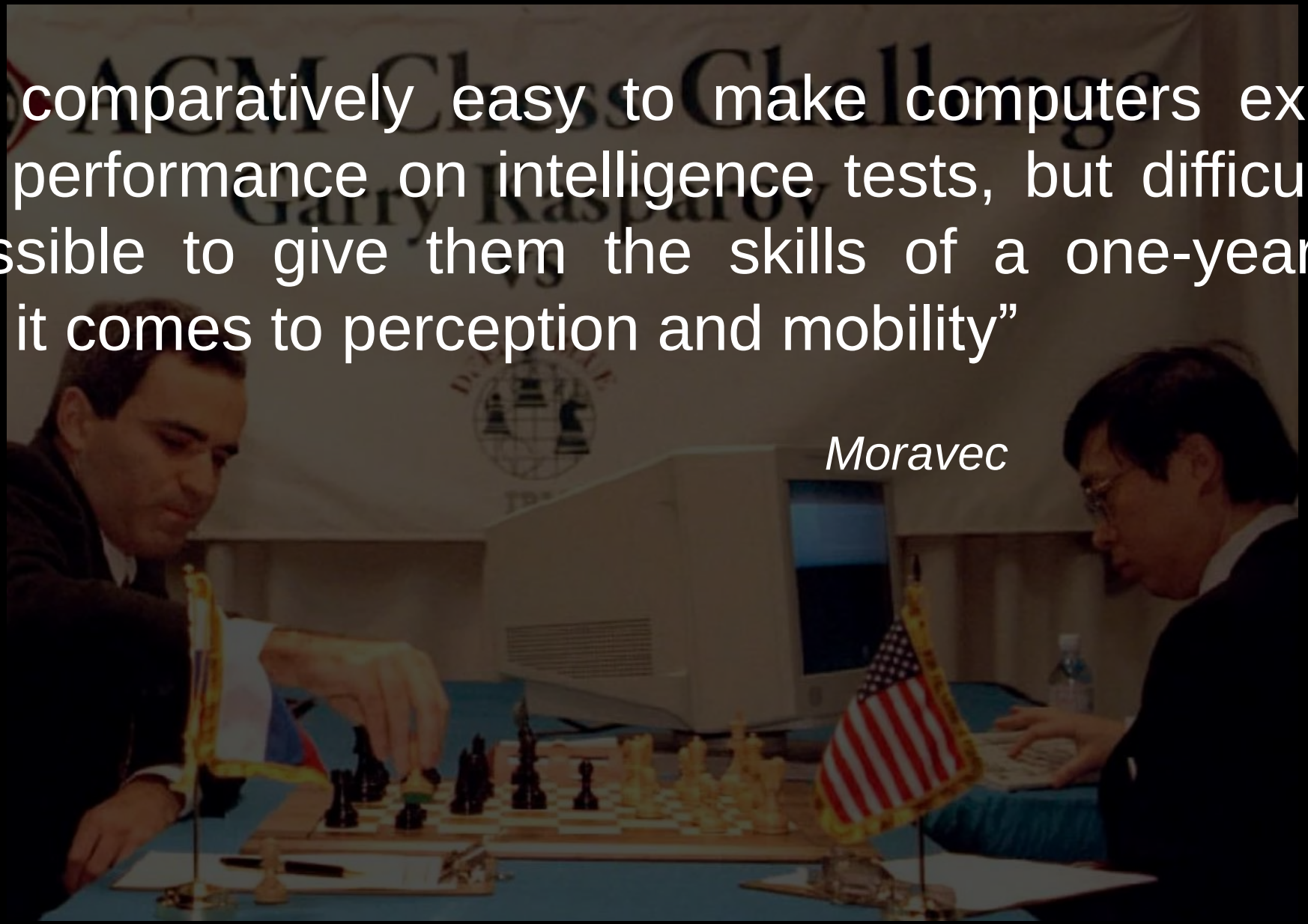
Getting a grip on the tactile perception of frictional information in humans and robots

Laurence Willemet

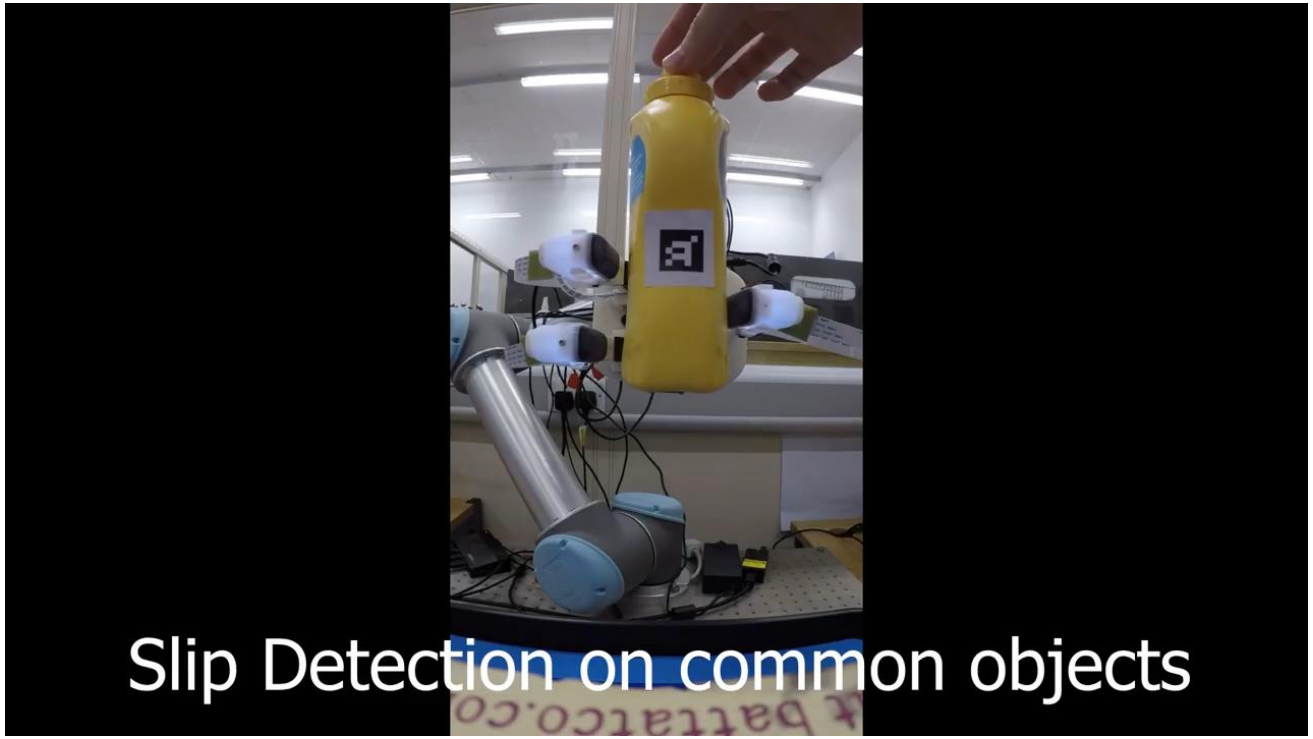
4-1-2024

“It is comparatively easy to make computers exhibit adult performance on intelligence tests, but difficult or impossible to give them the skills of a one-year-old when it comes to perception and mobility”

Moravec



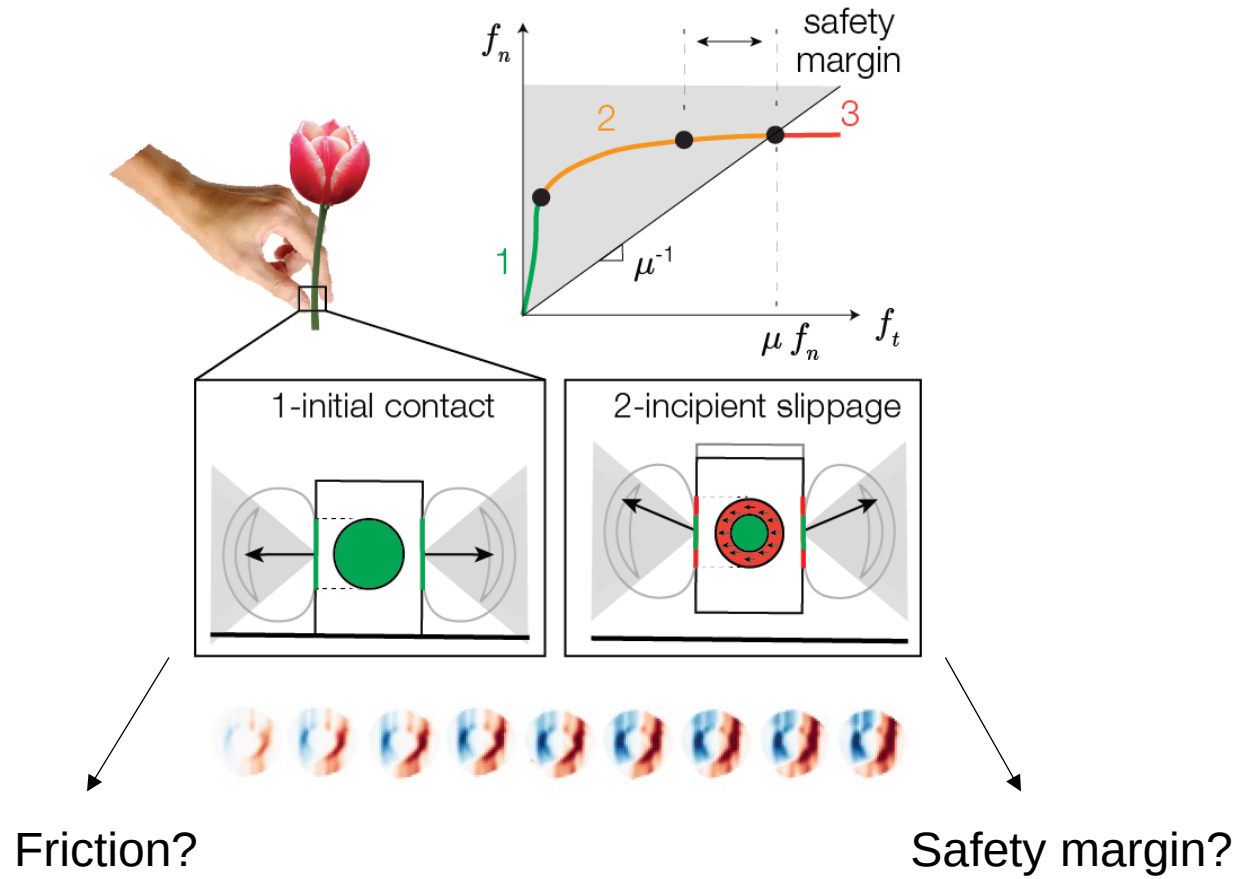
Reaction vs. prediction



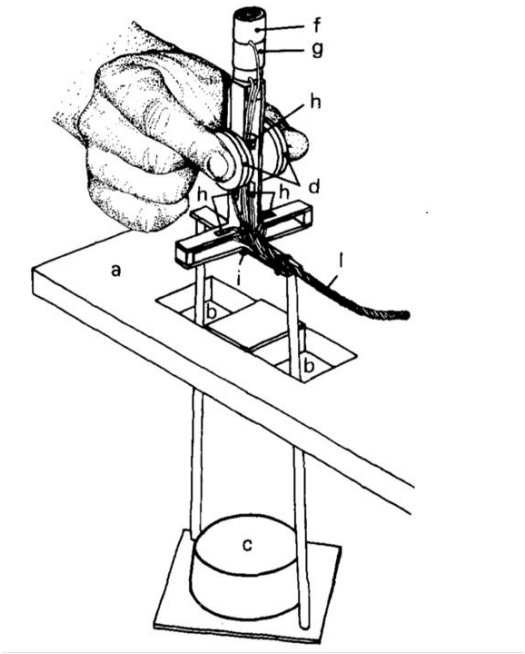
James and Lepora, 2020

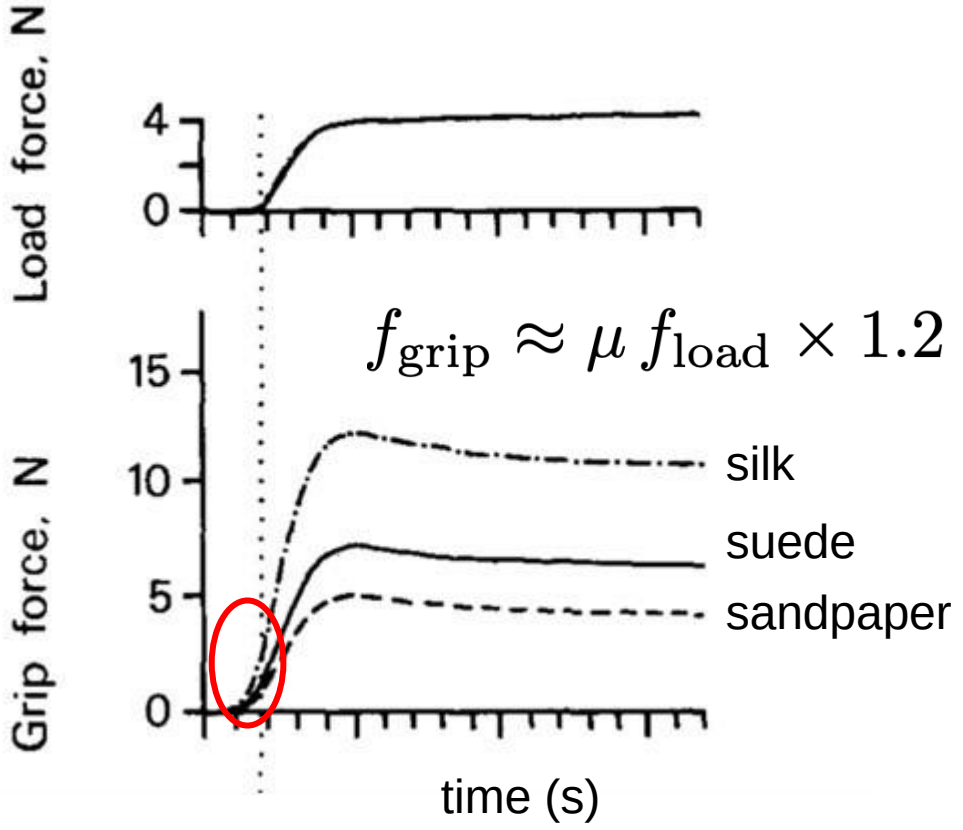
Grasping is about perceiving the interaction forces

Grip force regulation



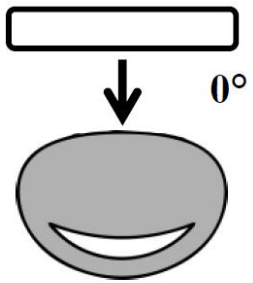
Grip force regulation

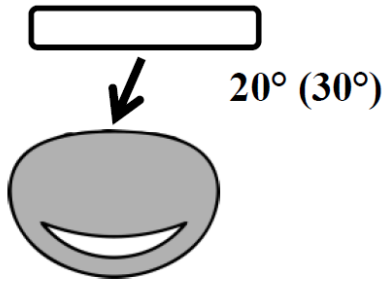


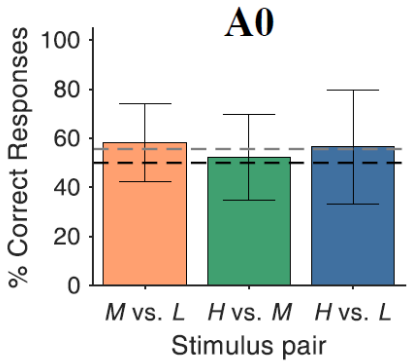


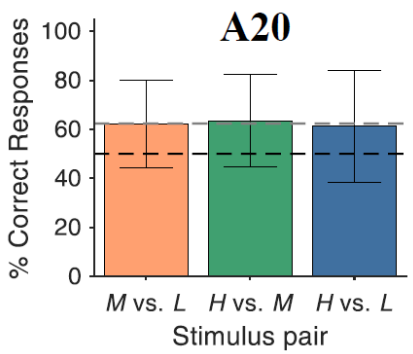
Johansson and Westling, 1984

Are we able to perceive friction on initial contact?





