



# Human Tactile Mechanics and the Design of Haptic Interfaces

Vincent Hayward



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actronika

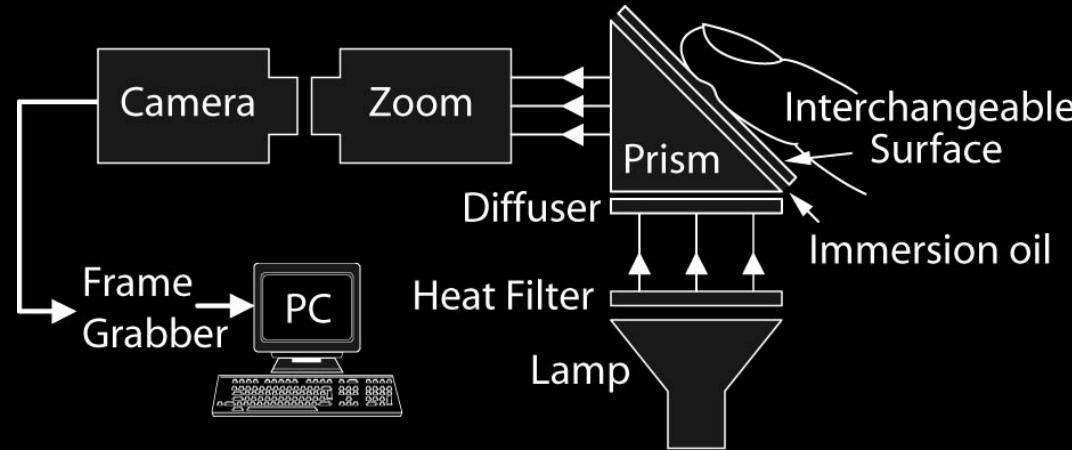


## 16th “la Dame à la licorne”

<http://www.laurefauvel.com/>

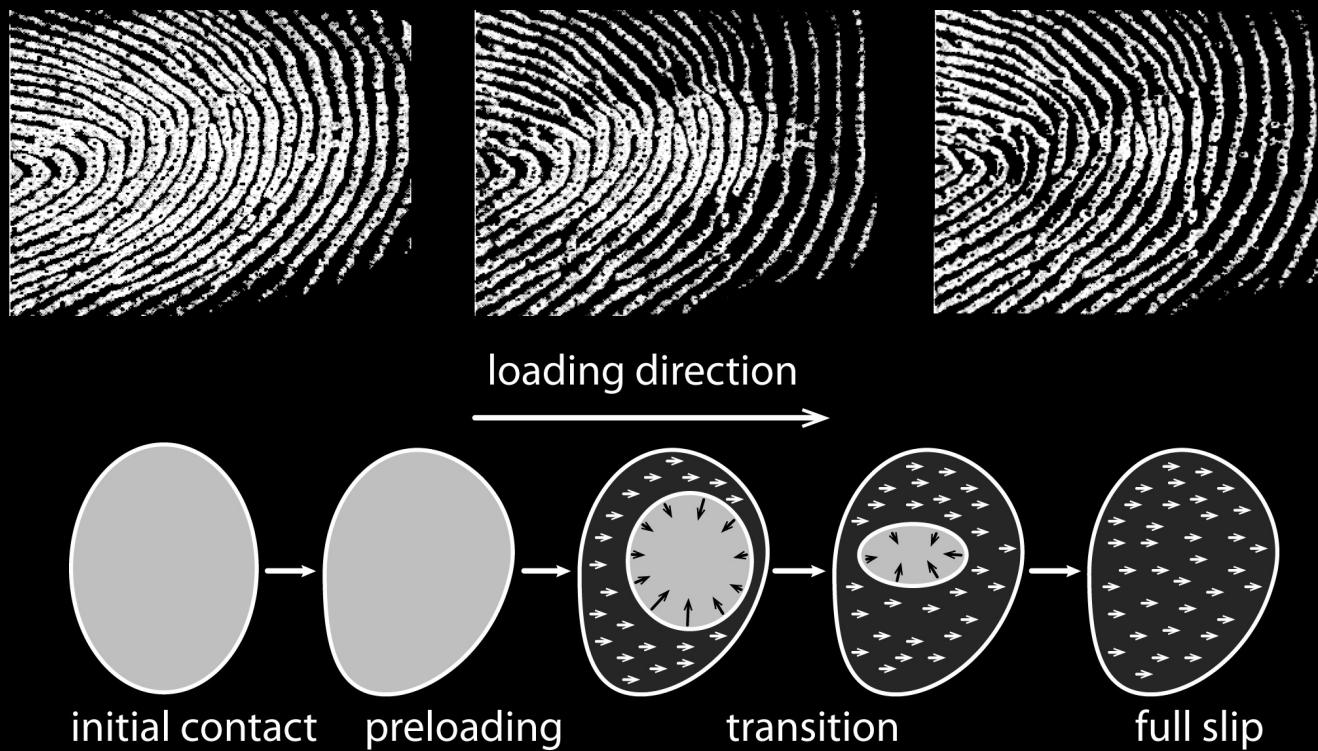


# Early Touch



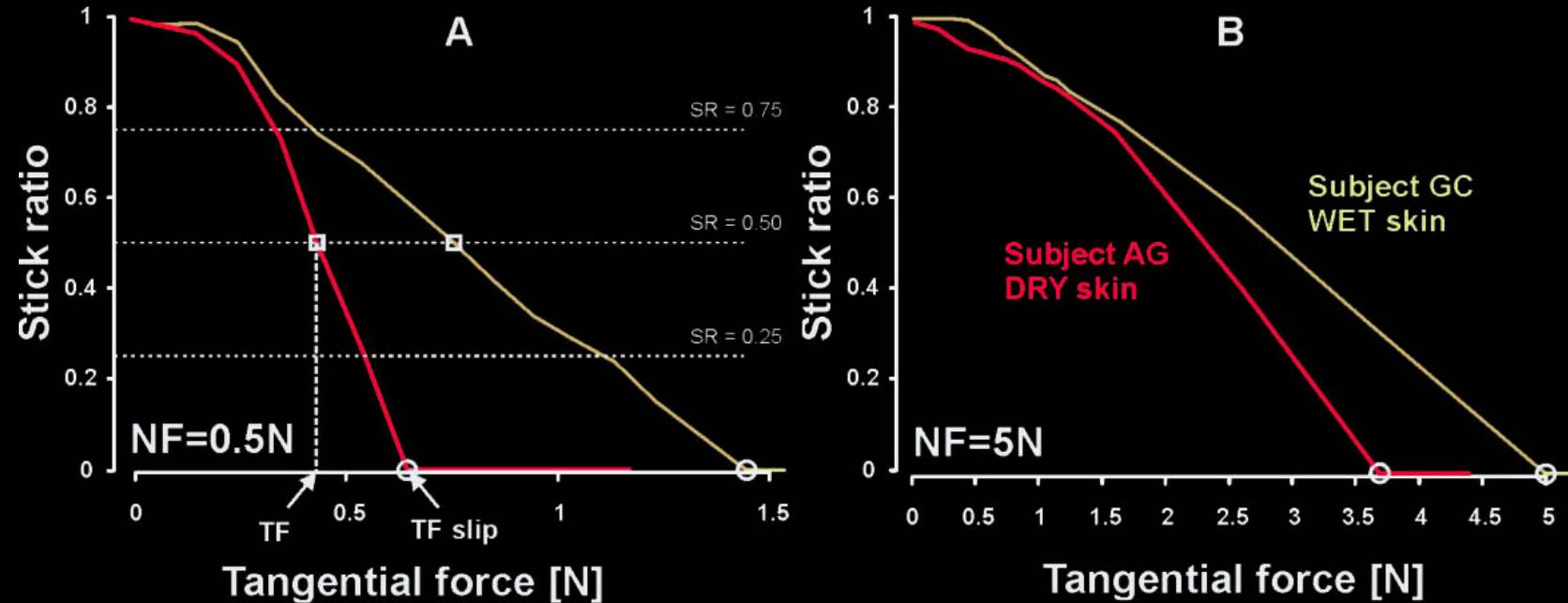
Levesque, V., Hayward, V. 2003. **Experimental Evidence of Lateral Skin Strain During Tactile Exploration.**  
Proc. *Eurohaptics 2003*. pp. 261–275

# Sliding Mechanics



André, T., Lévesque, V., Hayward, V., Lefèvre, P. and Thonnard, J-L. 2011.  
**Effect of skin hydration on the dynamics of fingertip gripping contact.**  
*Journal of the Royal Society Interface*, 8(64):1574–1583

# Sliding Mechanics



Delhaye, B., Lefevre, P., and Thonnard, J.-L. 2014.  
**Dynamics of fingertip contact during the onset of tangential slip.**  
*Journal of The Royal Society Interface*, 11.100:20140698.

Willemet, L., Kanzari, K., Monnoyer, J., Birznieks, I., & Wiertlewski, M. 2021.  
