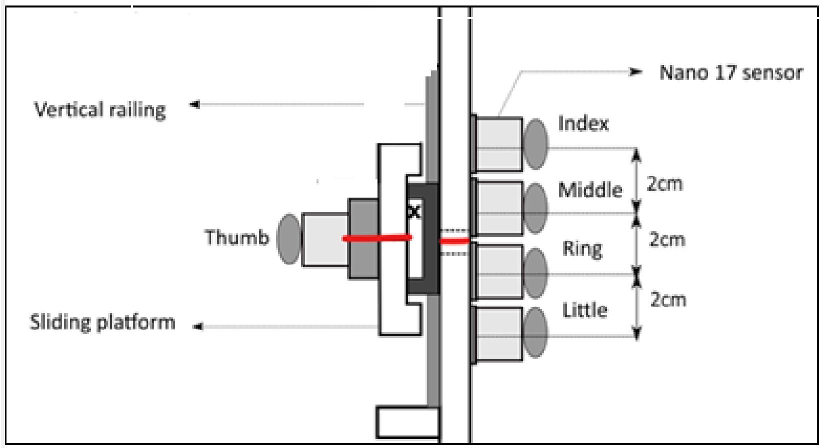
Mass of the handle including external load = 700gm

Thumb Normal force

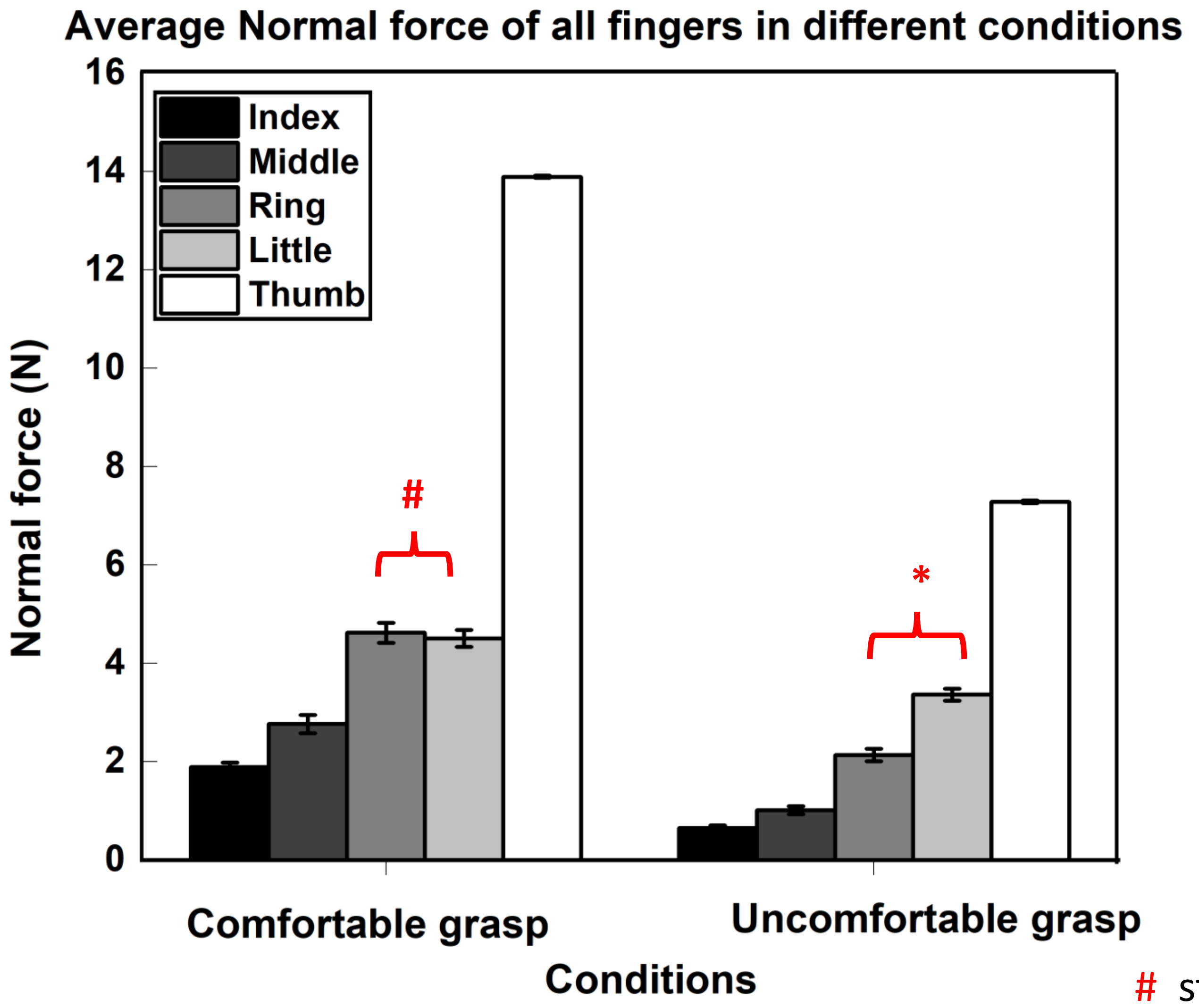
CONDITIONS

- **Comfortable grasp (25 trials)**
- **One hour rest**
- **Uncomfortable grasp (25 trials)**

Participant side of the handle frame



Experiment 3 - Results



statistically equivalent

* statistically different

Conclusion from third experiment results