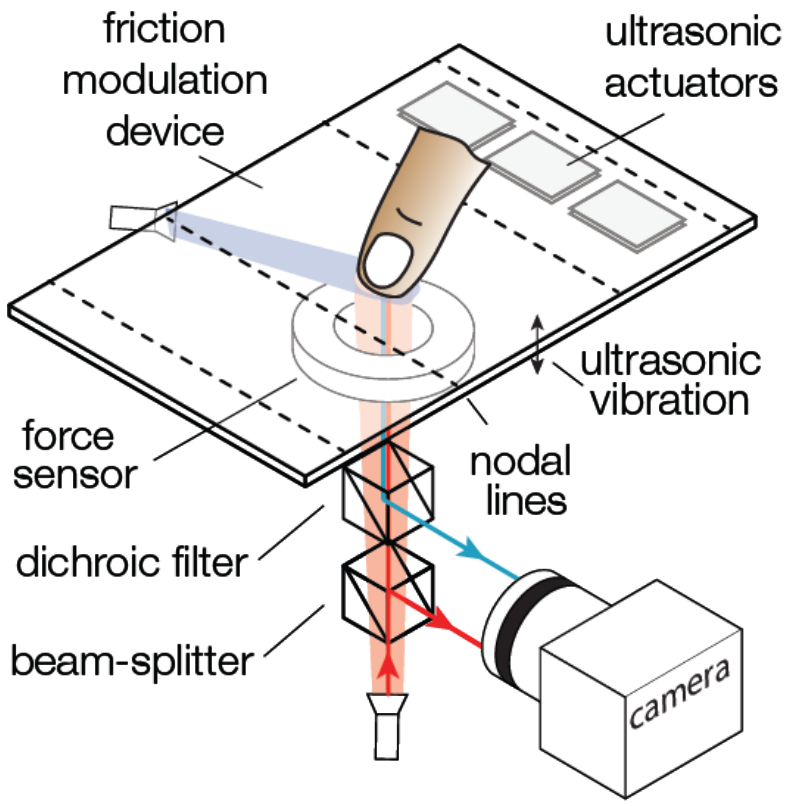


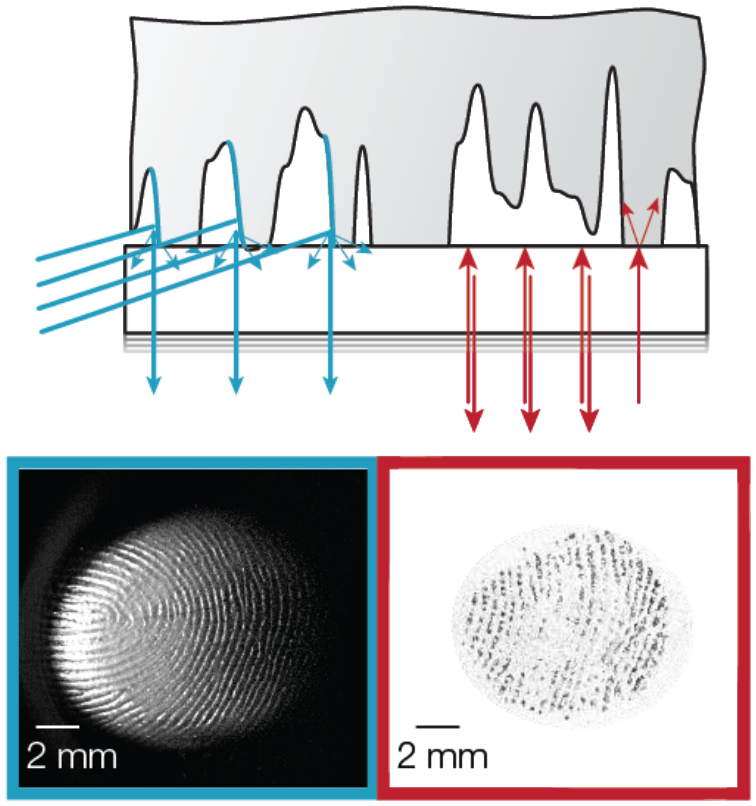


No perception when the subject is passive

Khamis et al., 2020

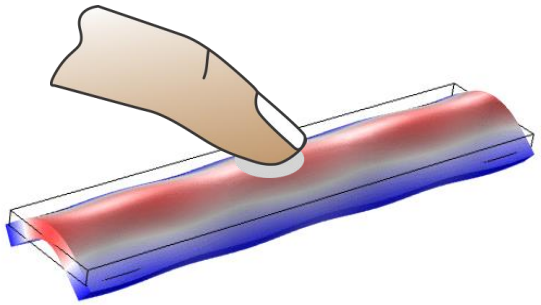
Experiment in active

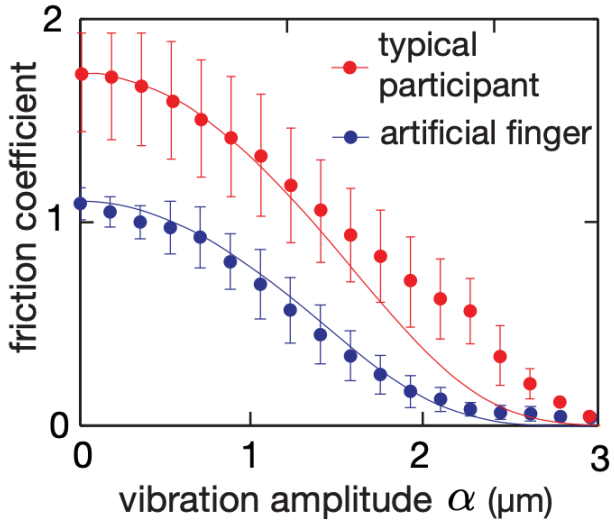


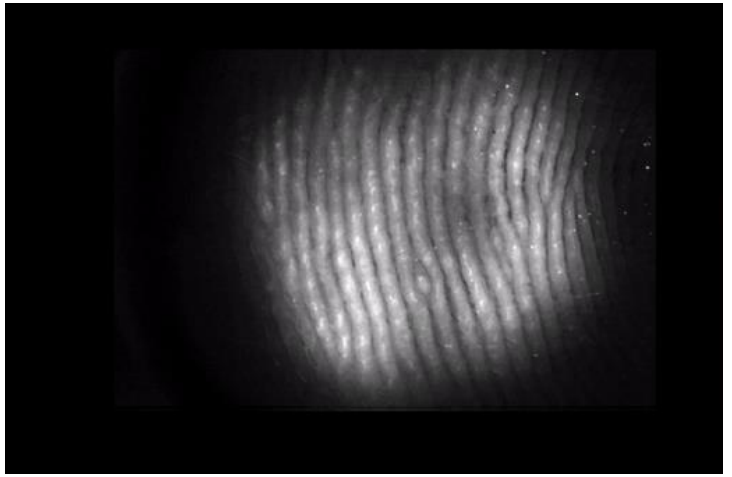


Willemet et al., Initial contact shapes the perception of friction (2021) PNAS

Friction modulation

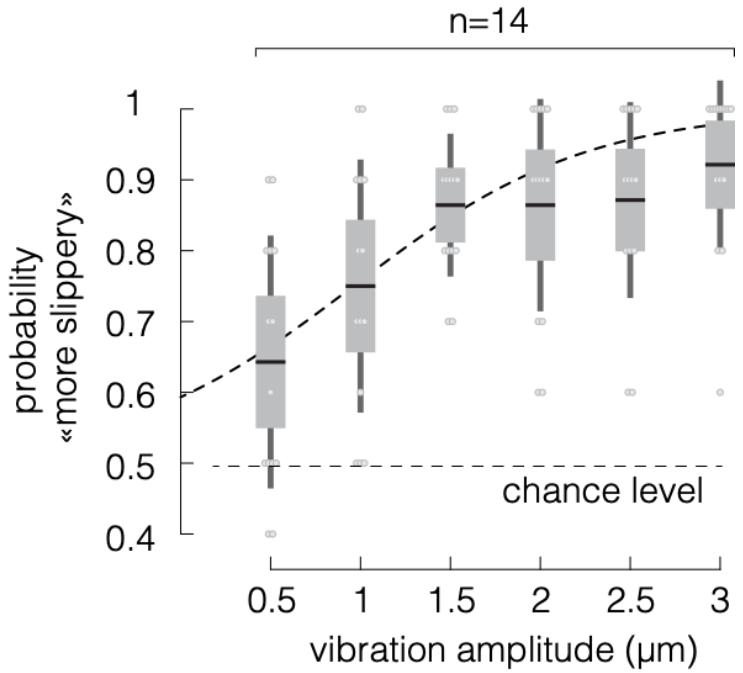






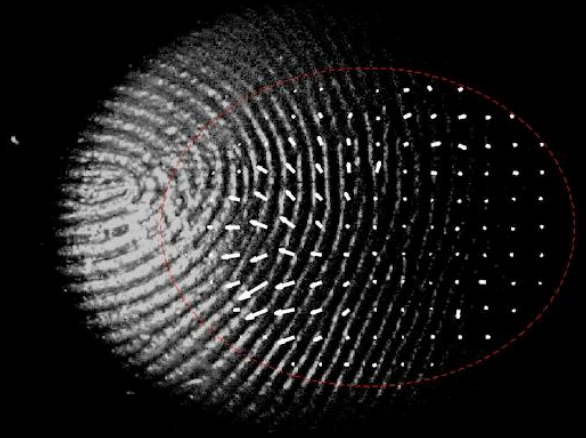
Wiertlewski M. et al., PNAS 2016

Psychophysical results

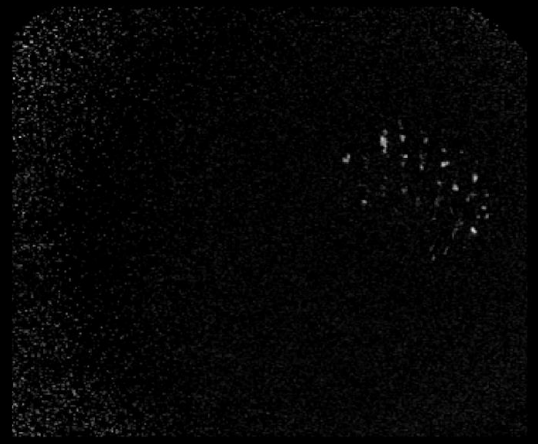


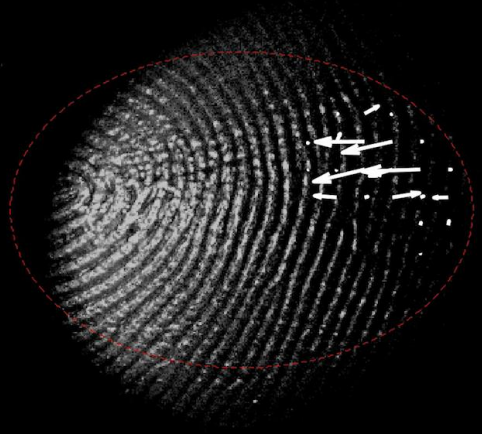
high friction

high friction

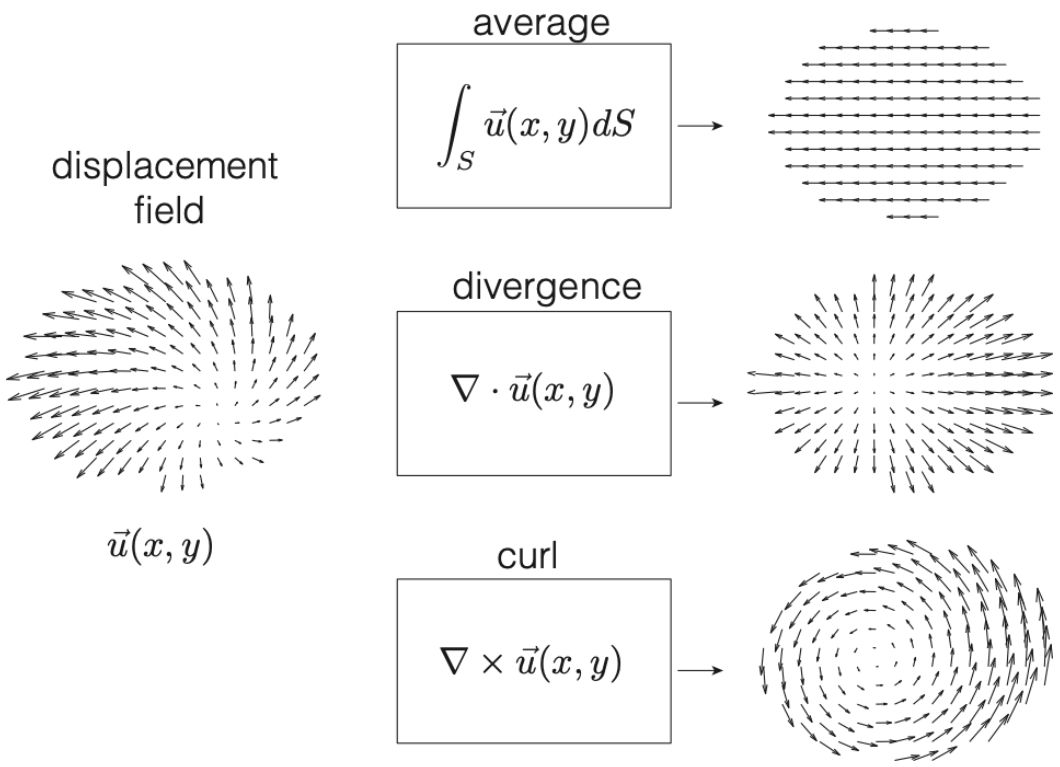


low friction

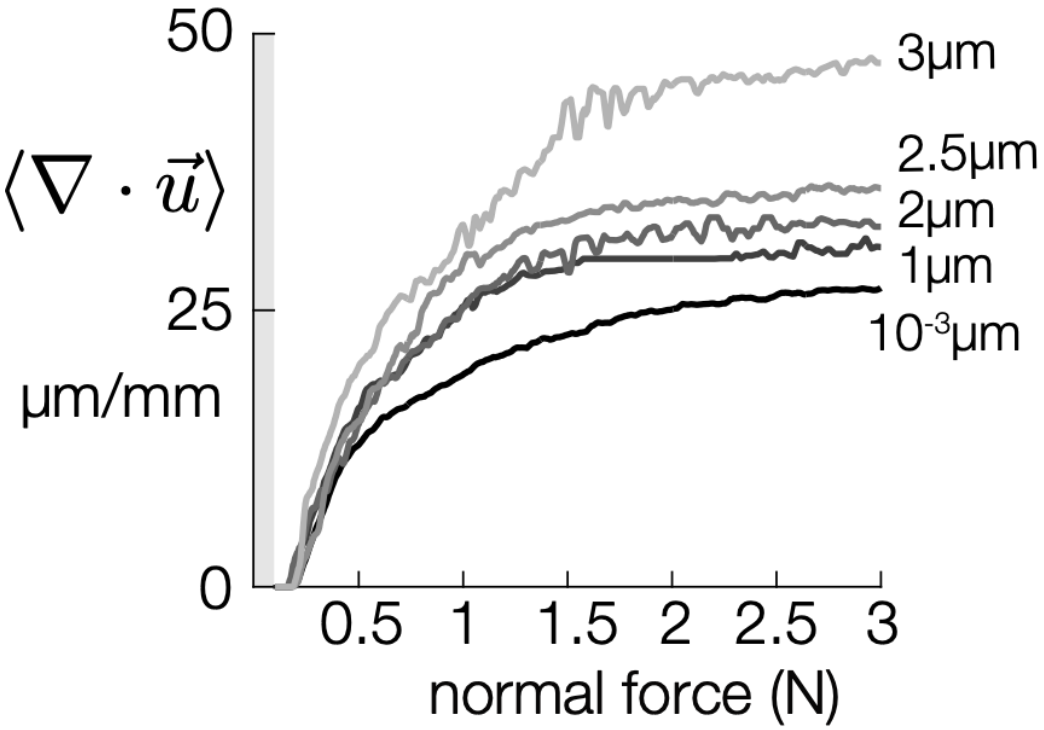




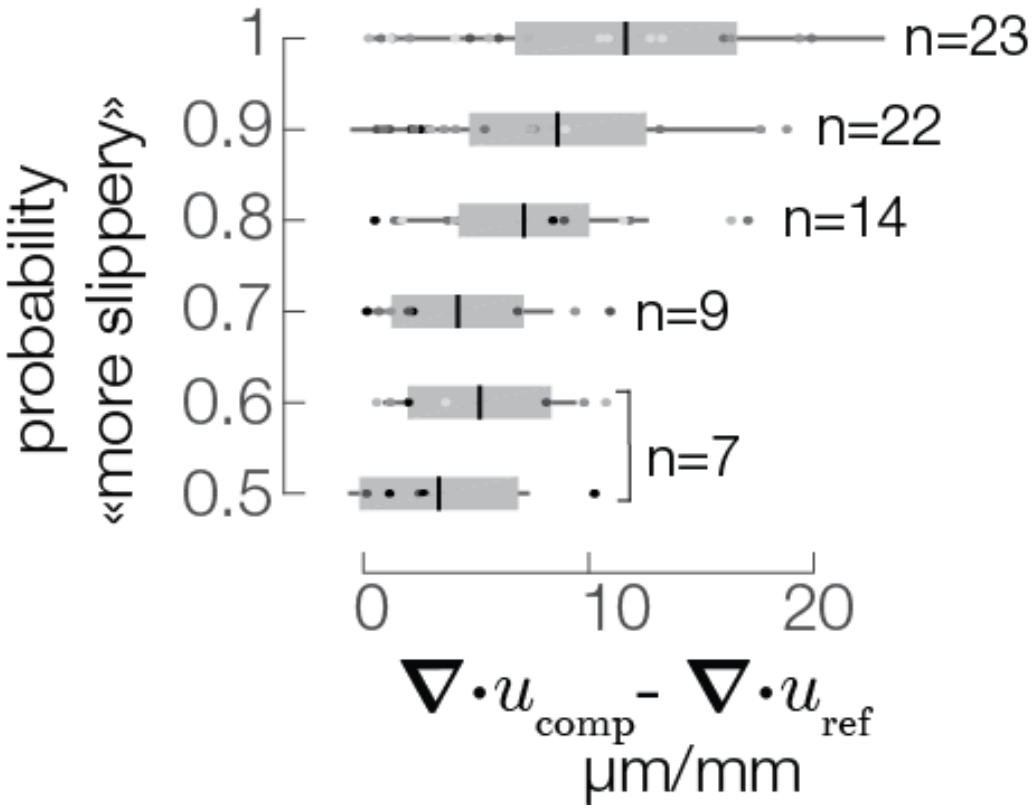
Friction and skin deformation



$$\int_S \nabla \cdot \vec{u}\,(x,y)dS = \int_S \frac{\partial u_x}{\partial x} + \frac{\partial u_y}{\partial y} dS$$

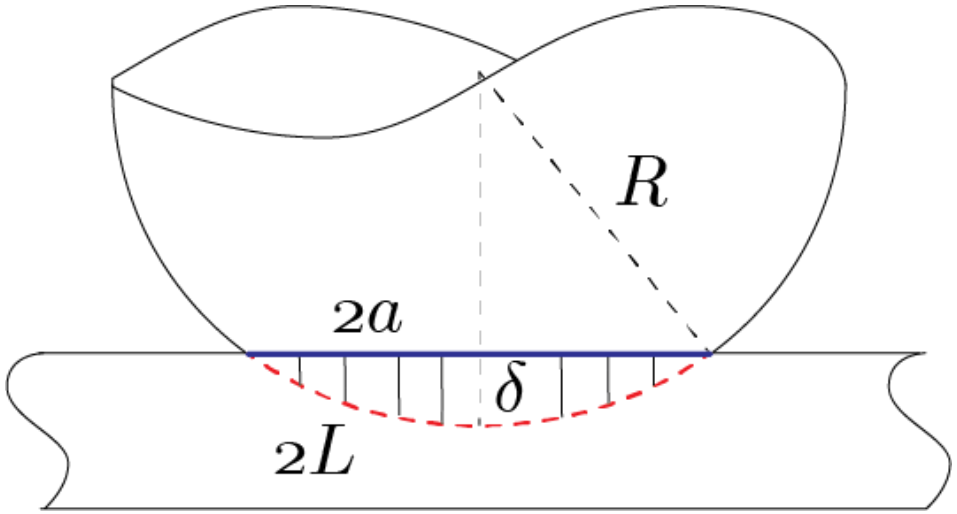


Skin deformation and friction perception



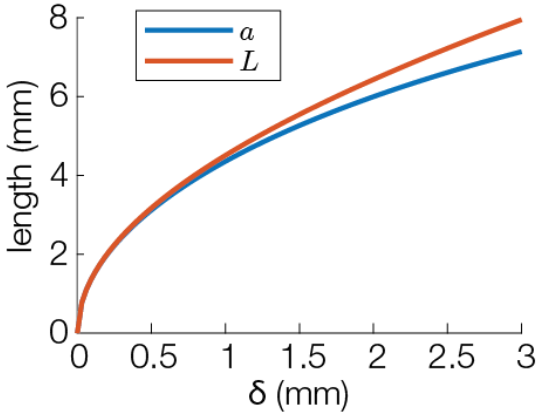
Spearman' s rank coefficient=0.28,
p=0.009

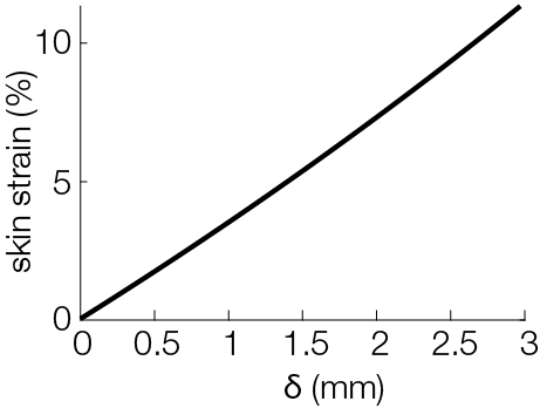
Where does this lateral strain comes from?