**Initial contact shapes the perception of friction.**  
*Proceedings of the National Academy of Sciences*, 118(49), e2109109118.

Delhaye, B., Jarocka, E., Barrea, A., Thonnard, J. L., Edin, B., & Lefevre, P. 2021.  
**High-resolution imaging of skin deformation shows that afferents from human fingertips signal slip onset.**  
*Elife*, 10:e64679.

Willemet, L., Huloux, L., & Wiertlewski, M. 2022.  
**Efficient tactile encoding of object slippage.**  
*Scientific Reports*, 12.1: 13192.

Monnoyer, J., Willemet, L., & Wiertlewski, M. 2023.  
**Rapid change of friction causes the illusion of touching a receding surface.**  
*Journal of the Royal Society Interface*, 20.199:20220718.

## Role of water



0.0 second

## Role of water



0.5 second

## Role of water



1.0 second

## Role of water



2.0 second

## Role of water



10 second

## Role of water



60 second

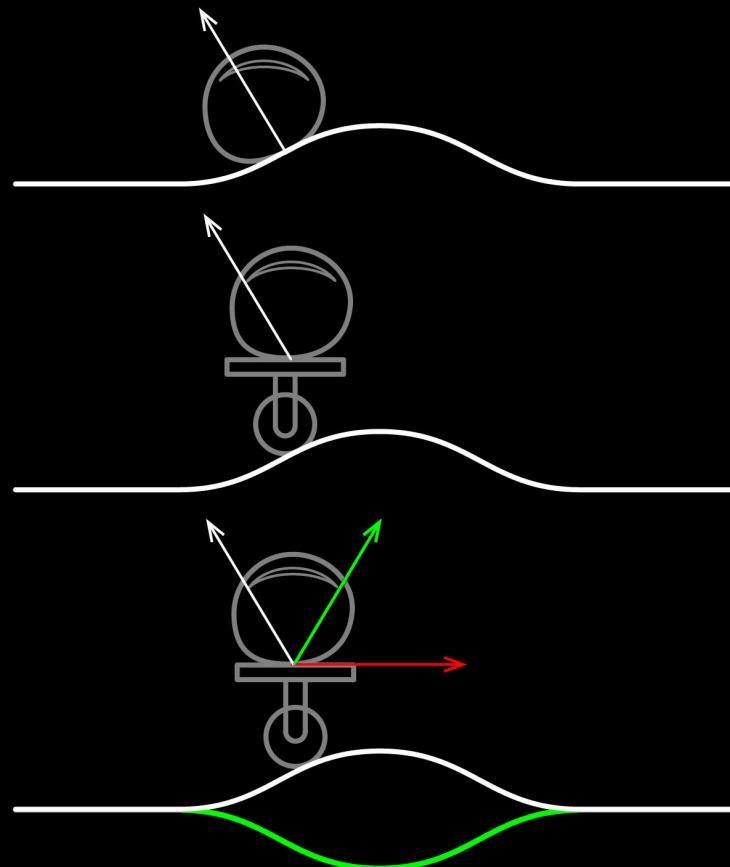
Dzidek, B., Bochereau, S., Johnson, S., Hayward, V., and Adams, M. 2017.

**Why pens have rubbery grips.**

*Proceedings of the National Academy of Science*, 114:10864–10869.