- During **uncomfortable grasp condition**,

Constraint on thumb **position-** Thumb was restricted to be placed at HOME position

Constraint on **handle design-** Thumb tangential force restricted

Task constraint- Thumb normal force restricted to minimal normal force of 7N

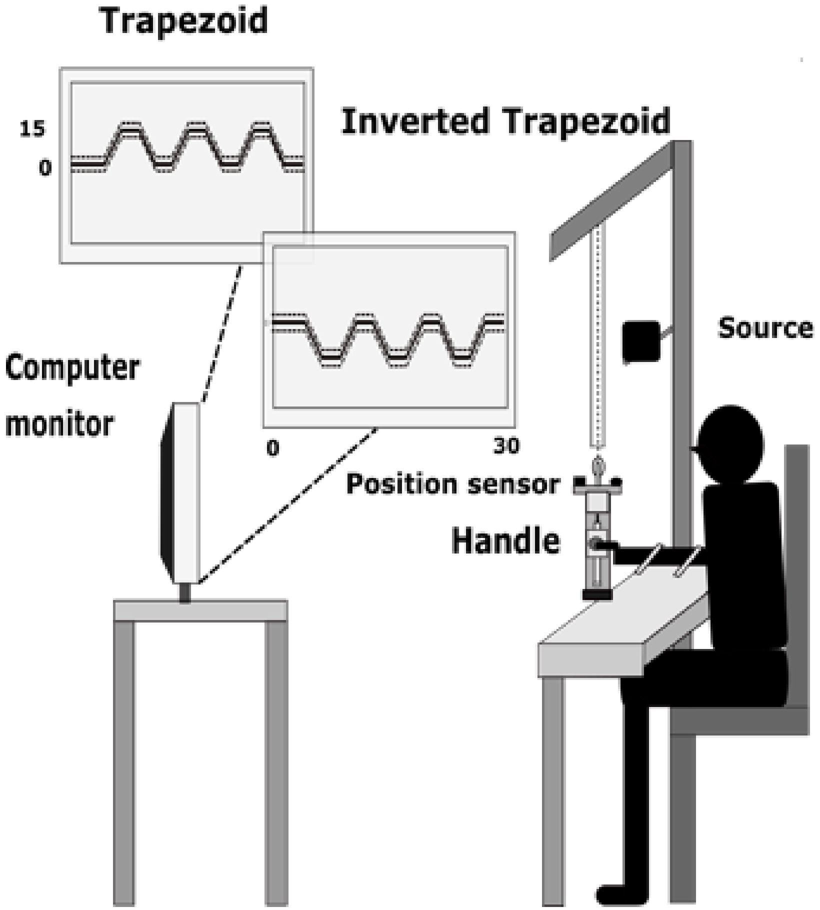
- It was confirmed that the difficulty associated with the task could be reason for MAH to be supported.