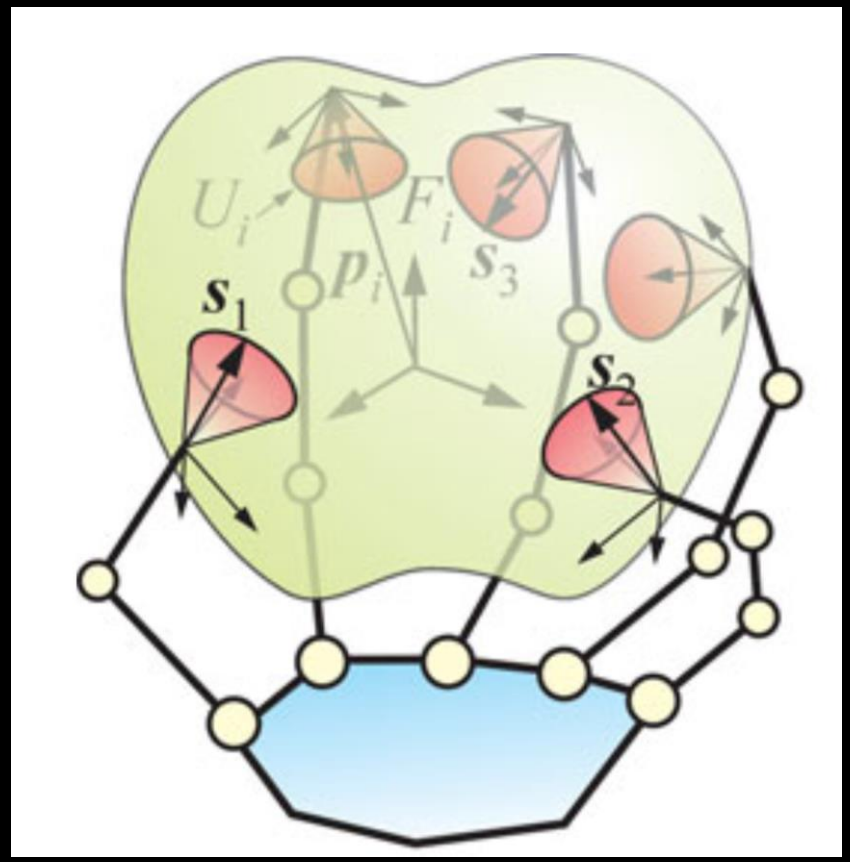
$$L = R\ \cos^{-1}\left(\frac{R-\delta}{R}\right)$$

$$a^2 = R^2 - (R-\delta)^2$$



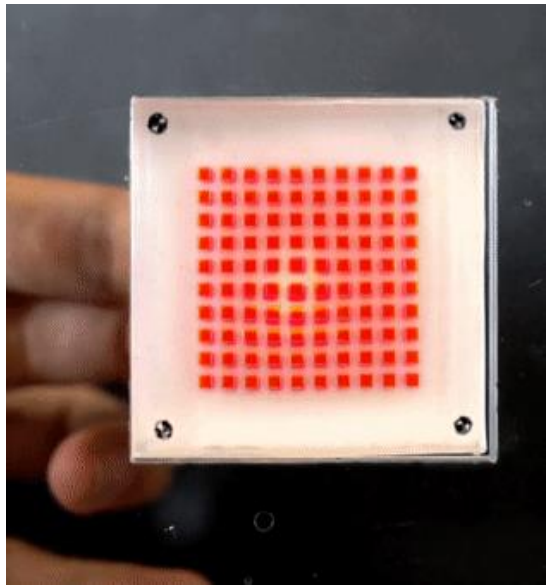


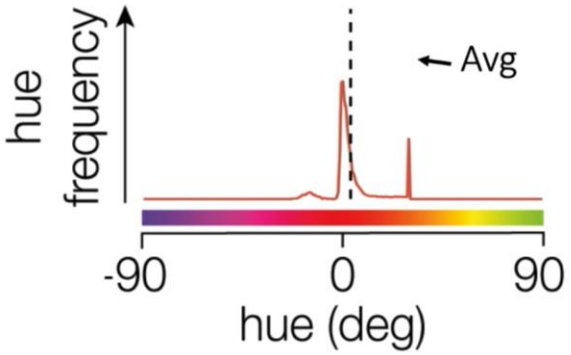
Friction perception is possible on initial contact

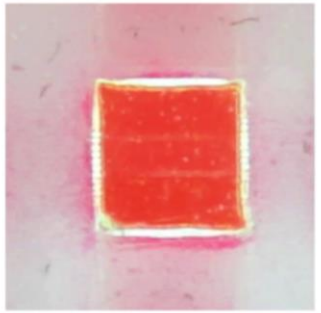


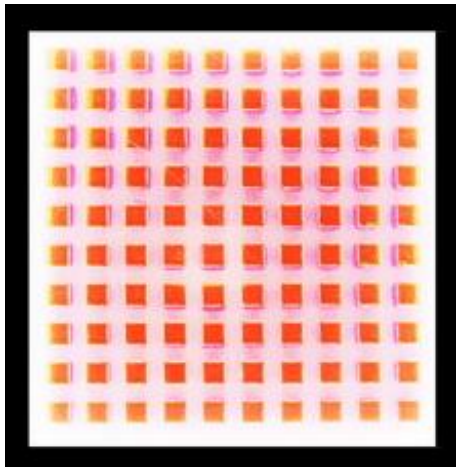
Can robots perceive this lateral expansion?