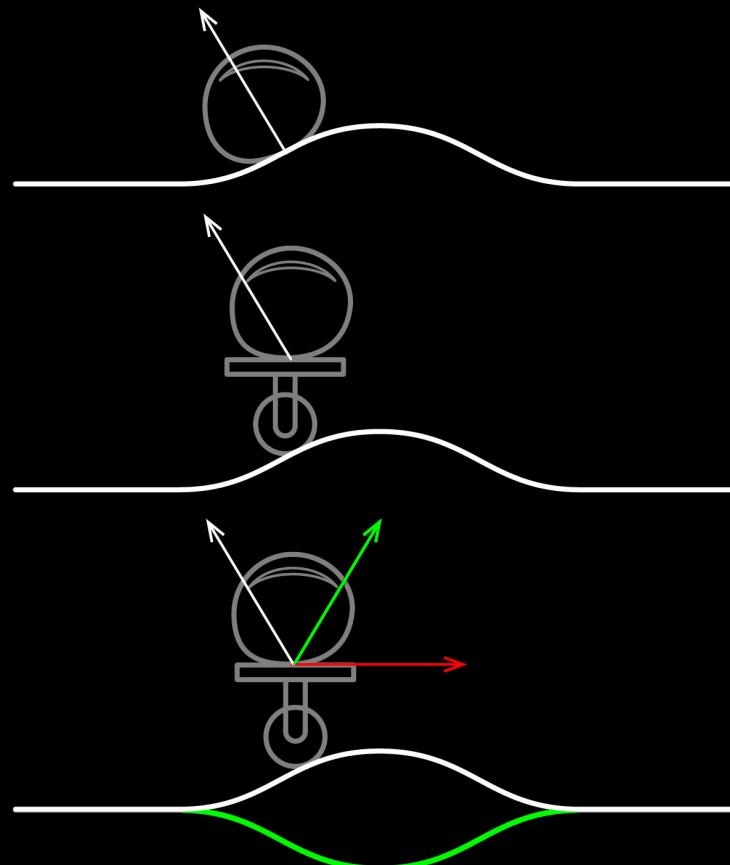
(See also **Sticky Fingers**, *Nature Physics*, News and Views, Nov 2017 and **Get a Grip** (*Nature Materials*, News and Views, Nov 2017)

# Overcoming Proprioception

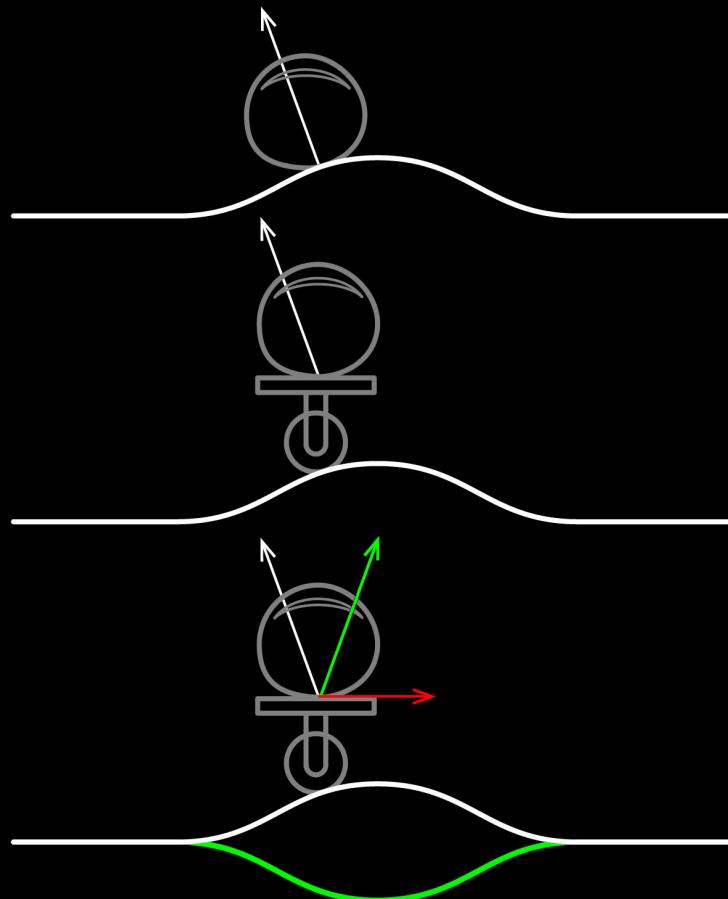


Robles De La Torre, G., Hayward, V. 2001.  
**Force Can Overcome Object Geometry In The Perception Of Shape Through Active Touch.**  
*Nature*, 412:445-448.