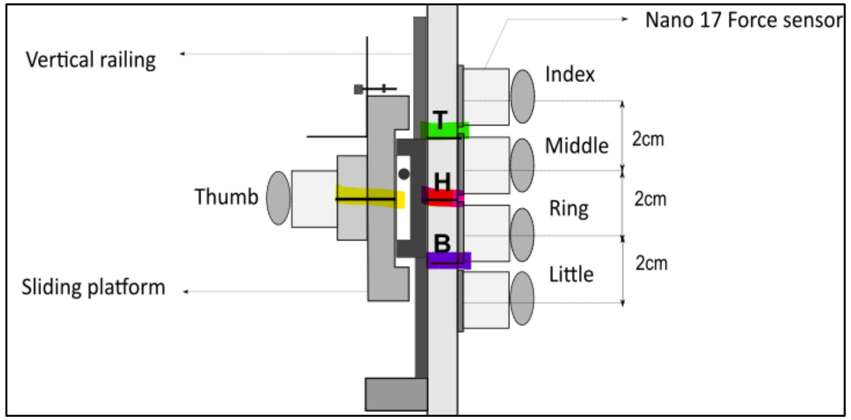
Experiment 4

(Pattern tracing study)

How do the peripheral fingers contribute to re-establish static equilibrium when there are torque changes introduced due to vertical translation of the thumb?