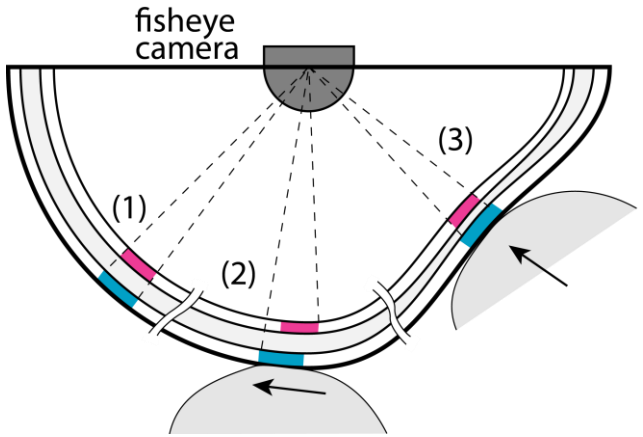
Tactile sensor: transduction principle

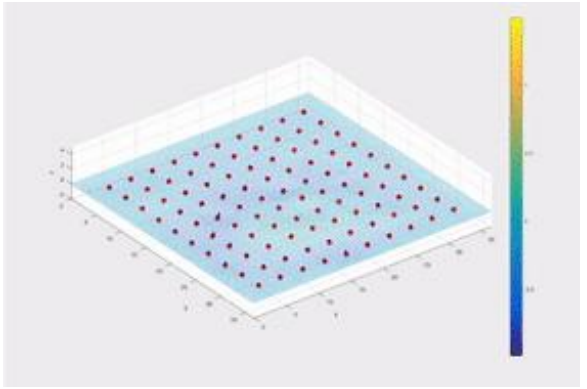






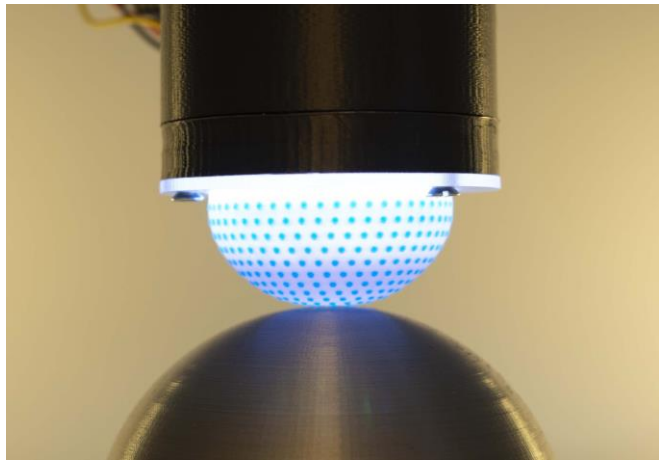


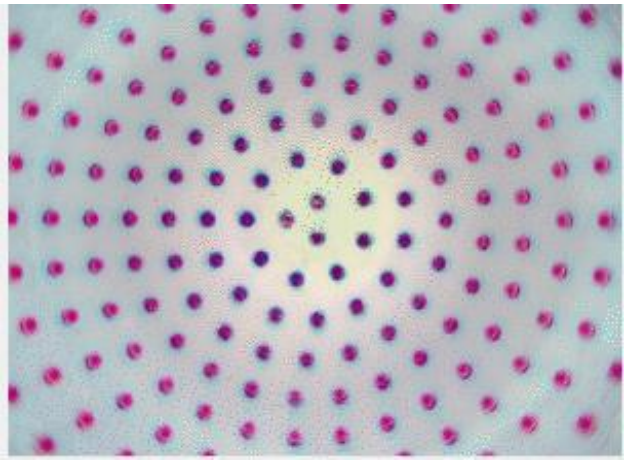


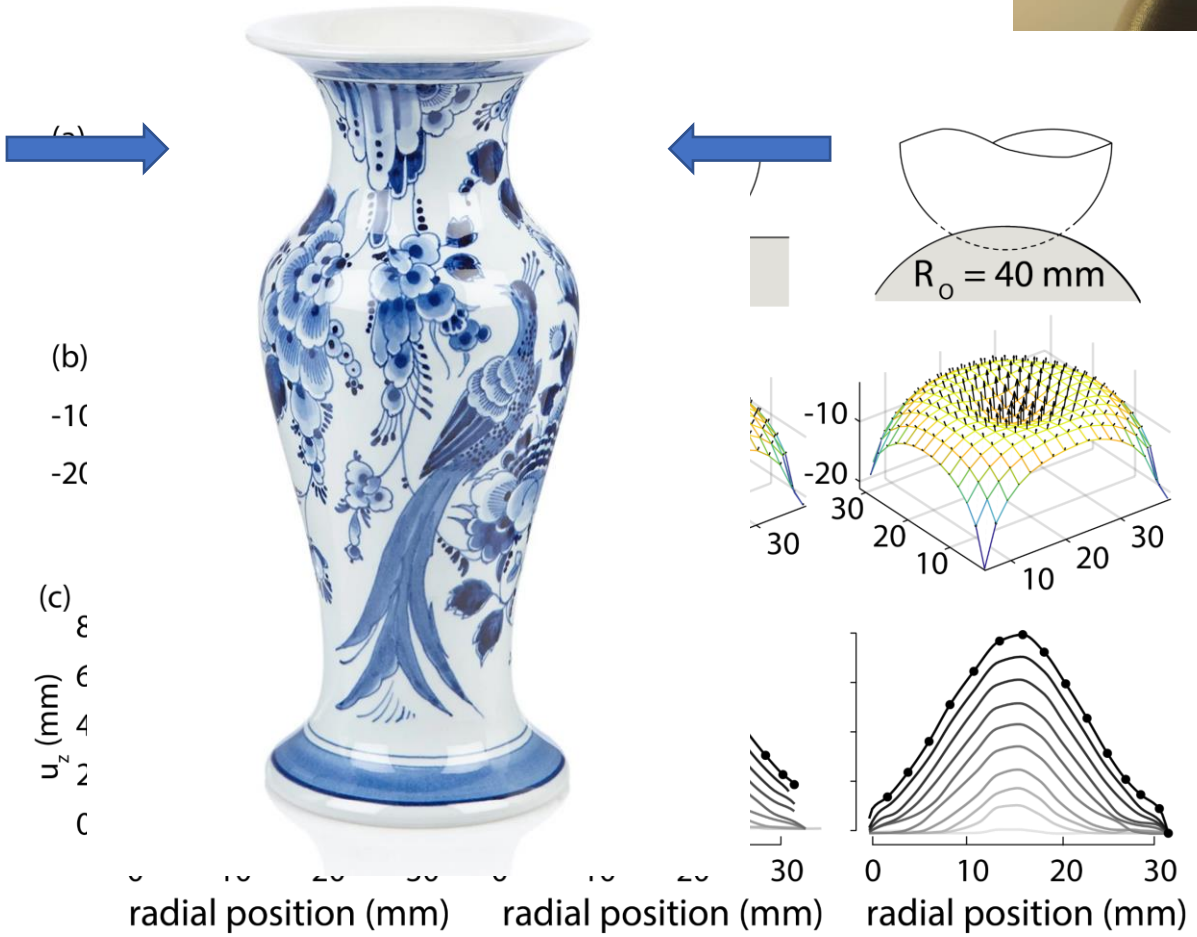


Lin, X. et al. (2019). IEEE Robotics and Automation Letters

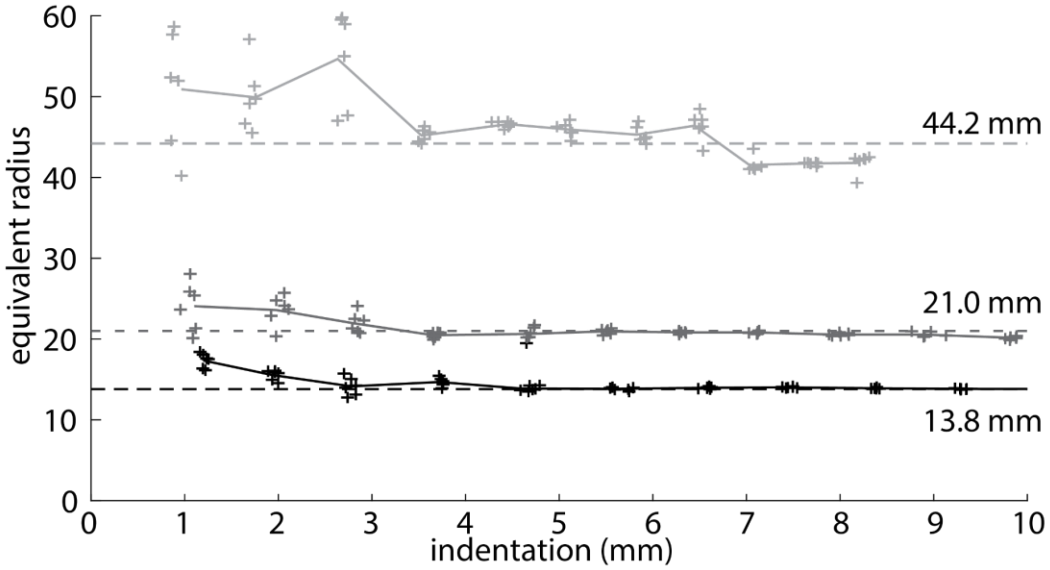
Curvature estimation



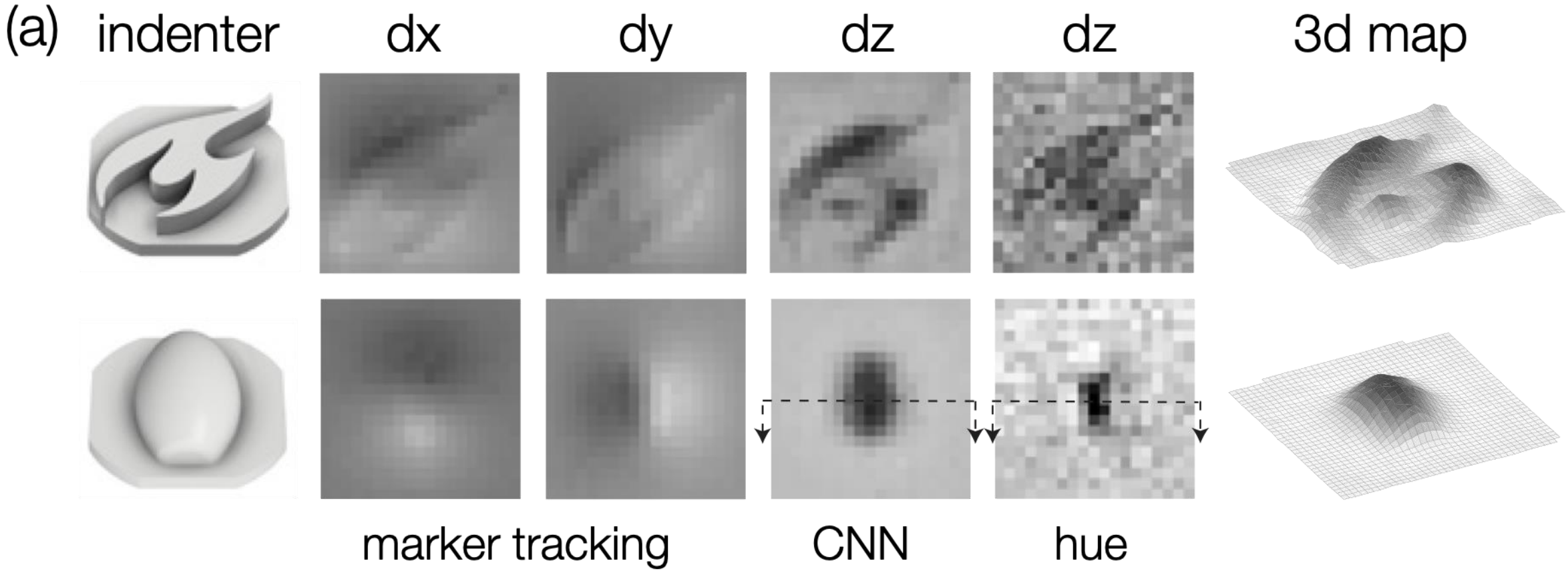




Hertz theory: $R_{eq} = \frac{a^2}{\delta_r}$

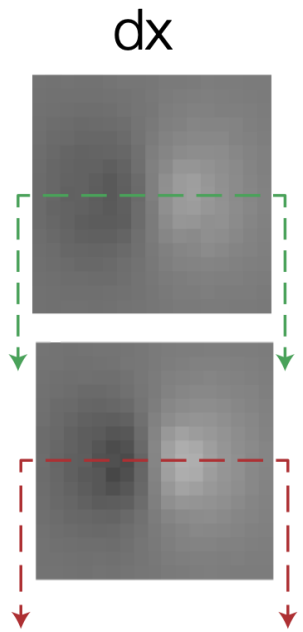


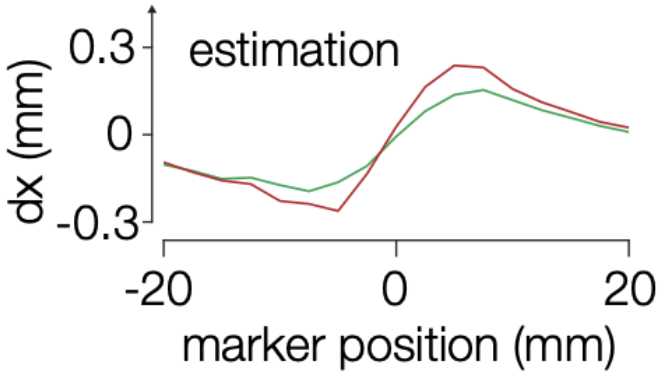
Shape reconstruction

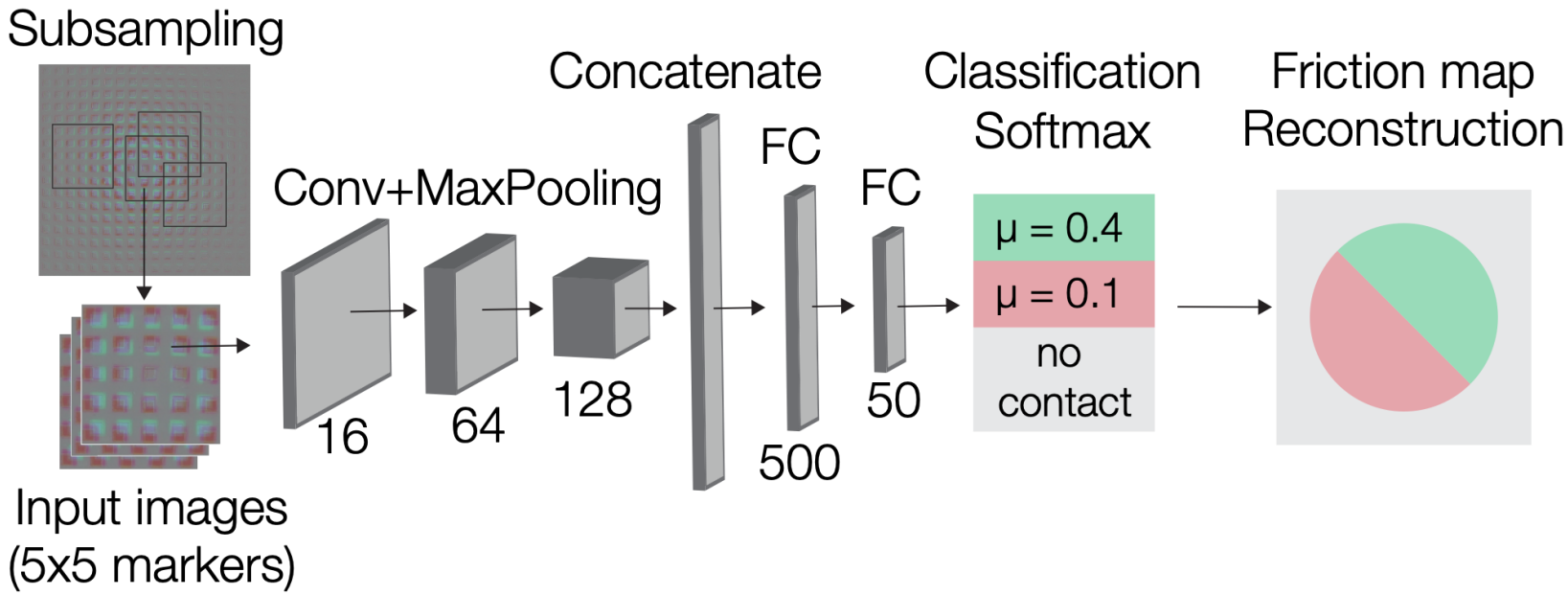


Friction perception

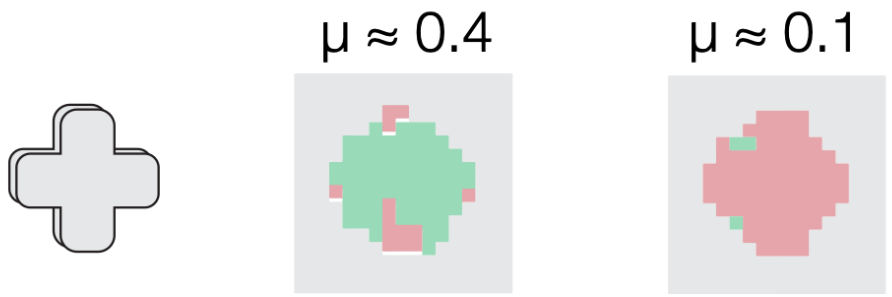
- μ ≈ 0.4
- μ ≈ 0.1

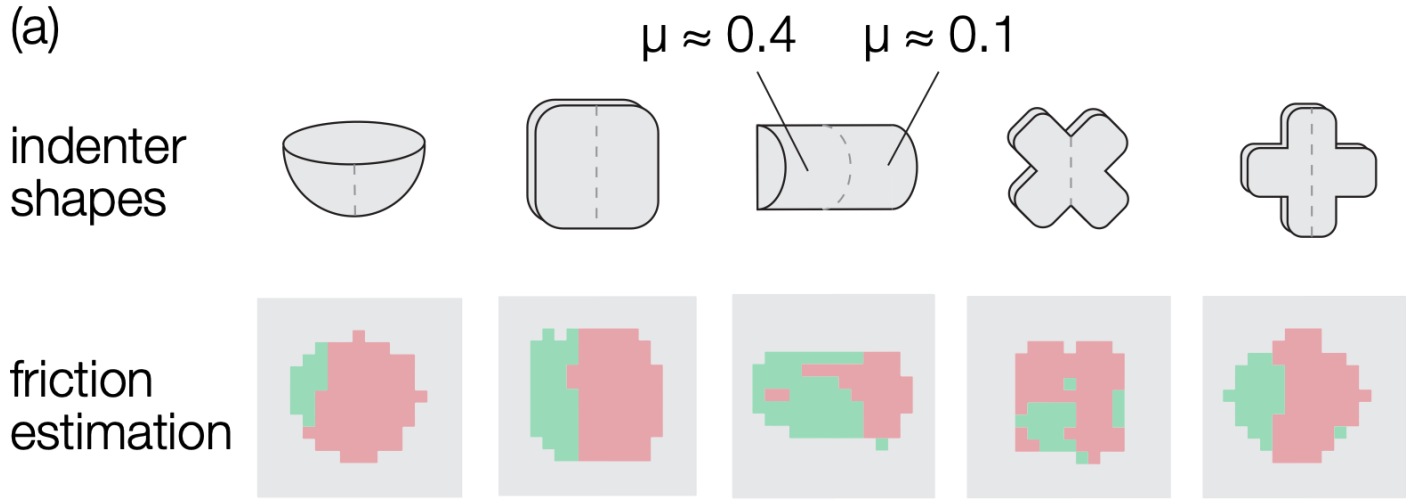


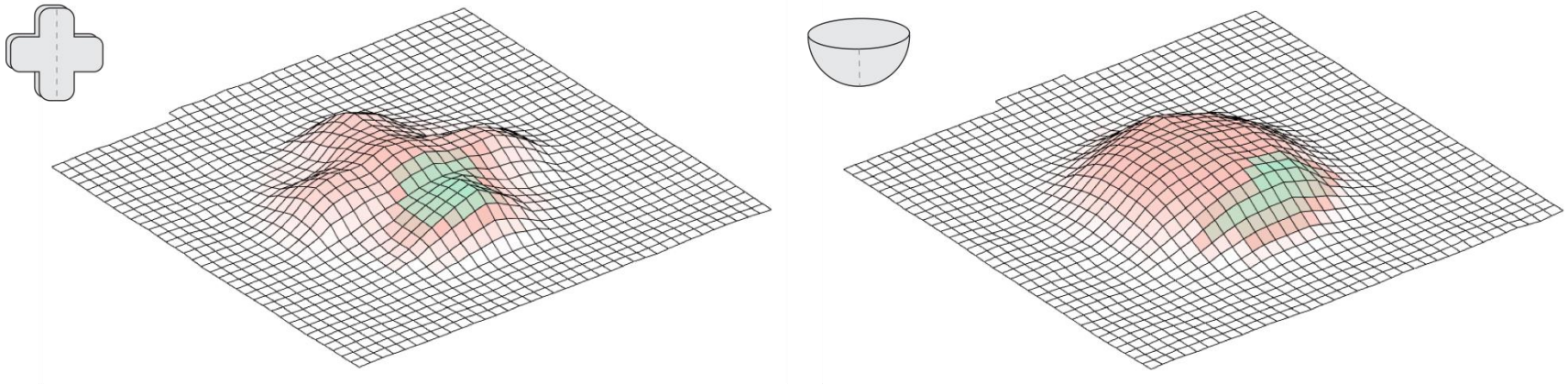




Friction perception



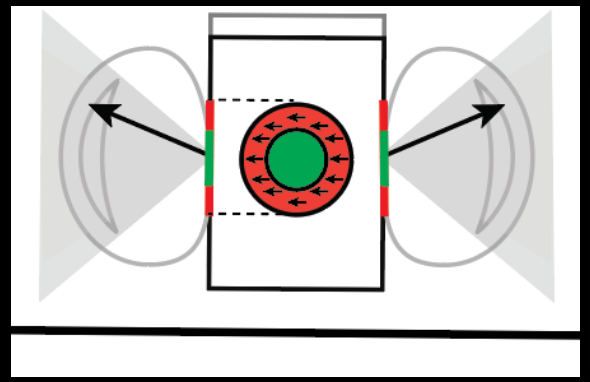




Area with high friction

Area with low friction

Grip force is continuously adjusted to keep a 20% safety margin



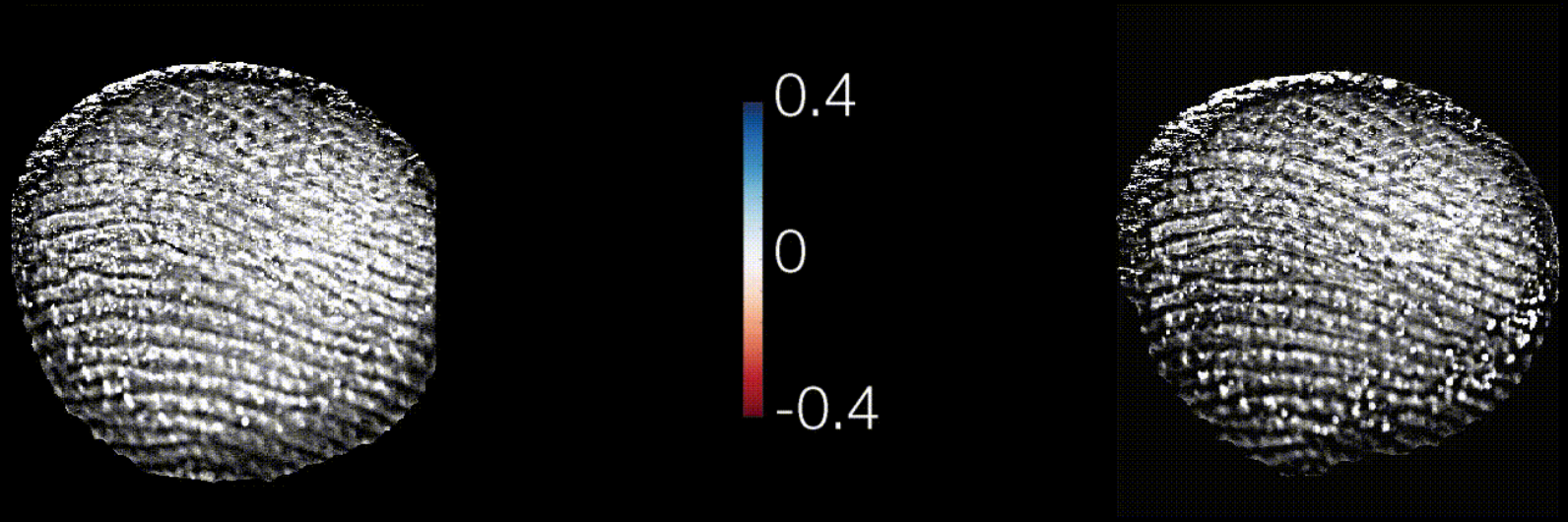
Skin deformation during incipient slippage

wet cherry

= high friction

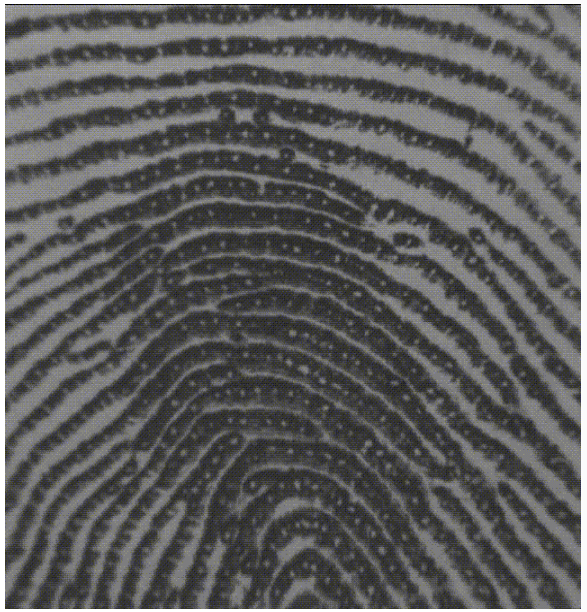
dry cherry

= low friction



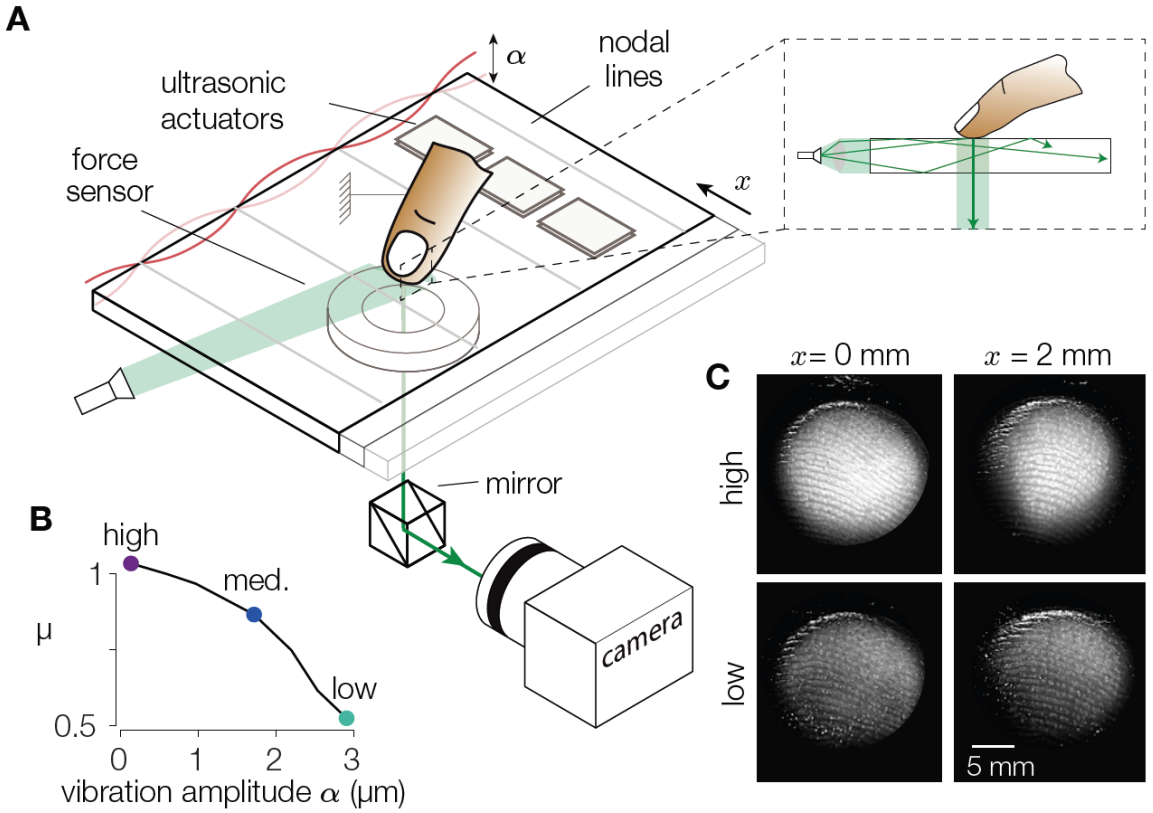
Finger slippage

high friction

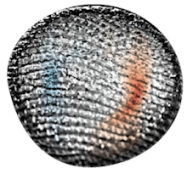


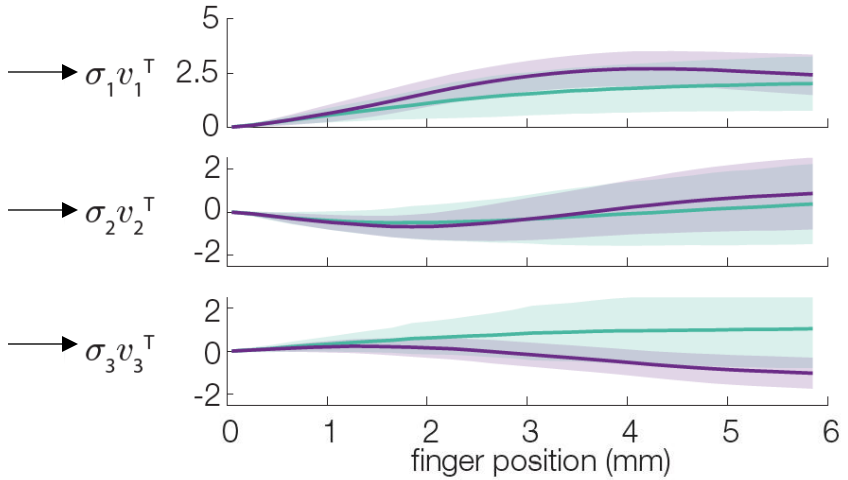
low friction

Setup


A
ultrasonic actuators
force sensor
nodal lines
α
x
mirror
camera
B
high
med.
low
μ
1
0.5
0
1
2
3
vibration amplitude α (μm)
C
x= 0 mm
x = 2 mm
high
low
5 mm
D
longitudinal strains
high
medium
low
40%
0
-40
E
safety margin
friction
0.5
0.8
1.1
relative displacement x(mm)