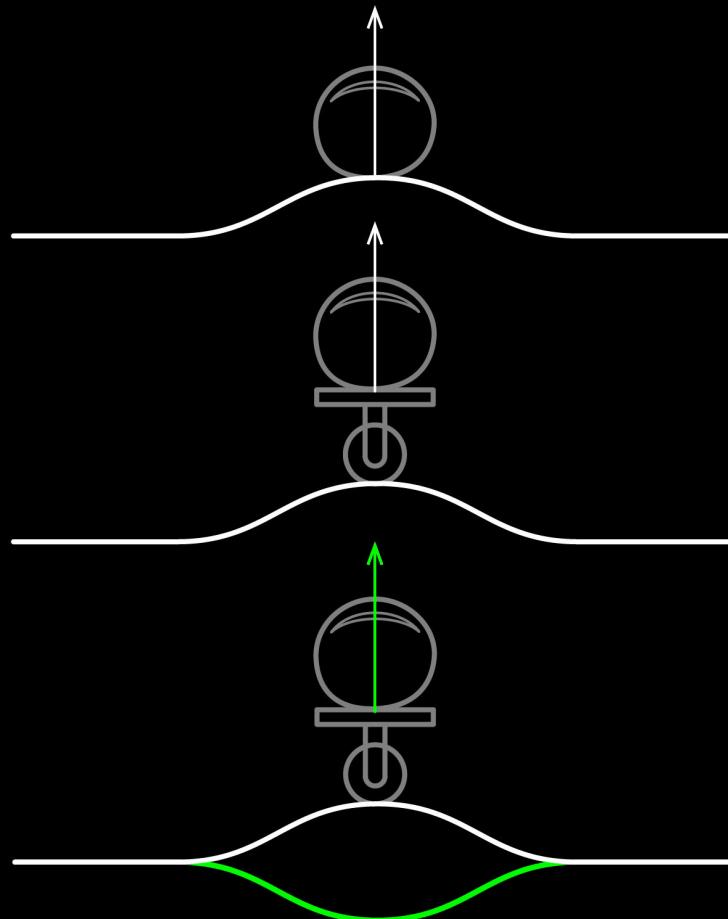
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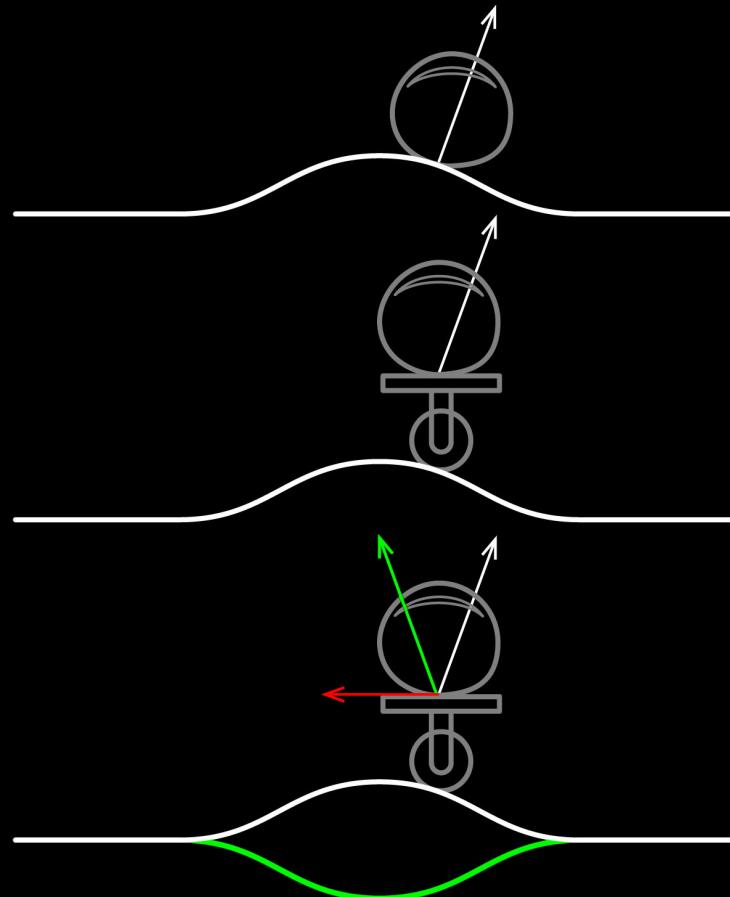
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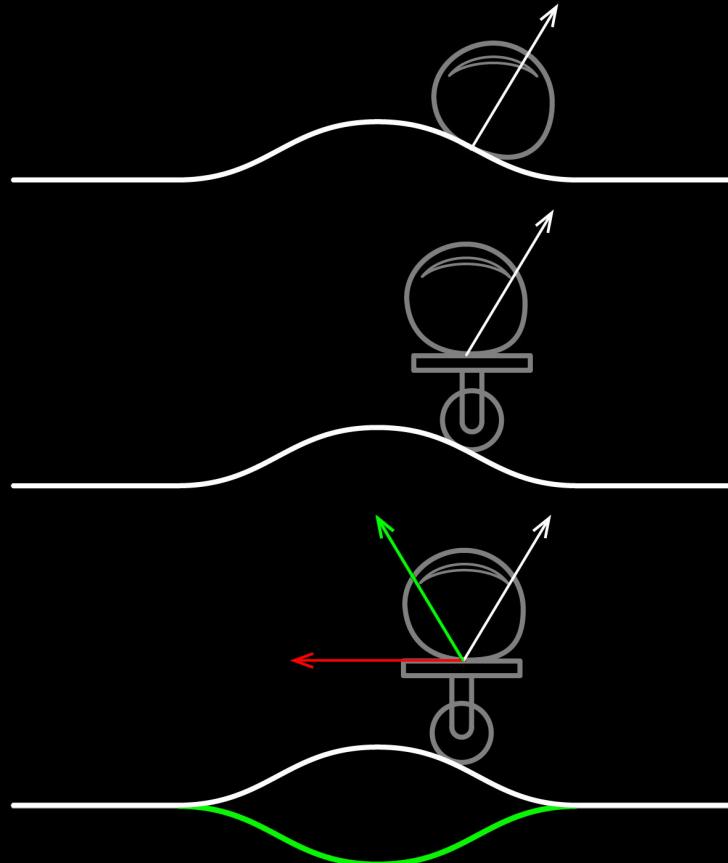
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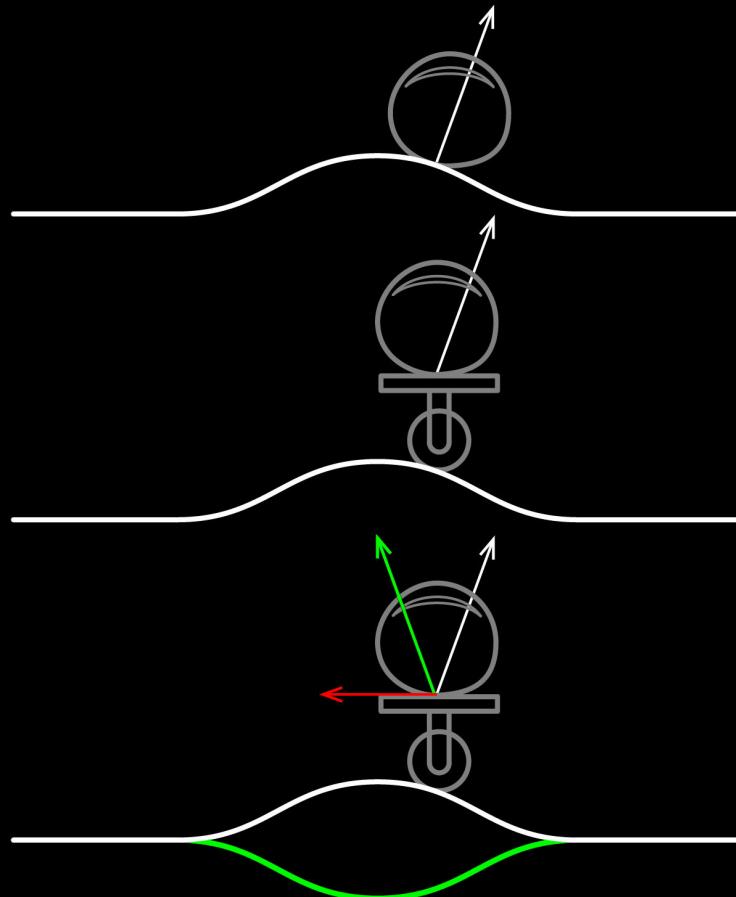