Experimental setup and handle

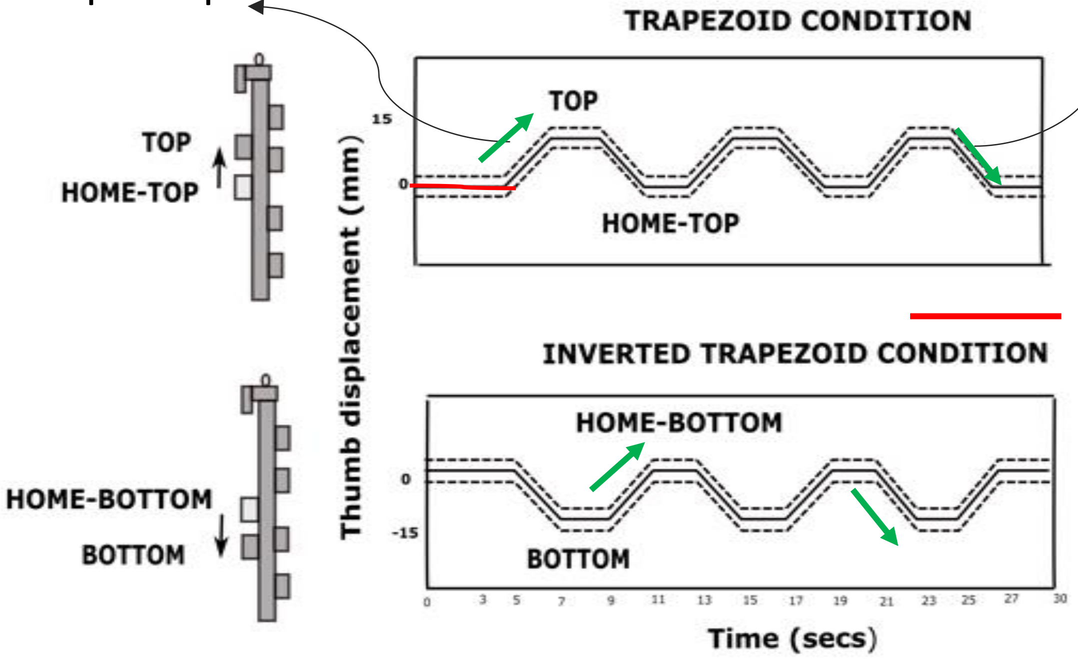




T- Top, H-Home, B-Bottom

Up-ramp

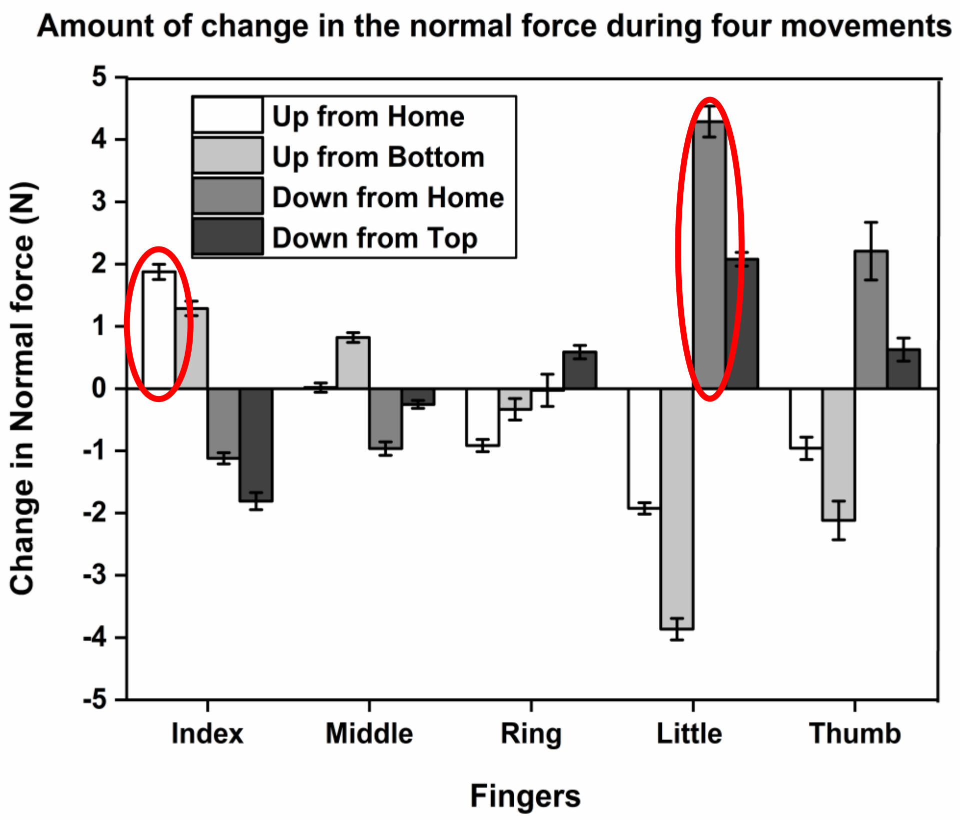
Down-ramp



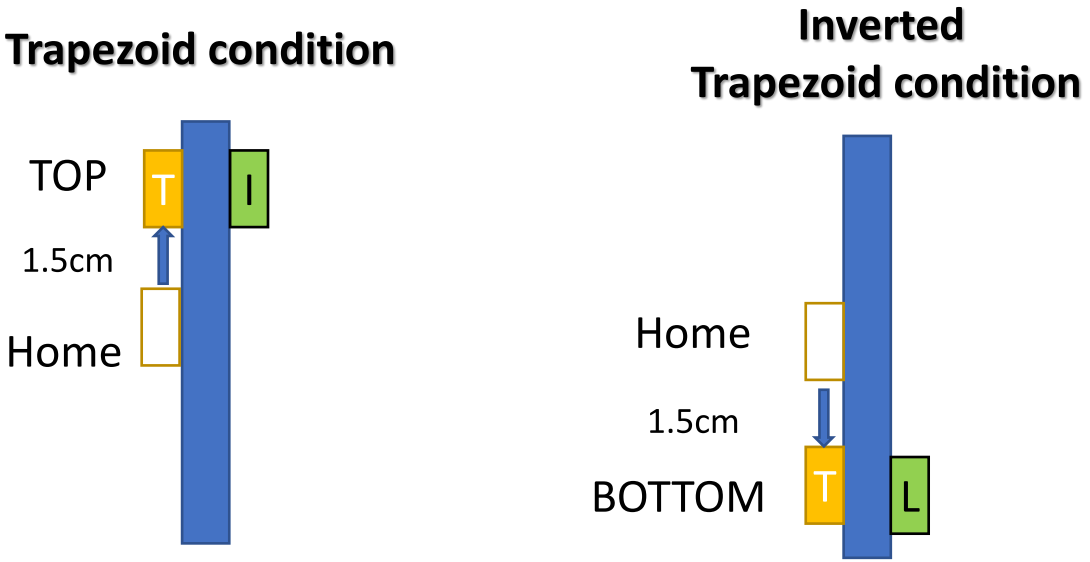
Feedback line = Thumb platform position data