Dimensionality reduction

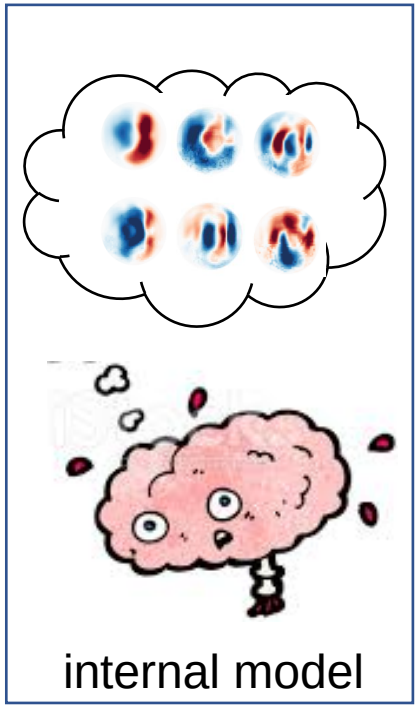




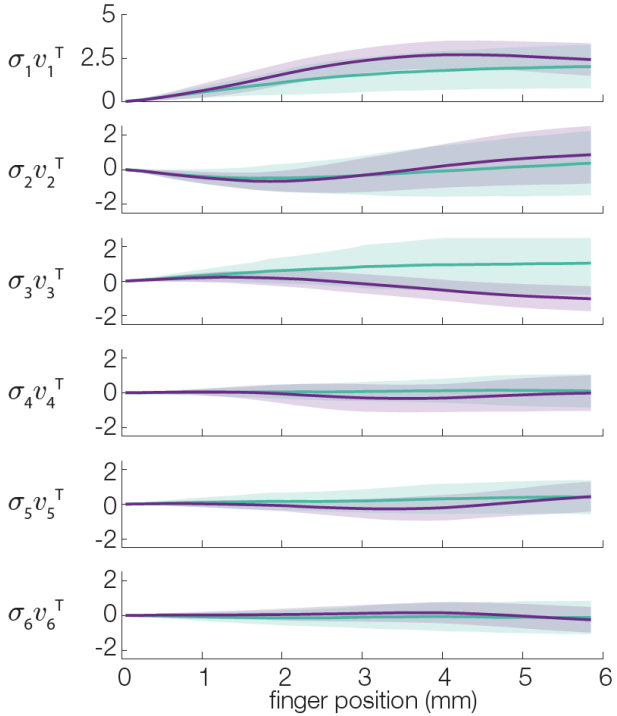
$$\hat{\varepsilon}(x,t) = \sum_{i=1}^{r} u_i(x)\,\sigma_i v_i(t)$$

Willemet et al., Efficient tactile encoding of object slippage (2022)

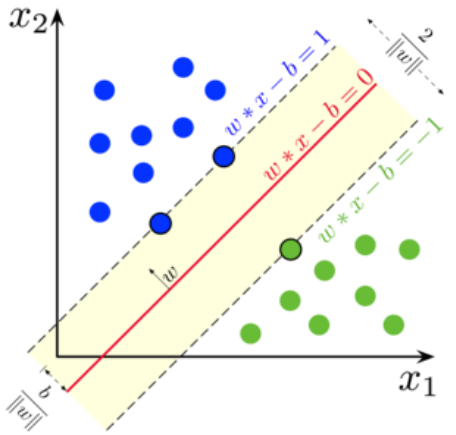
Safety margin estimation



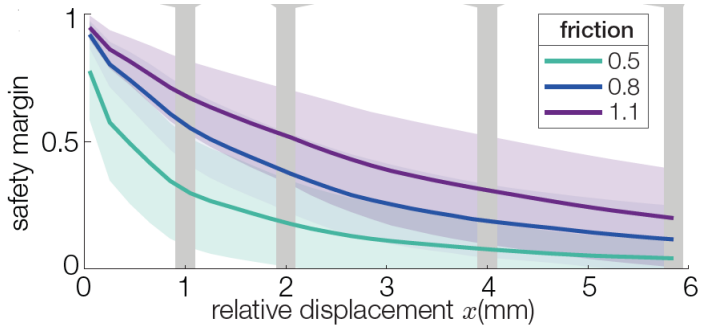
Contribution of each bases
= temporal evolution σv^T



Support Vector Machine

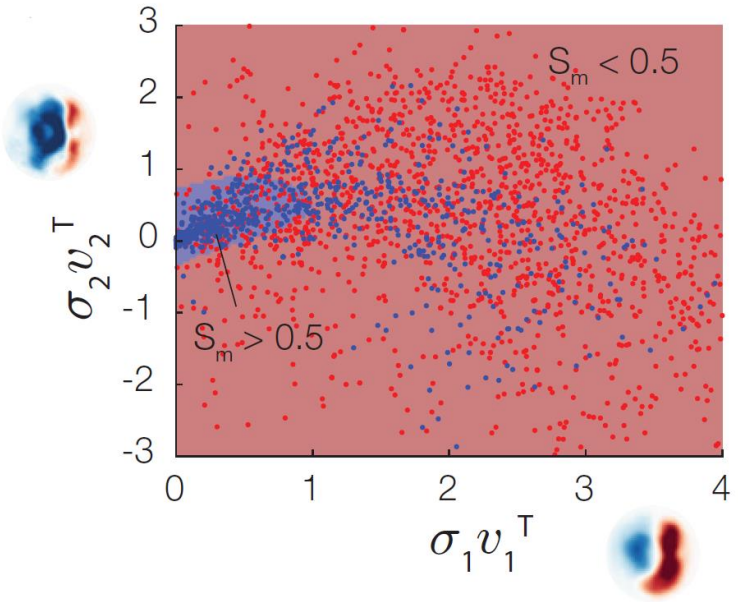


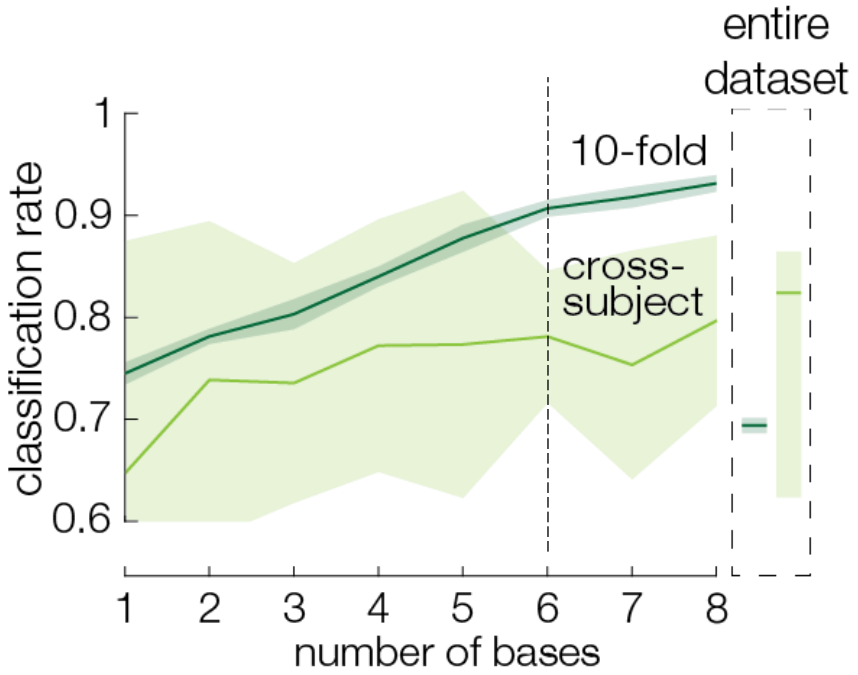
Safety margin

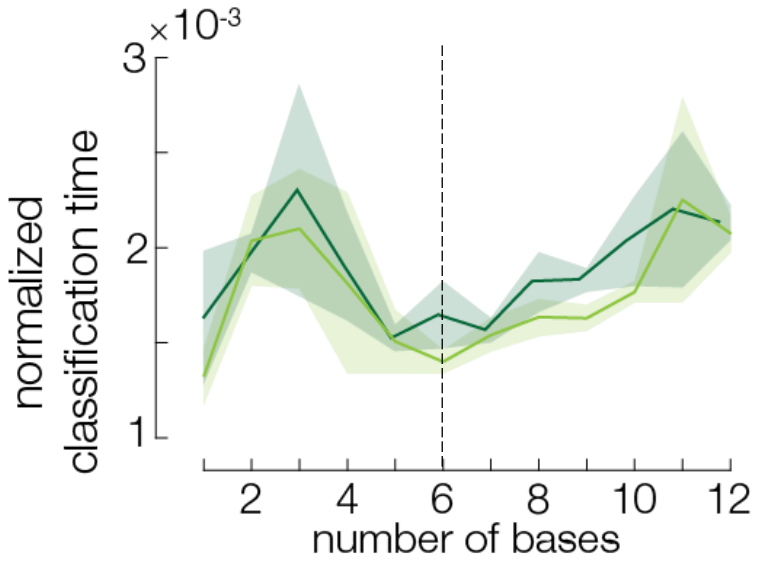


How to choose the optimal number of bases?