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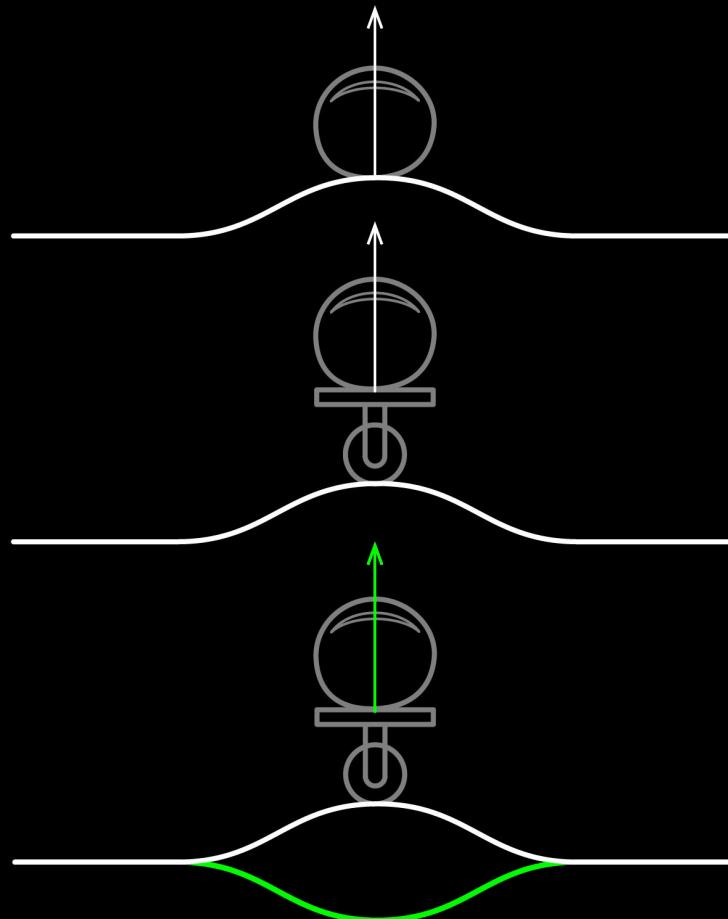
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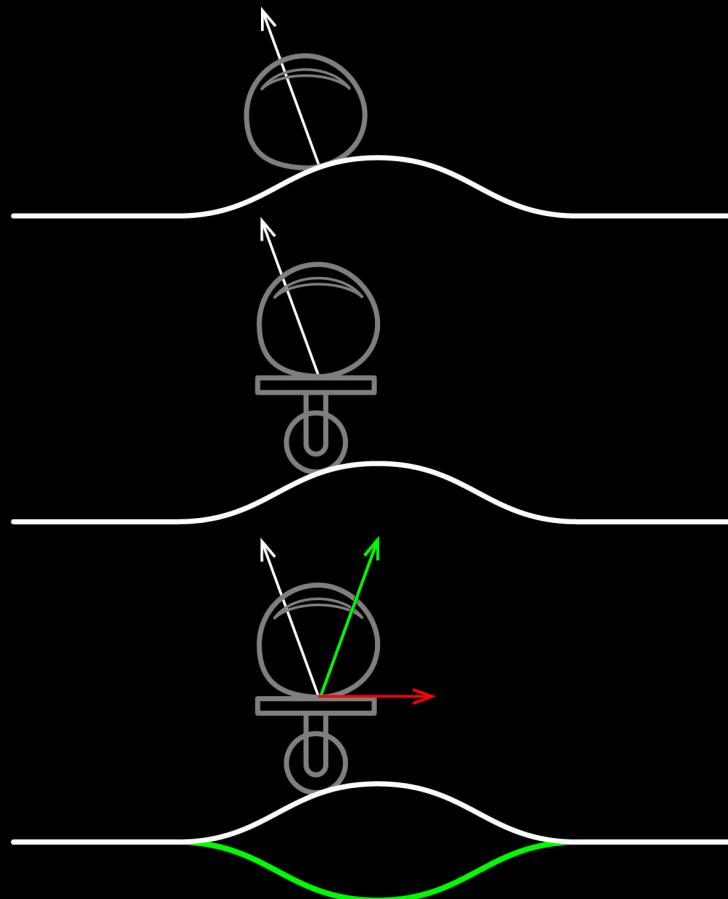
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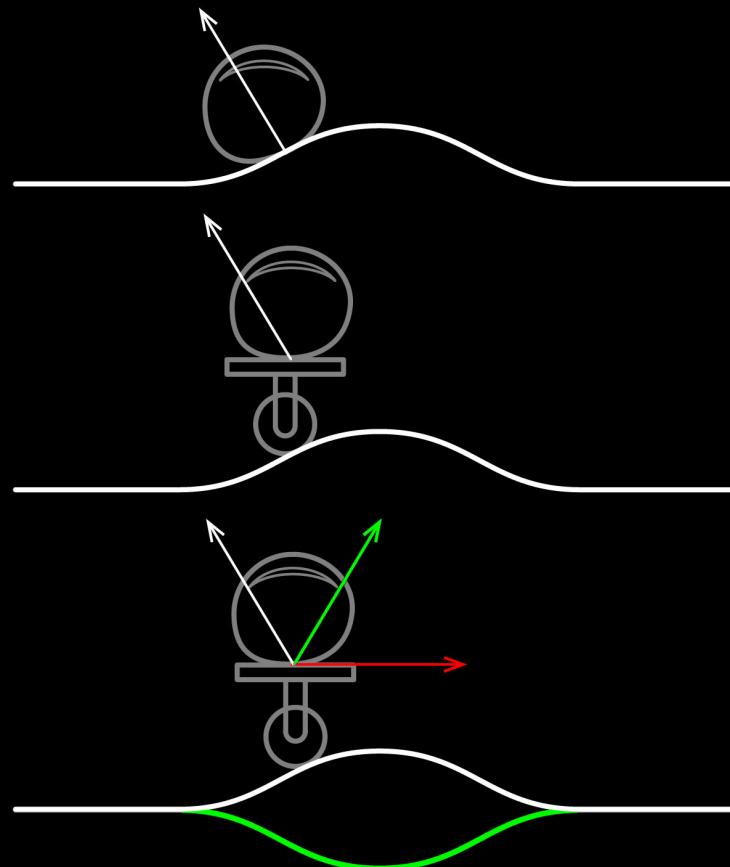