Experiment 4 - Results

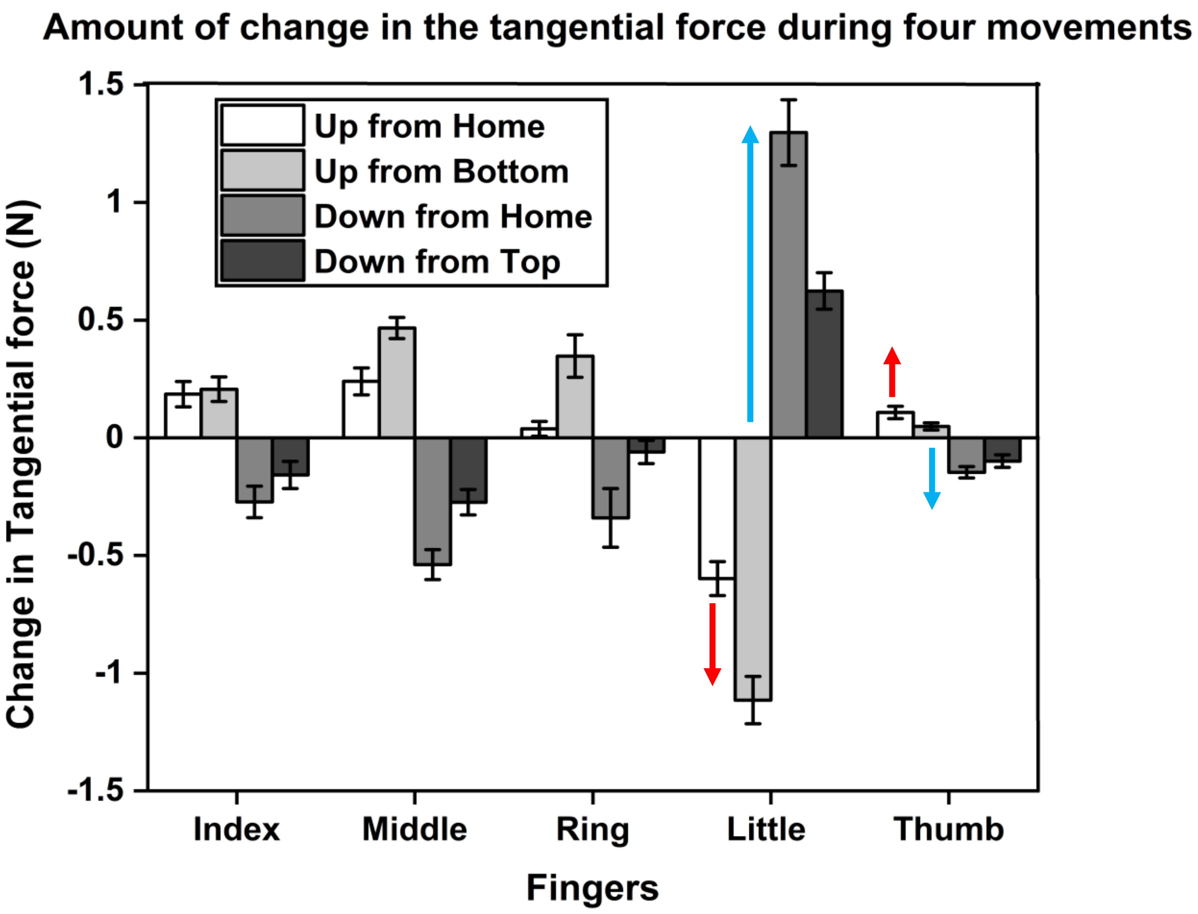
Change in the normal force



Change in the normal force of index finger (during upward translation) **vs** Change in the normal force of the little finger (during downward translation)

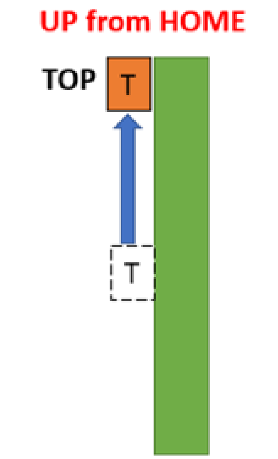


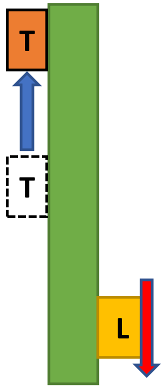
Change in the tangential force



Conclusion from fourth experiment results

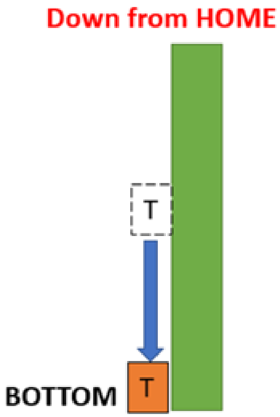
Radial abduction or extension of CMC joint of thumb