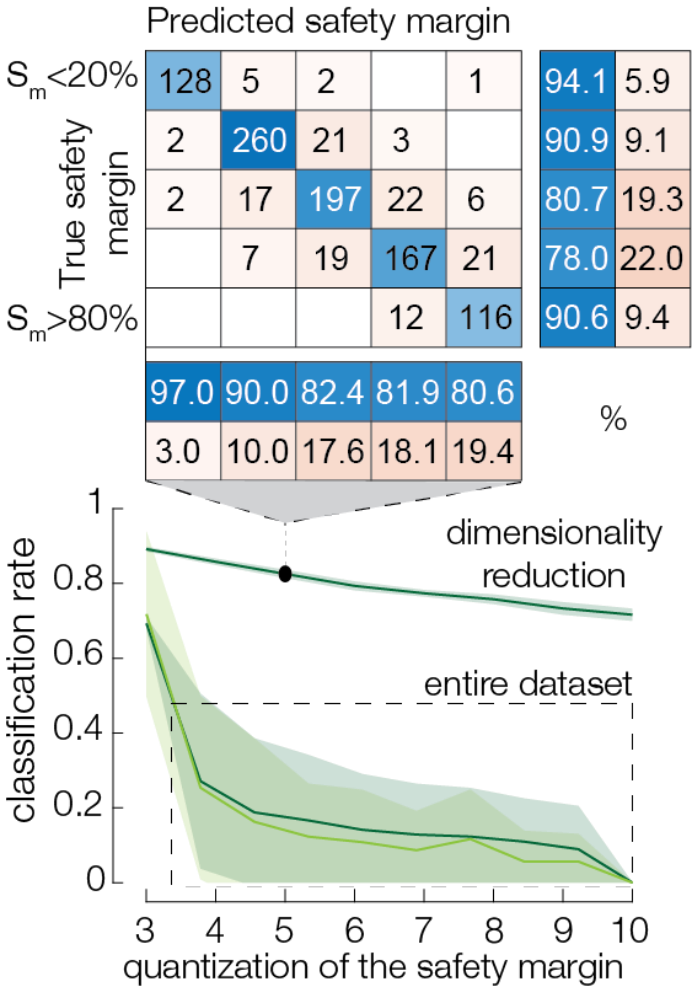
2 bases





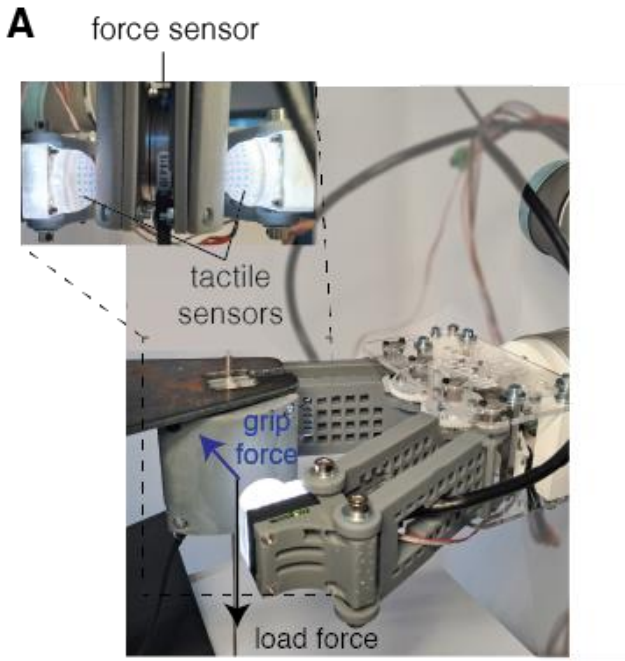


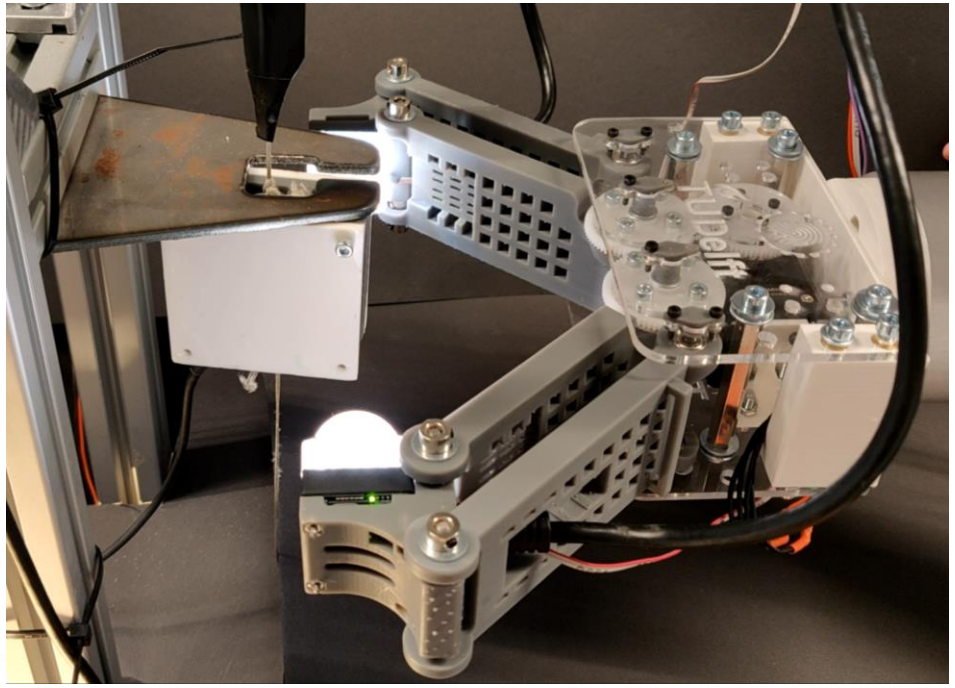
Refining the accuracy of the estimation

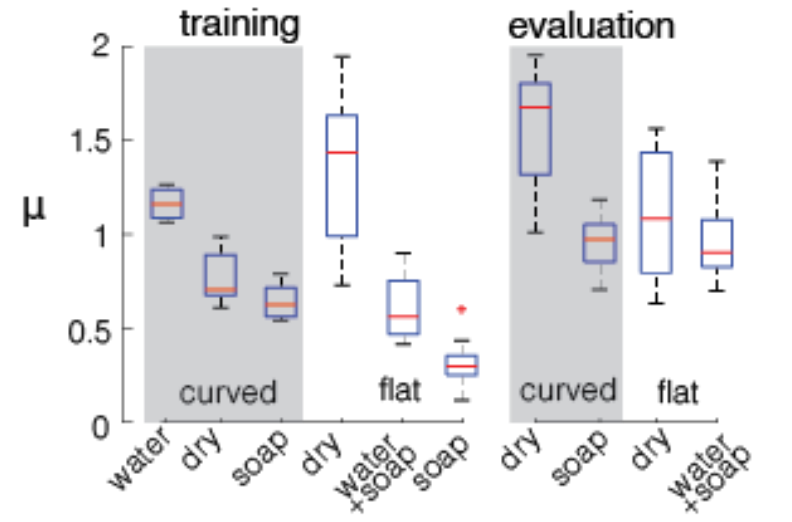


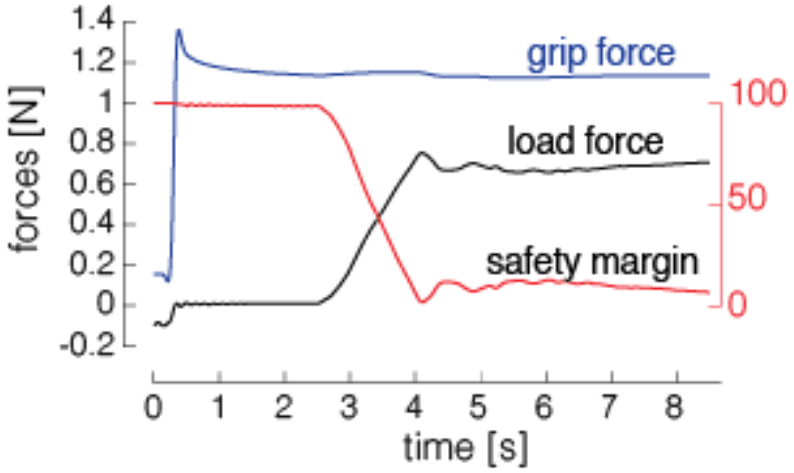
...for control in robotics

Data acquisition

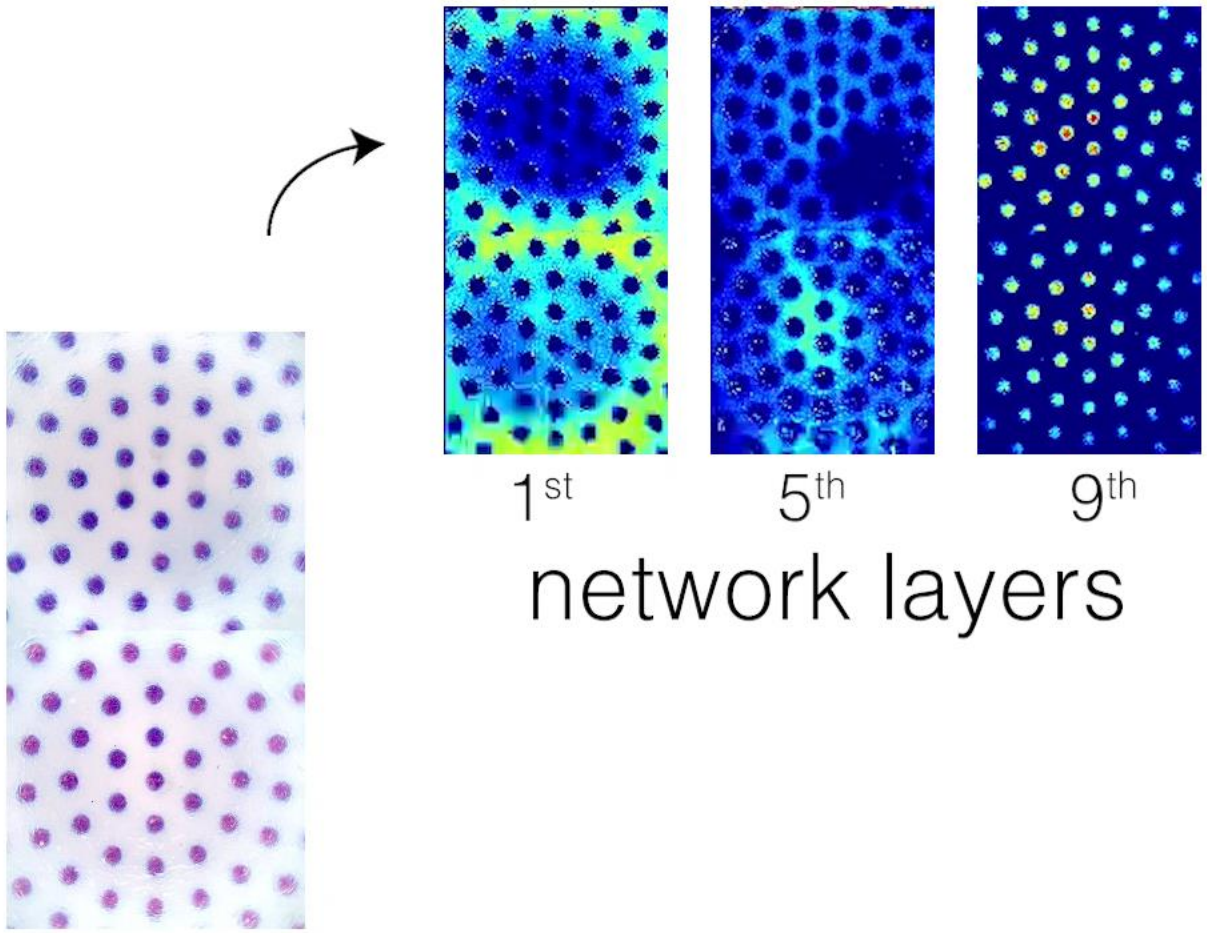




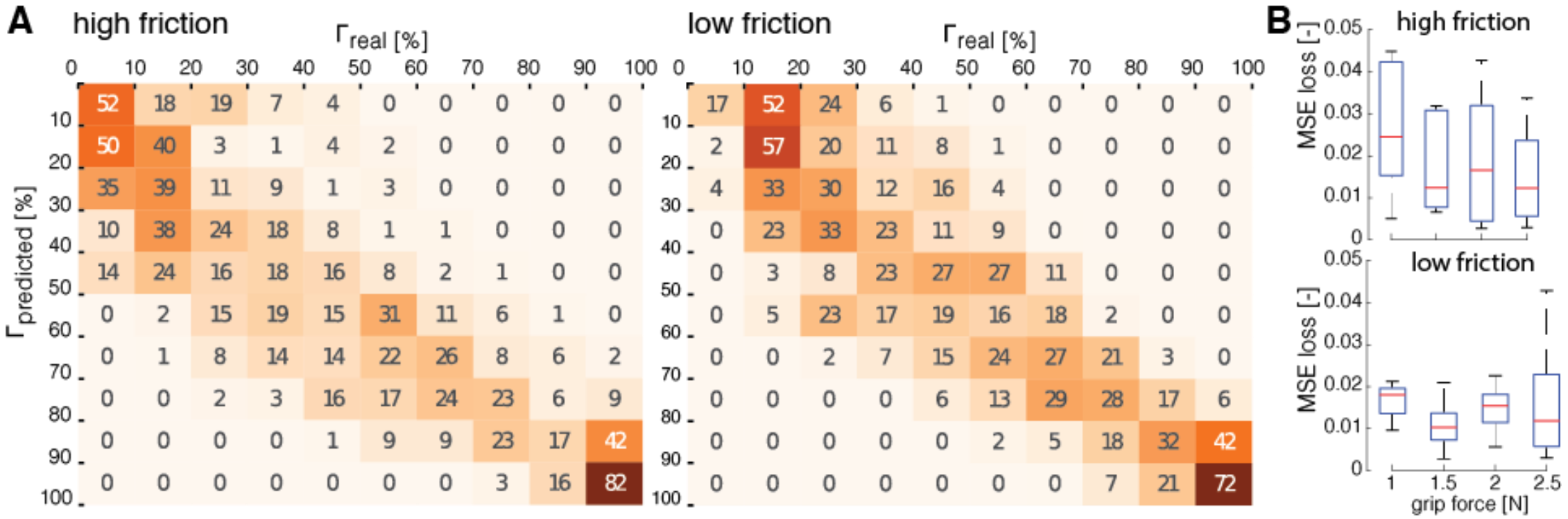




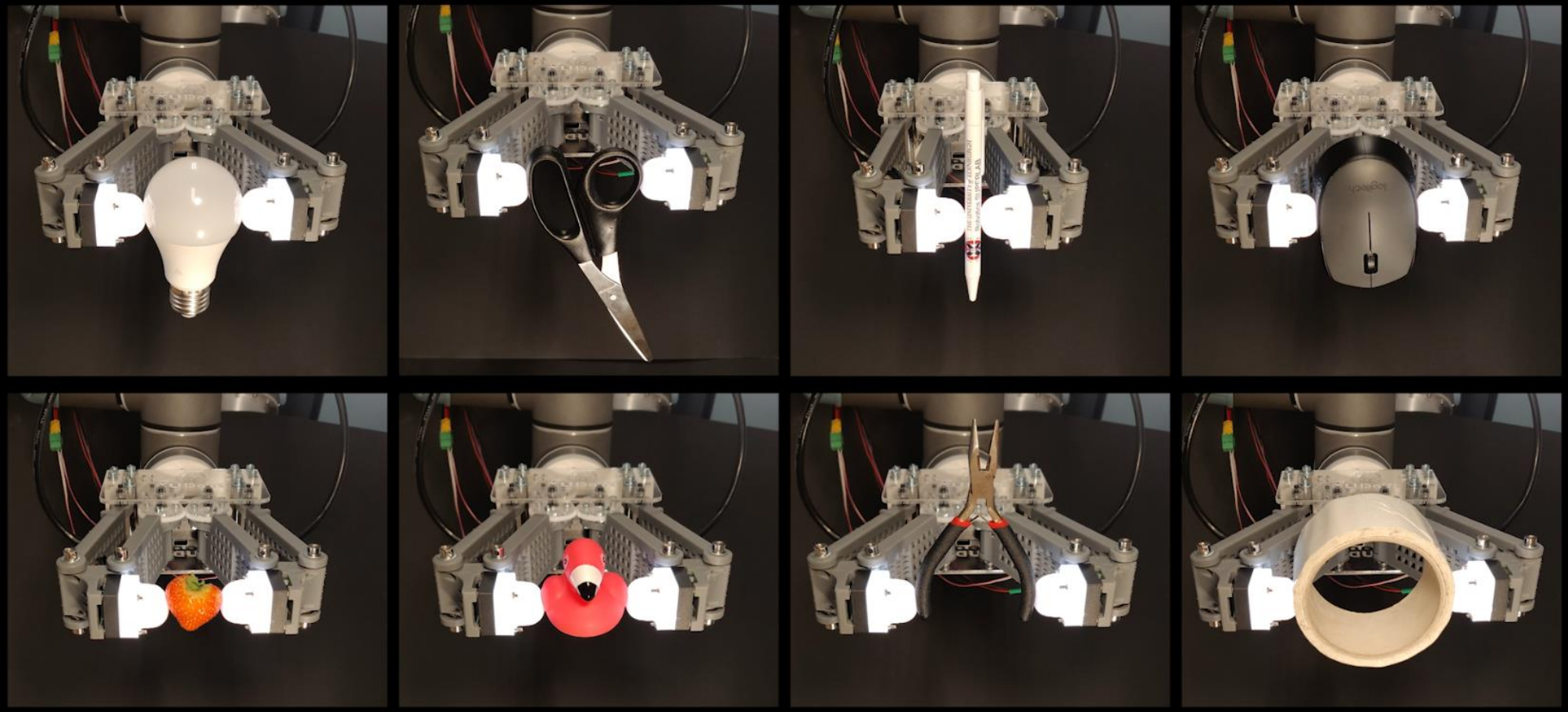
Safety margin prediction in robotics



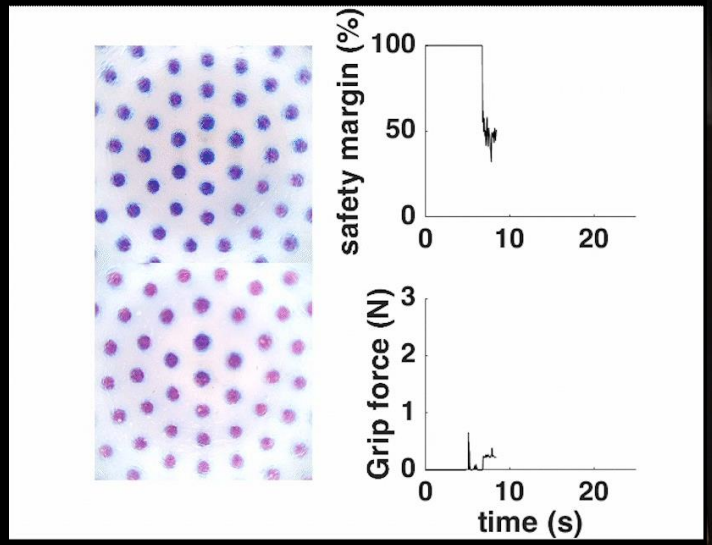
Safety margin estimation

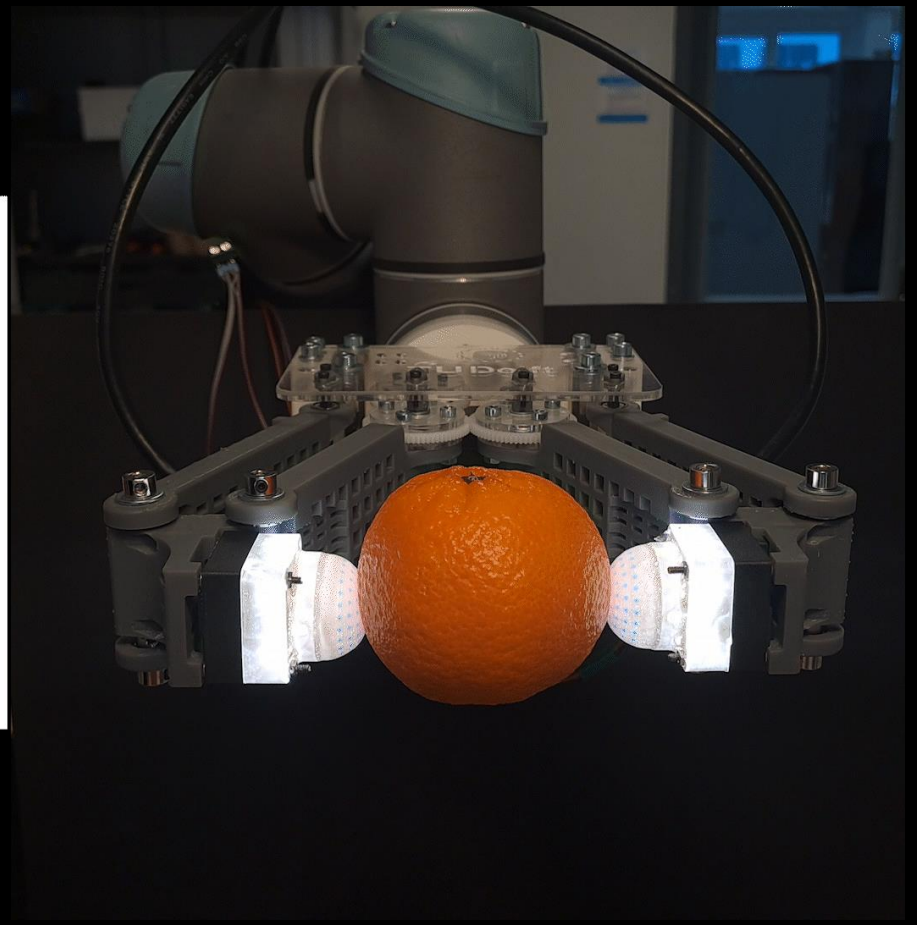


Grip force adaptation during grasping



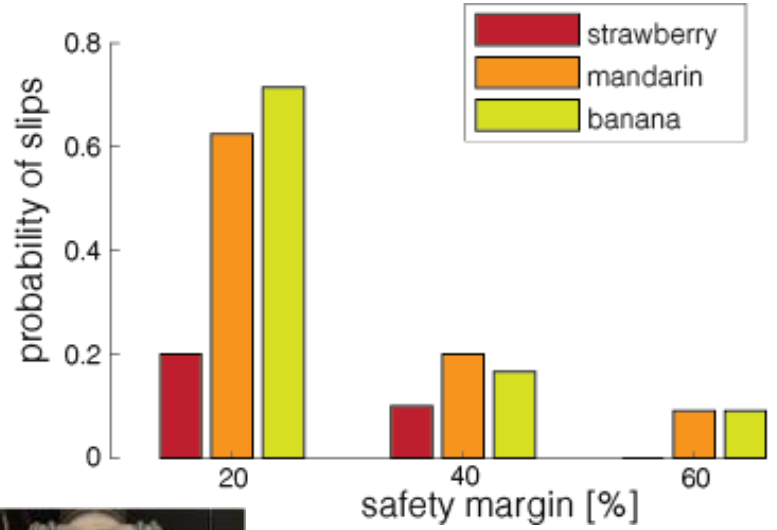
Reacting to external perturbations

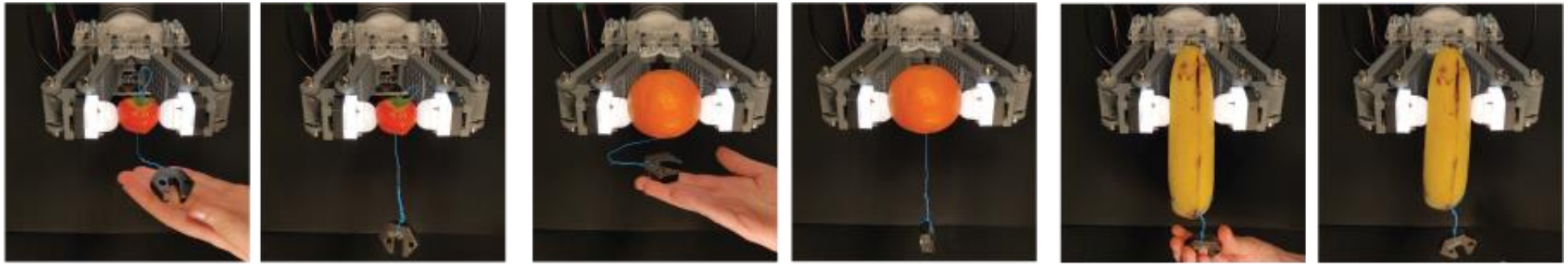


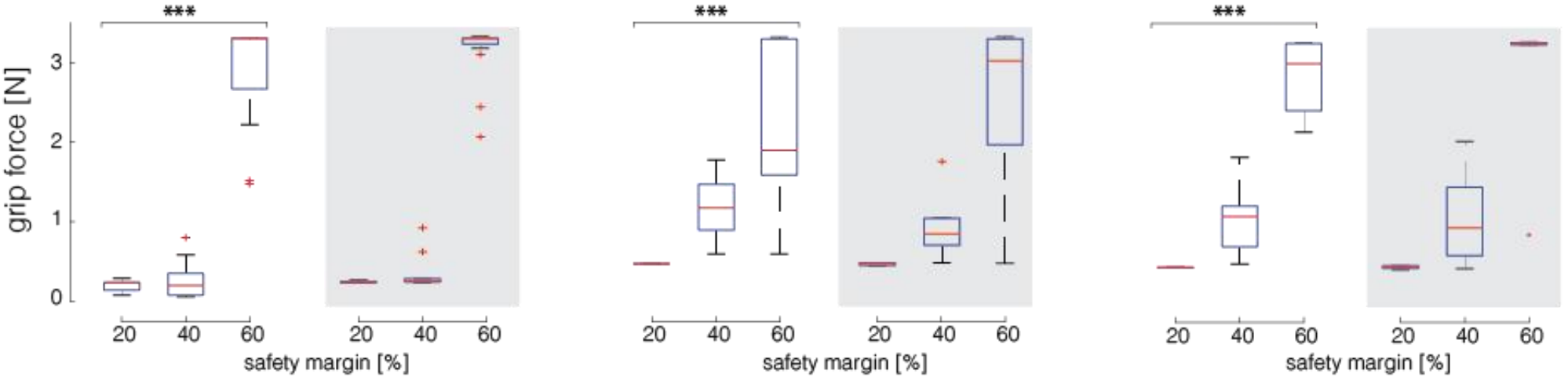


Reacting to external perturbations

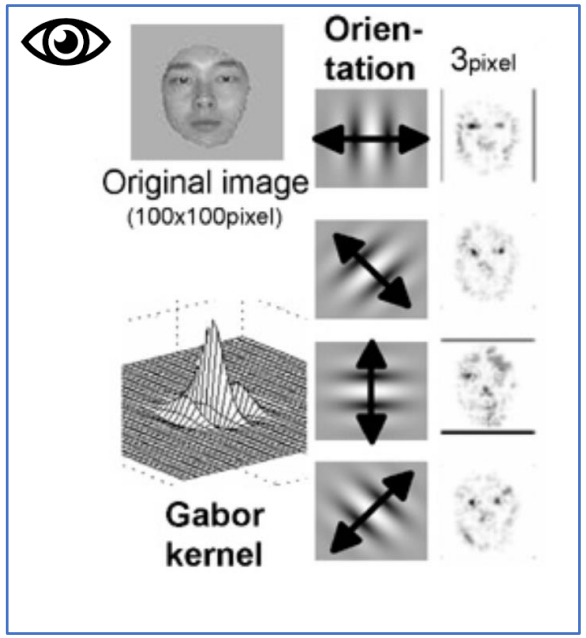
Grip force control

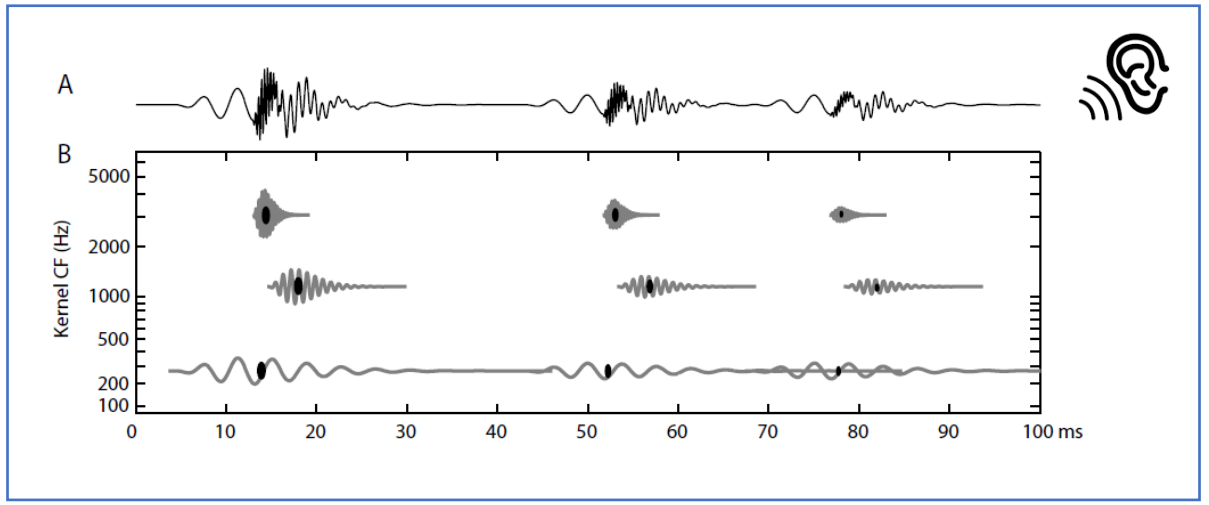




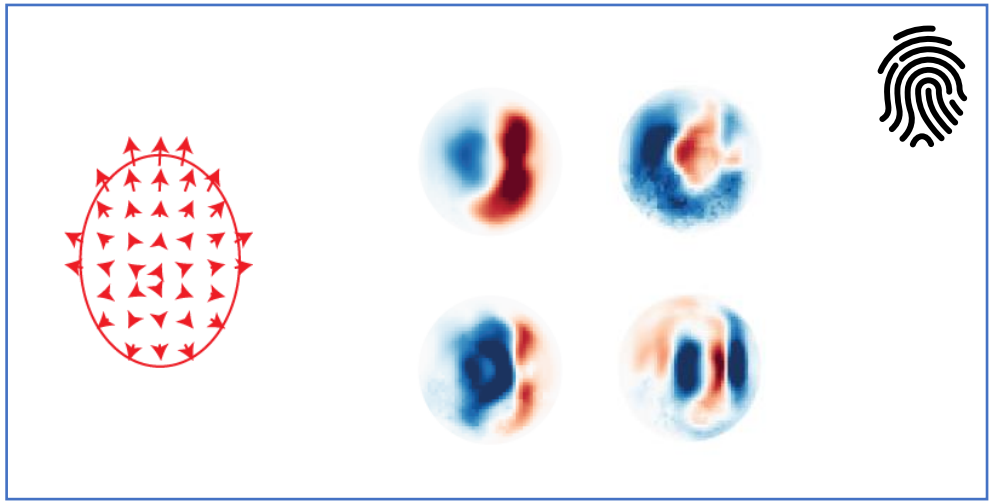


Conclusion





Bell et Sejnowski, 1997
Lewicki, 2002