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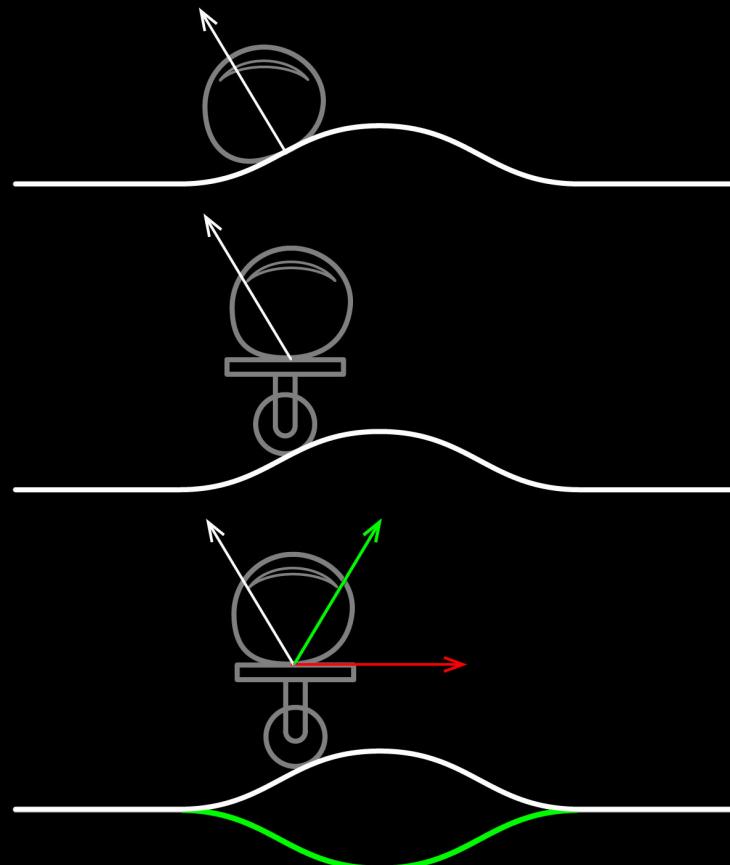
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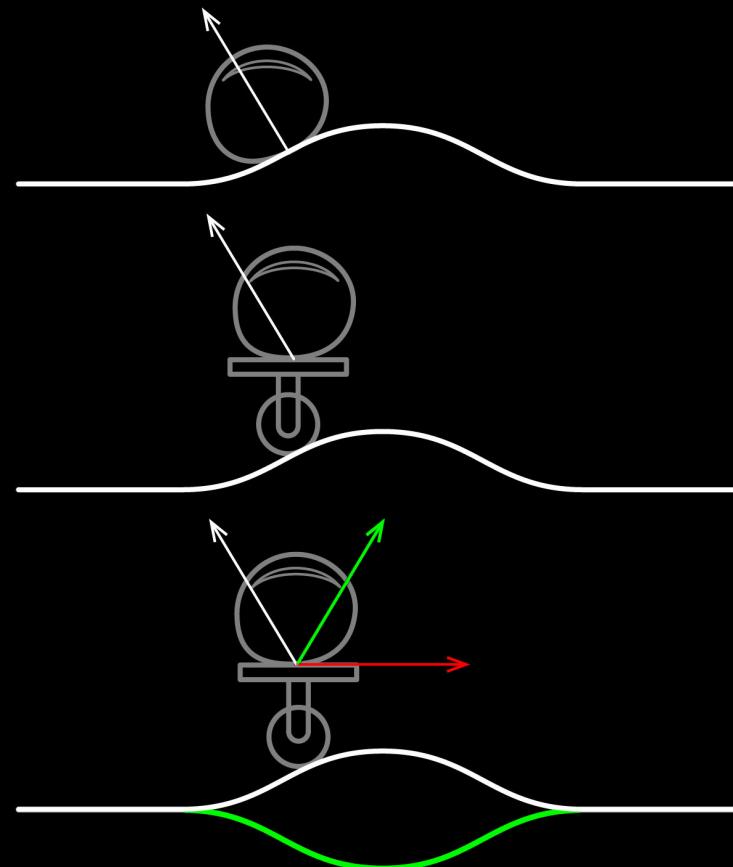
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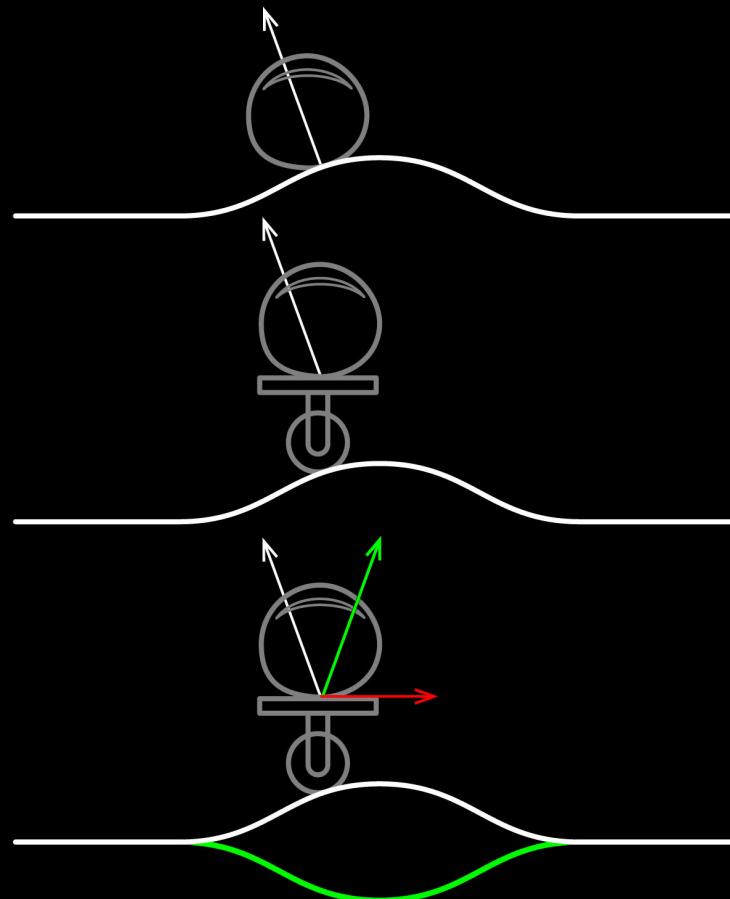
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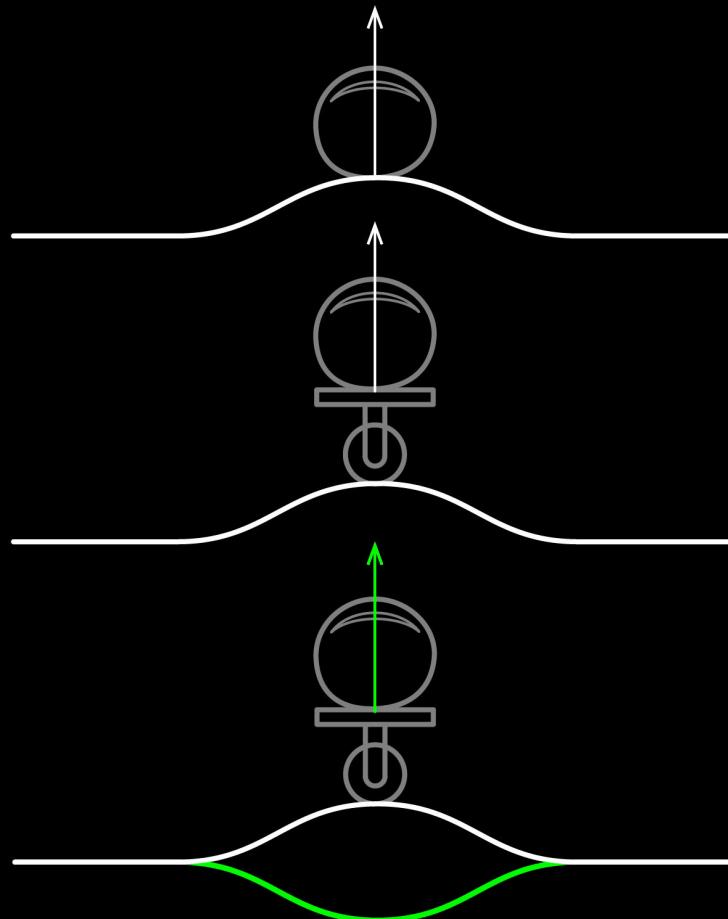