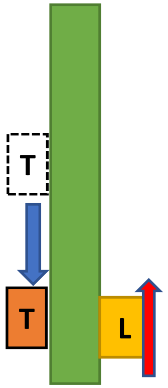


Abduction of little finger

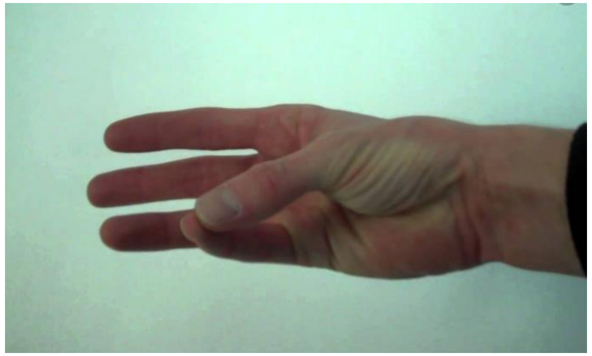
Opposition or Flexion of CMC joint of thumb



CMC- Carpometacarpal joint



Opposition of little finger



Major Contributions

1) **Role of ulnar fingers in establishing static equilibrium was studied (Experiment 1)**

Published article: Comparable Behaviour of Ring and Little Fingers Due to an Artificial Reduction in Thumb Contribution to Hold Objects, in PeerJ, Banuvathy Rajakumar and Varadhan Skm, 2020, doi: 10.7717/peerj.9962, 8:e9962, Open-Access- Yes, Indexed by- Scopus, WOS.

Published book chapter: Comparable Safety Margins of the Ulnar Fingers When the Thumb Remains on an Unsteady Slider, in *Recent Advances in Applied Mechanics* (eds. Tadepalli, T. & Narayanamurthy, V.) 261–274 (Springer, 2022), Rajakumar, B. & Varadhan, S. K. M. doi:10.1007/978-981-16-9539-1_19. (SCOPUS indexed)

2) **At what situation the strategy of MAH was adopted by CNS was confirmed (Experiment 2 and 3)**

Accepted for publication: Validity of Mechanical advantage hypothesis of human grasping depends on the nature of task difficulty, Banuvathy Rajakumar, Swarnab Dutta and Varadhan SKM- submitted in Scientific Reports, Nature publishing group, Open-Access- Yes, Indexed by- Scopus, WOS.

Submitted for review: Evidence to support the mechanical advantage hypothesis of grasping at low force levels, Banuvathy Rajakumar and Varadhan SKM- submitted in Scientific Reports- currently under review, Nature publishing group, Open-Access- Yes, Indexed by- Scopus, WOS.

Major Contributions

3) **Continuous assessment of flexion and extension forces of the thumb (Experiment 4)**

Accepted for publication: Dataset of fingertip forces while grasping a handle with unsteady thumb platform- Rajakumar Banuvathy and SKM Varadhan- data descriptor submitted in Scientific data, Nature publishing group, Open-Access- Yes, Indexed by- Scopus, WOS.

4) **Distinct behavior of little finger was observed when the thumb was translating in the vertical direction while grasping. Thus the biomechanical relationship between thumb and little finger was identified from the fingertip forces. (Experiment 4)**

Published article: Distinct Behavior of the Little Finger during the Vertical Translation of an Unsteady Thumb Platform While Grasping, in Scientific Reports, Rajakumar Banuvathy and SKM Varadhan, 2021, doi: 10.1038/s41598-021-00420-5, 11(1):21064, Nature publishing group, Open-Access- Yes, Indexed by- Scopus, WOS.

References

Niu, X., Latash, M. & Zatsiorsky, V. Effects of Grasping Force Magnitude on the Coordination of Digit Forces in Multi-finger Prehension. *Experimental brain research. Experimentelle Hirnforschung. Expérimentation cérébrale* **194**, 115–29 (2009).

Zatsiorsky, V. M., Gregory, R. W. & Latash, M. L. Force and torque production in static multifinger prehension: biomechanics and control. I. Biomechanics. *Biological Cybernetics* **87**, 50–57 (2002).

Zatsiorsky, V. M., Gregory, R. W. & Latash, M. L. Force and torque production in static multifinger prehension: biomechanics and control. I. Biomechanics. Biol Cybern 87, 50 (2002).

Slota, G. P., Latash, M. L. & Zatsiorsky, V. M. Tangential Finger Forces Use Mechanical Advantage during Static Grasping. Journal of Applied Biomechanics 28, 78–84 (2012).

Solnik, S., Zatsiorsky, V. M. & Latash, M. L. Internal Forces during Static Prehension: Effects of Age and Grasp Configuration. J Mot Behav 46, 211–222 (2014).

Thank you