- Minute lateral skin strains inform on:
  - **friction** on initial contact
  - **safety margin** during a lift
- We can use these patterns to predict frictional events and anticipate slippage in robotics

Thank you!

lwilleme@mit.edu

Hypotheses

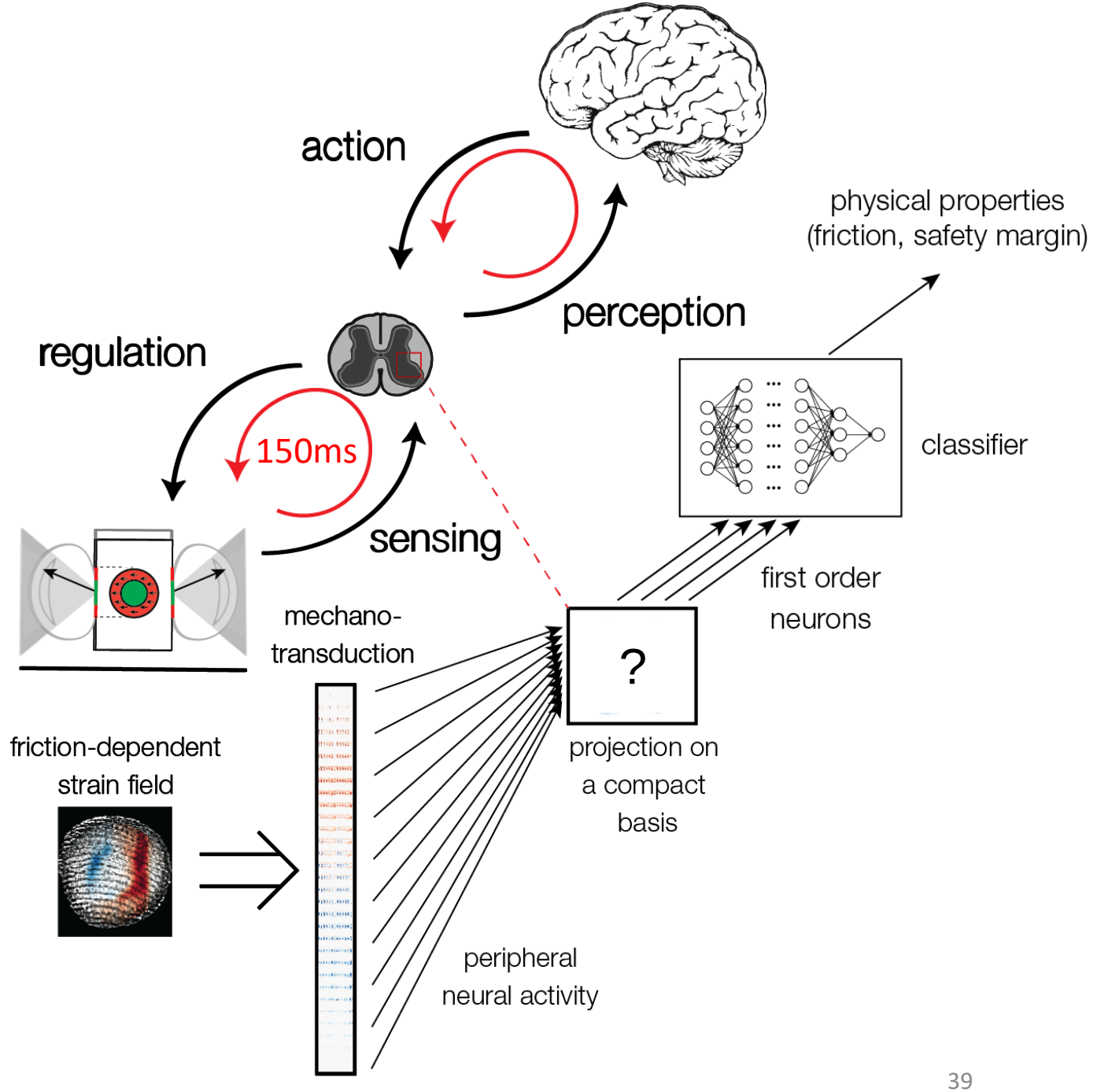
1) Regulation of grip force supraspinally mediated

Cole et al., 1988
Johansson et al., 2004

Efficient coding strategy to quickly infer physical properties

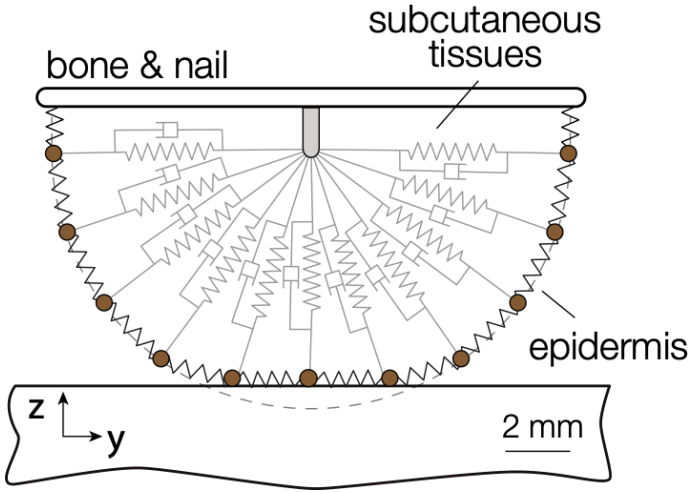
Barlow et al., 1961

2) Conscious perception for planning and control

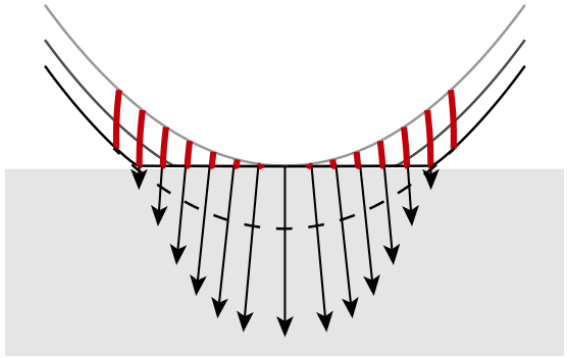


Where does the lateral strain comes from?

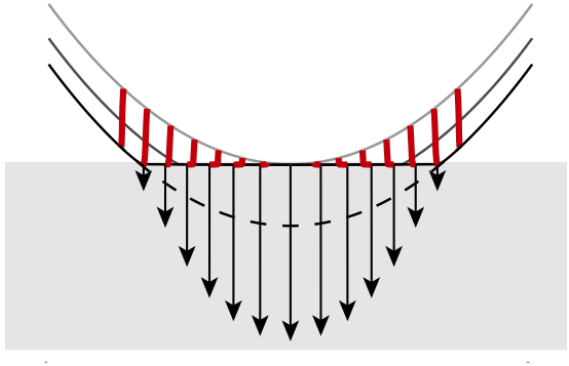
- Not predicted by Hertzian contact
- FDTD Simulation with friction



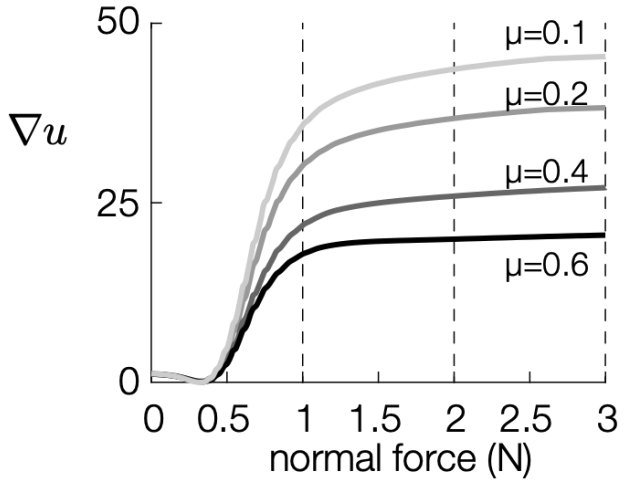
High friction



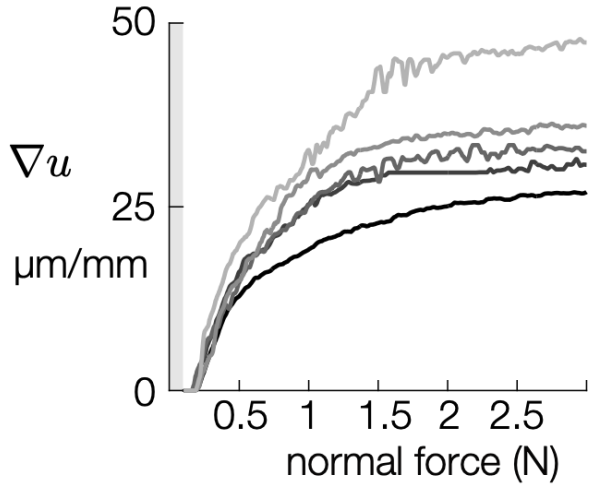
Low friction



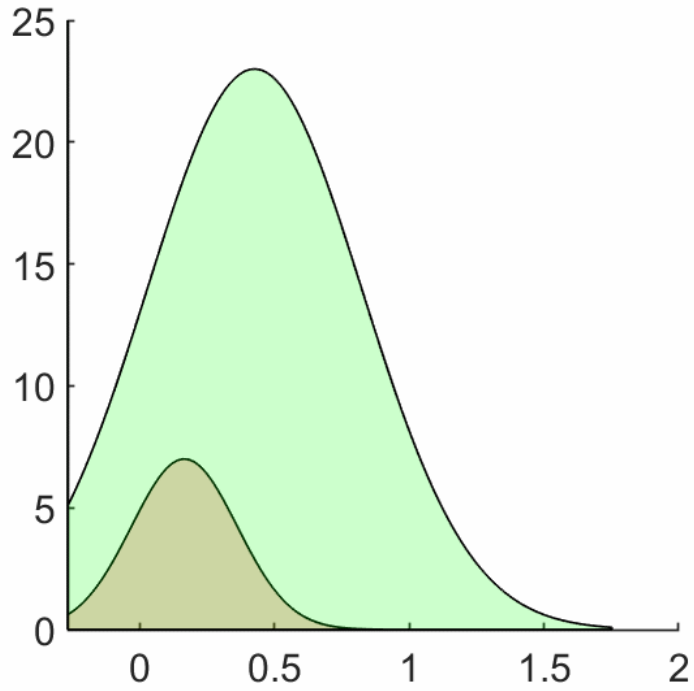
Simulated



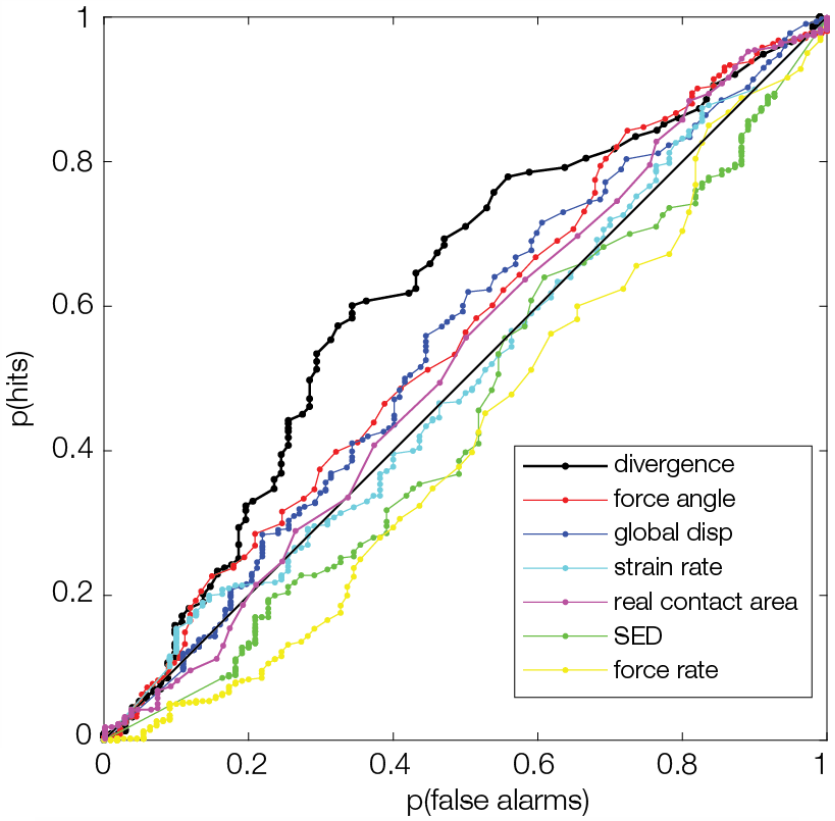
Measured



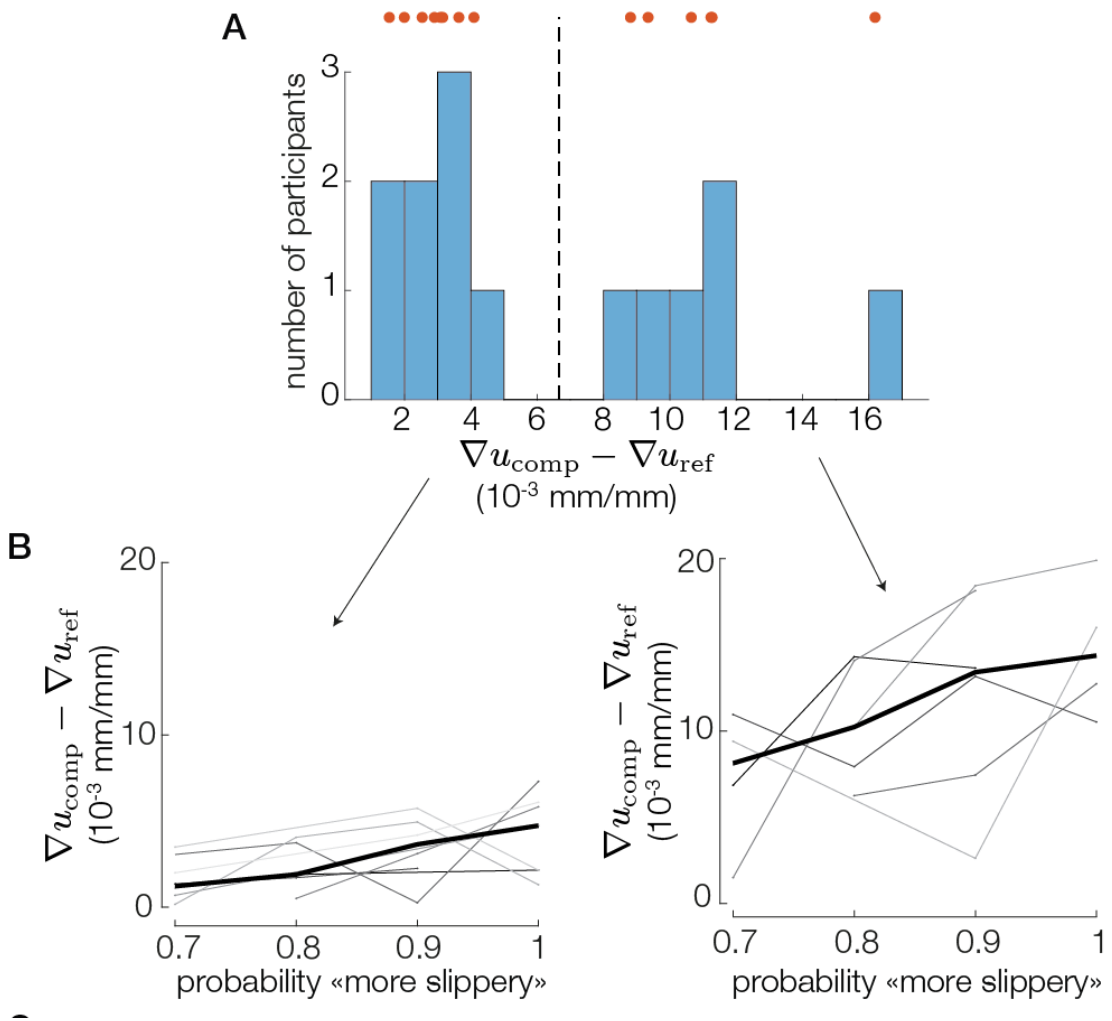
Skin deformation and friction perception