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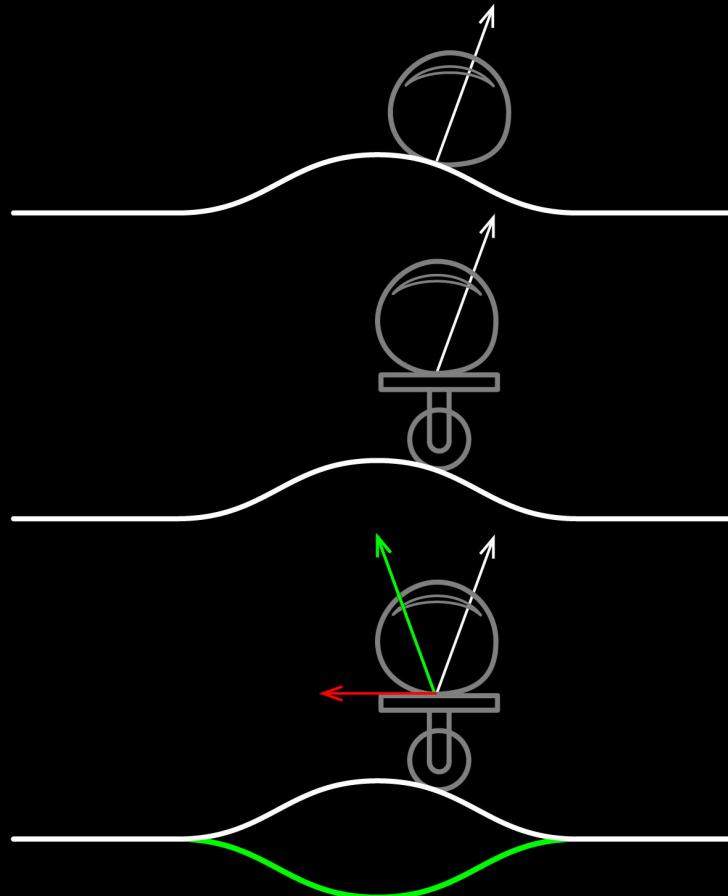
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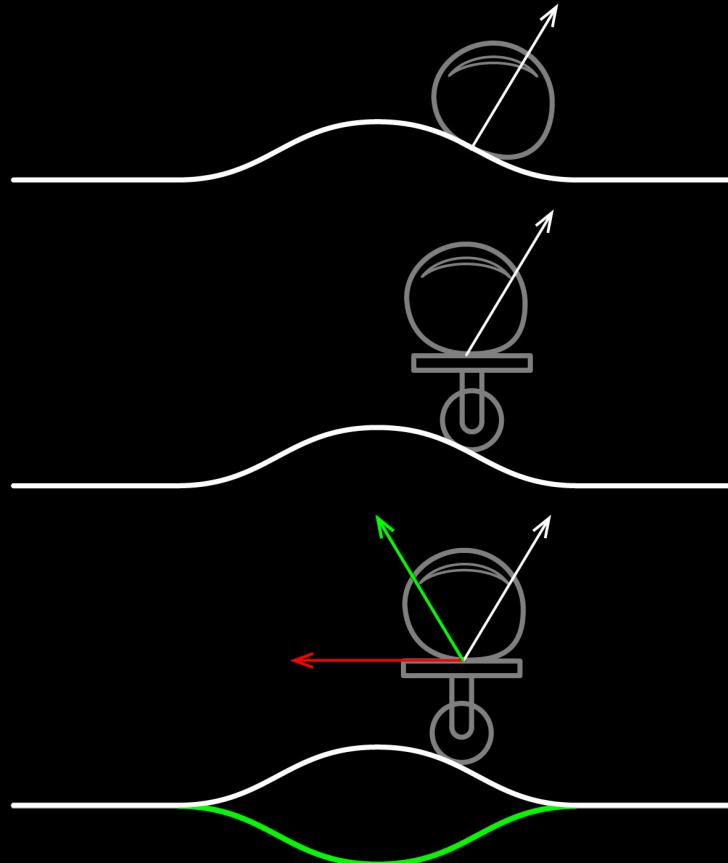
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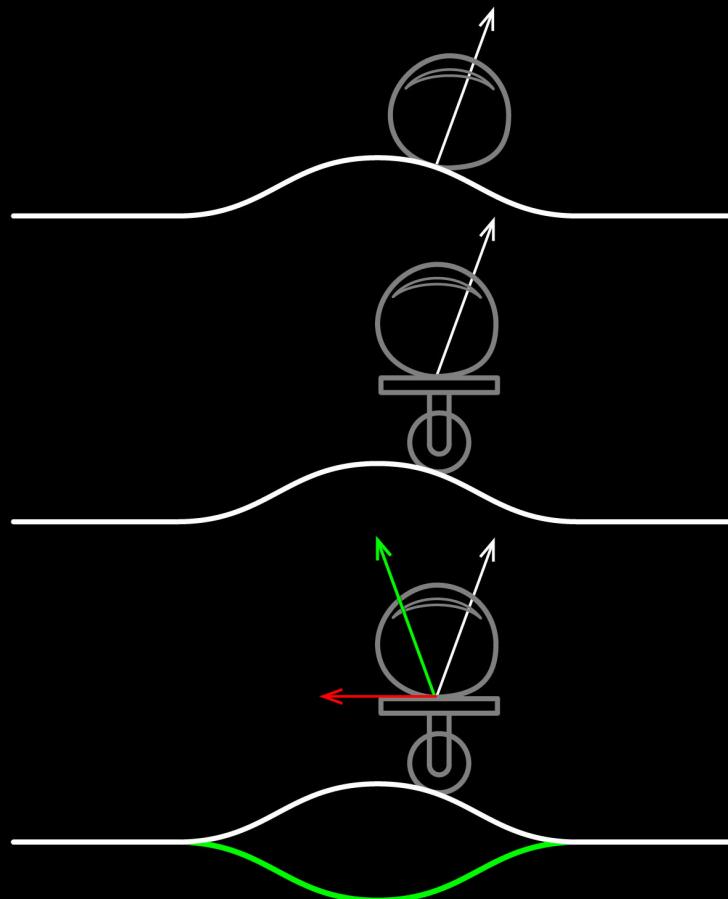