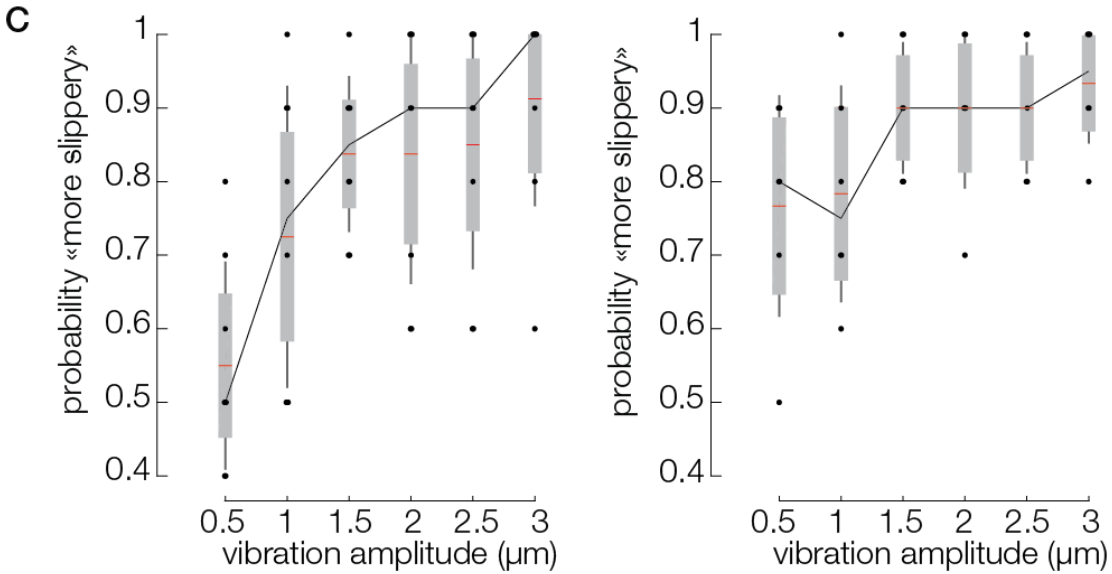


divergence difference between reference and comparison

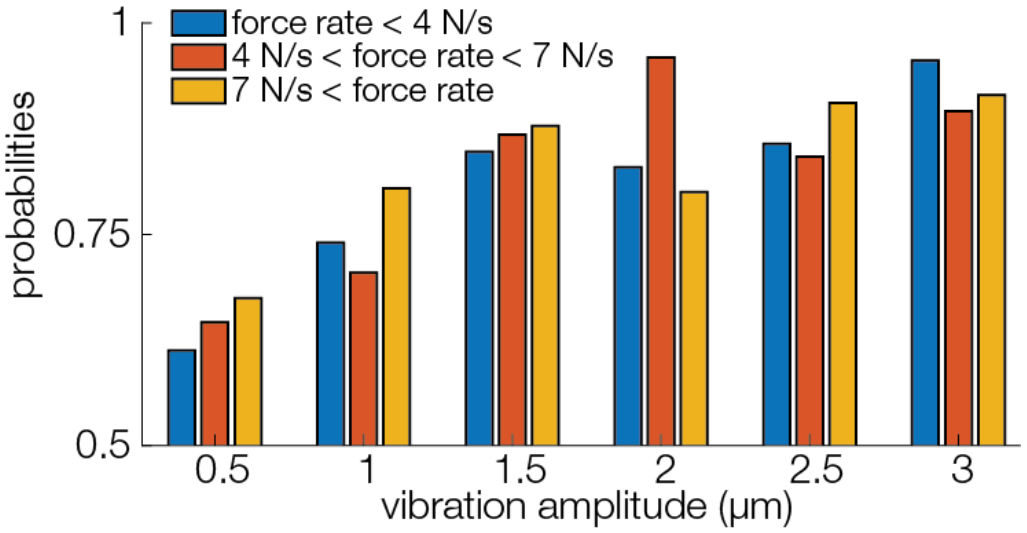


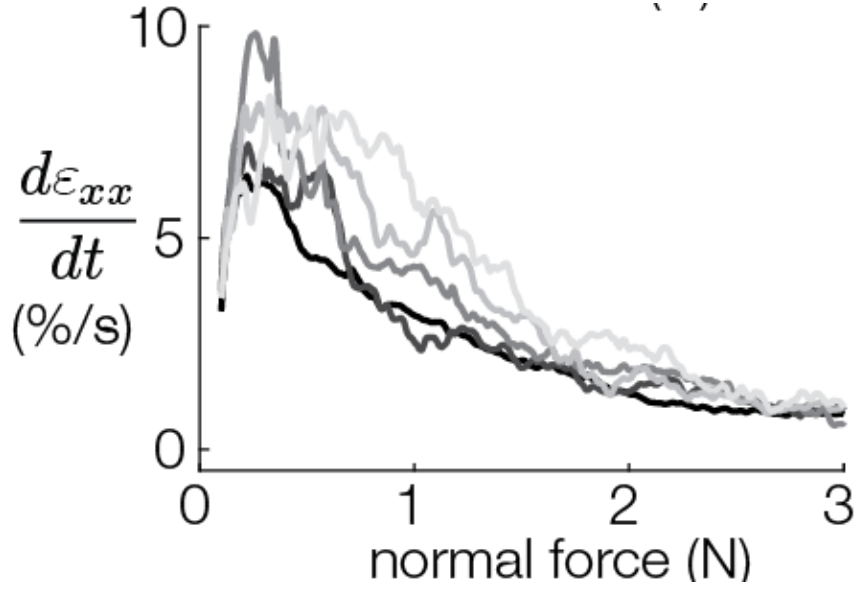
Individual performance



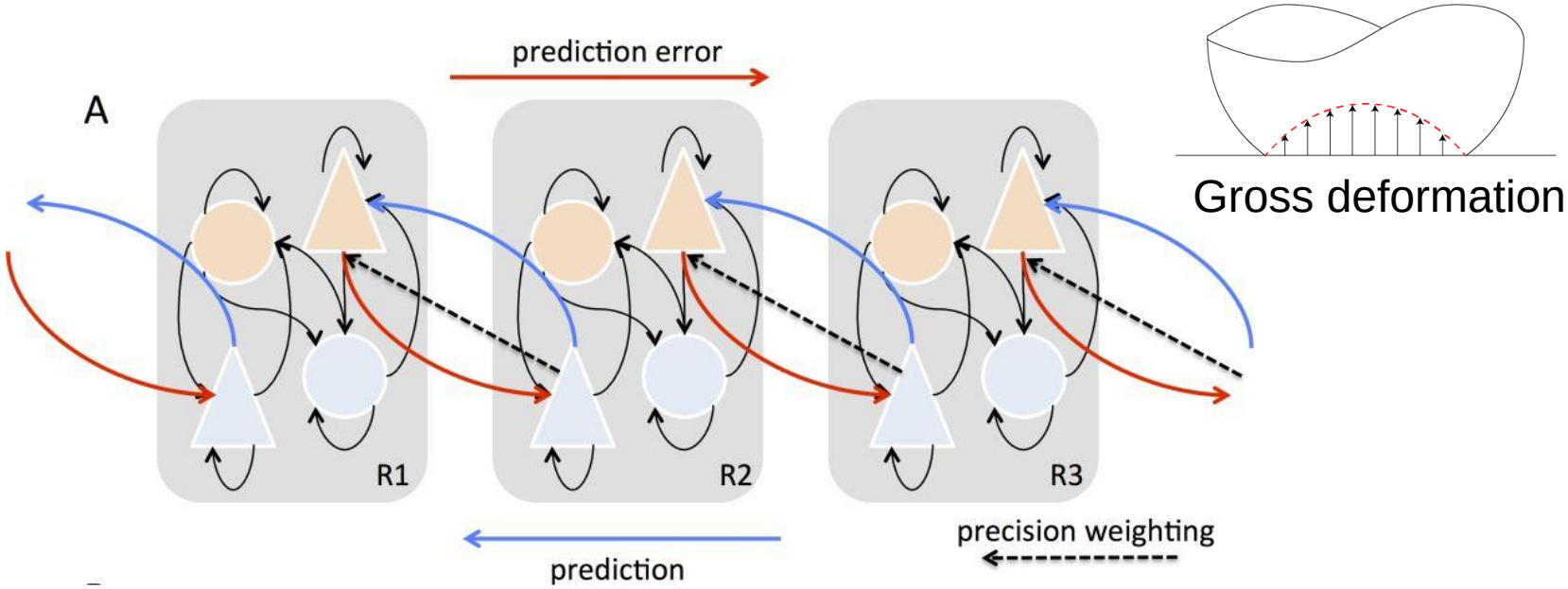


Strain rate


force rate < 4 N/s
4 N/s < force rate < 7 N/s
7 N/s < force rate
probabilities
1
0.75
0.5
0.5
1
1.5
2
2.5
3
vibration amplitude (μm)

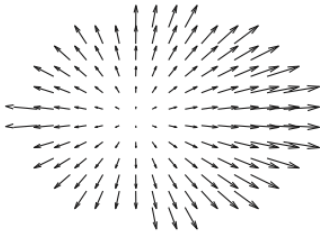

$\frac{d\varepsilon_{xx}}{dt}$
(%/s)
10
5
0
0
1
2
3
normal force (N)

Sensation is a form of best guessing

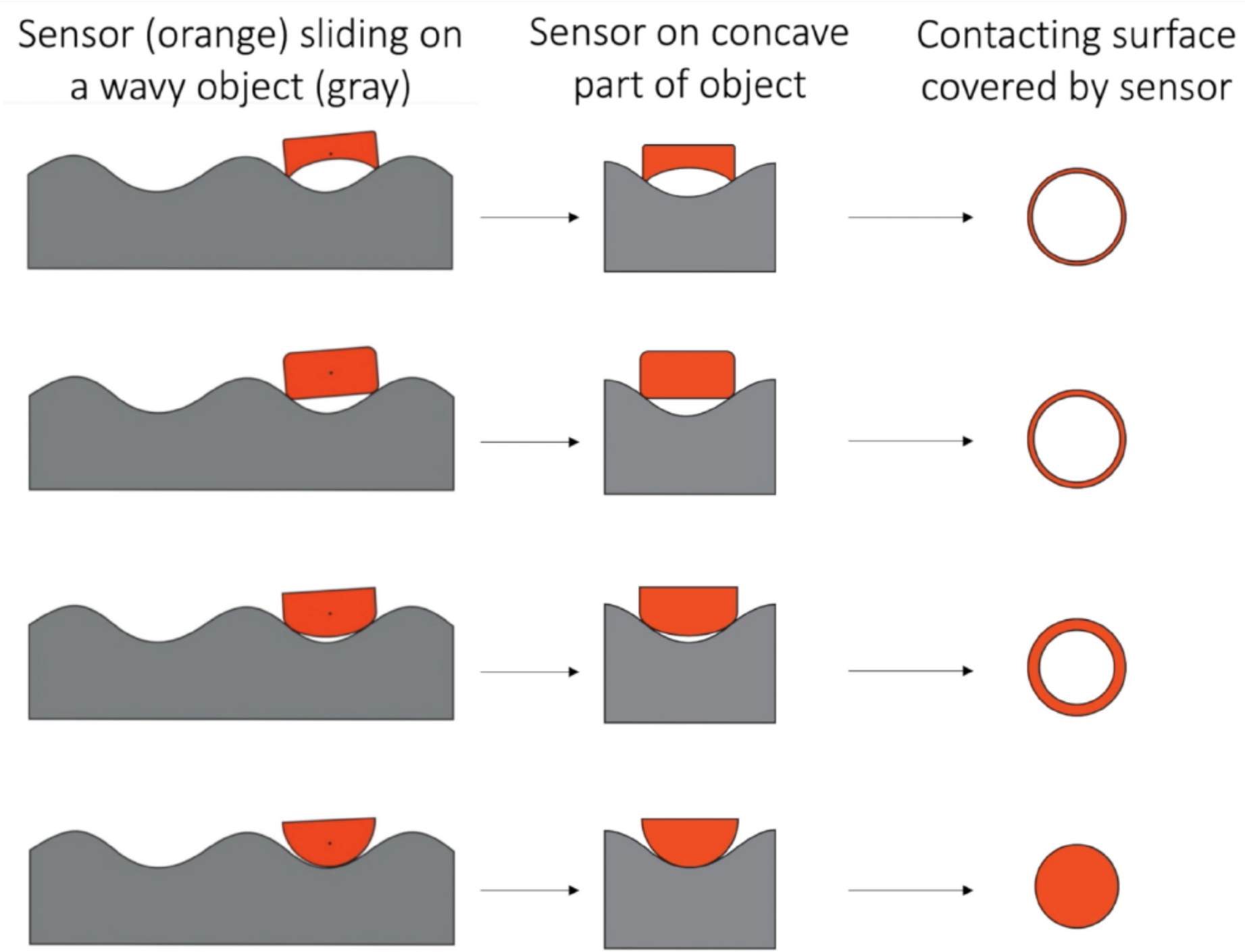


Gross deformation

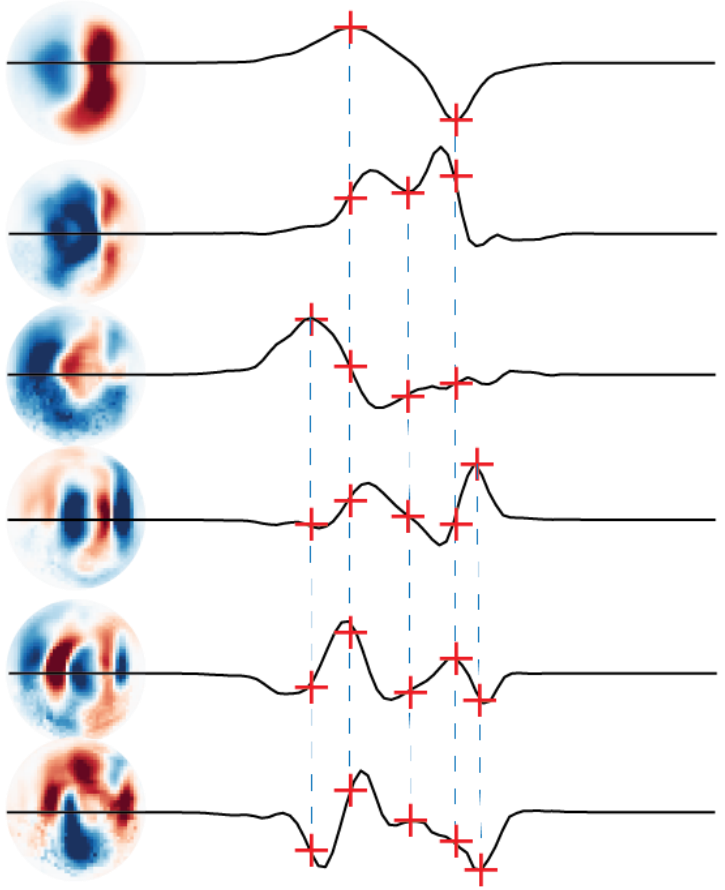
Diverging deformation



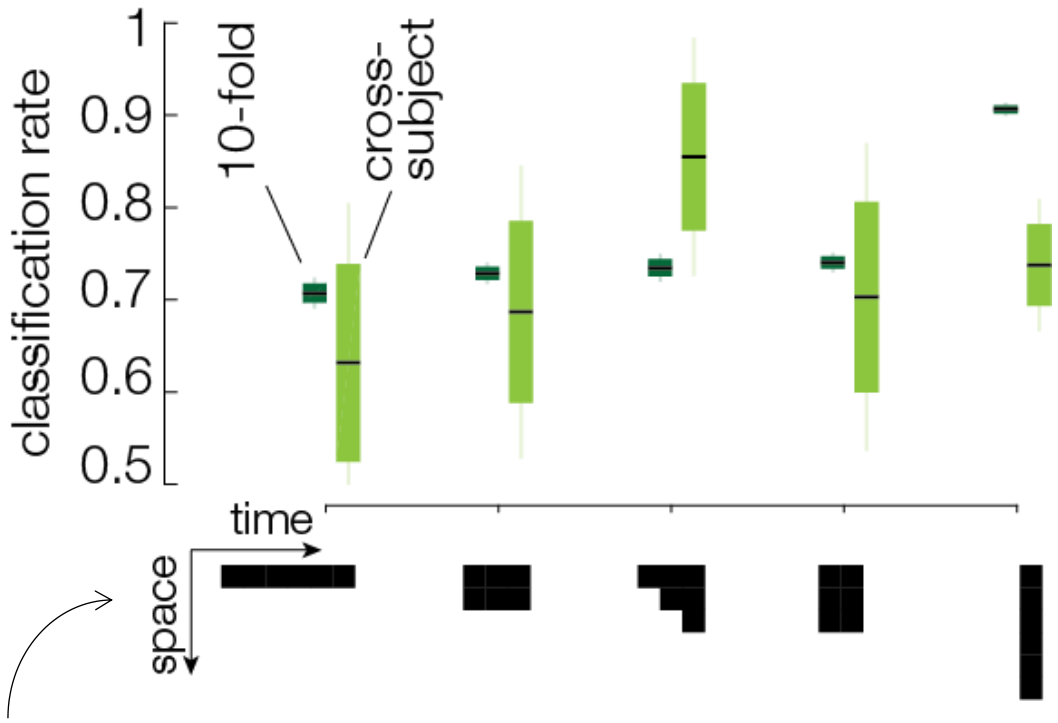
Seth et al., 2013


Sensor (orange) sliding on a wavy object (gray)
Sensor on concave part of object
Contacting surface covered by sensor

Hypothesis on mechanoreceptors placement



Effect of adding priors



Number of bases used for the estimation

Future work:

Experiment in unpredictable conditions: same direction, same speed.

During a grasping task

Felix Roel