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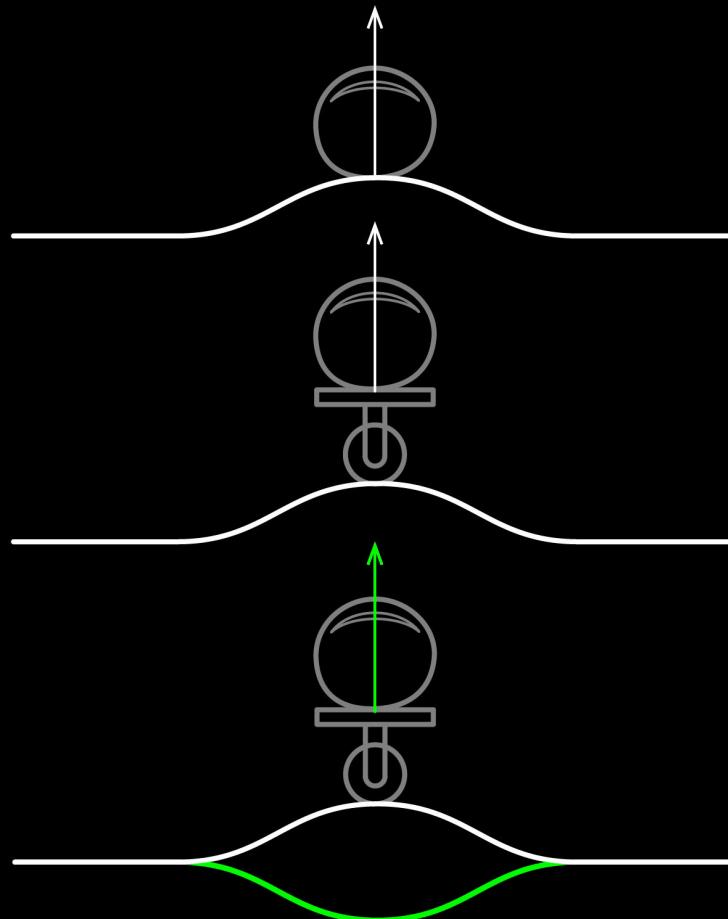
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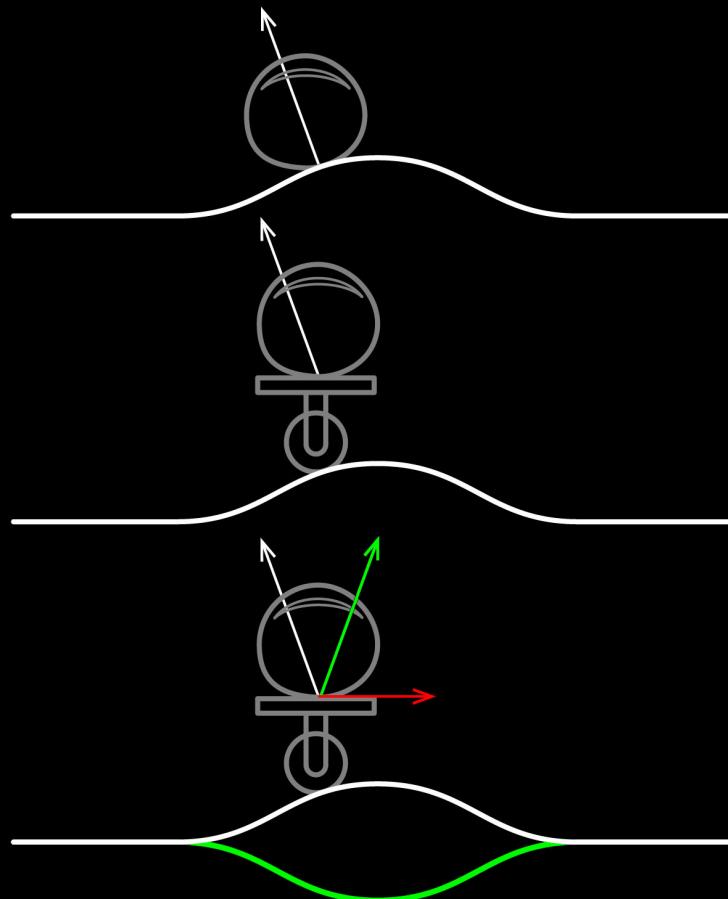
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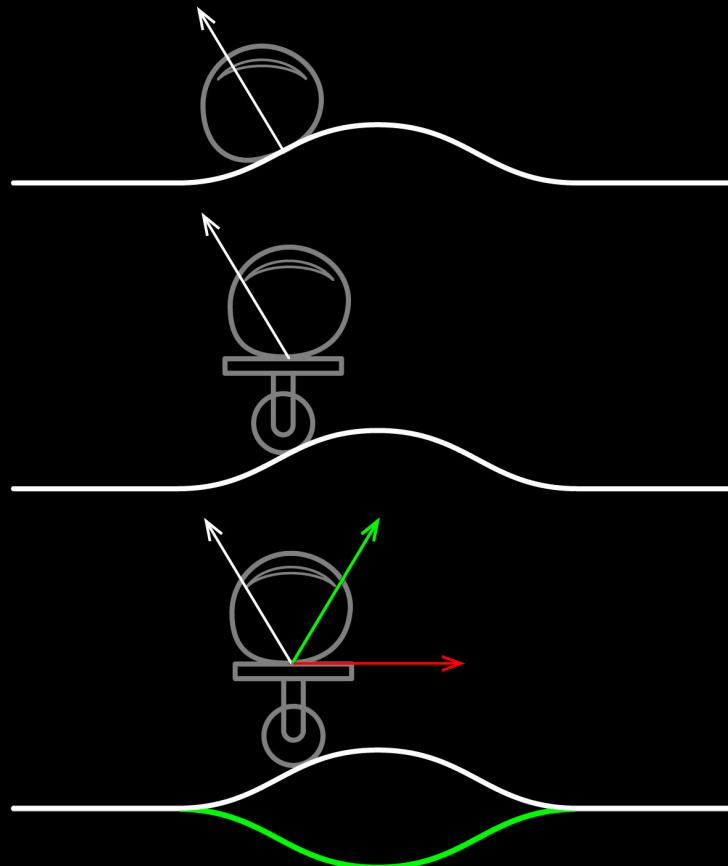
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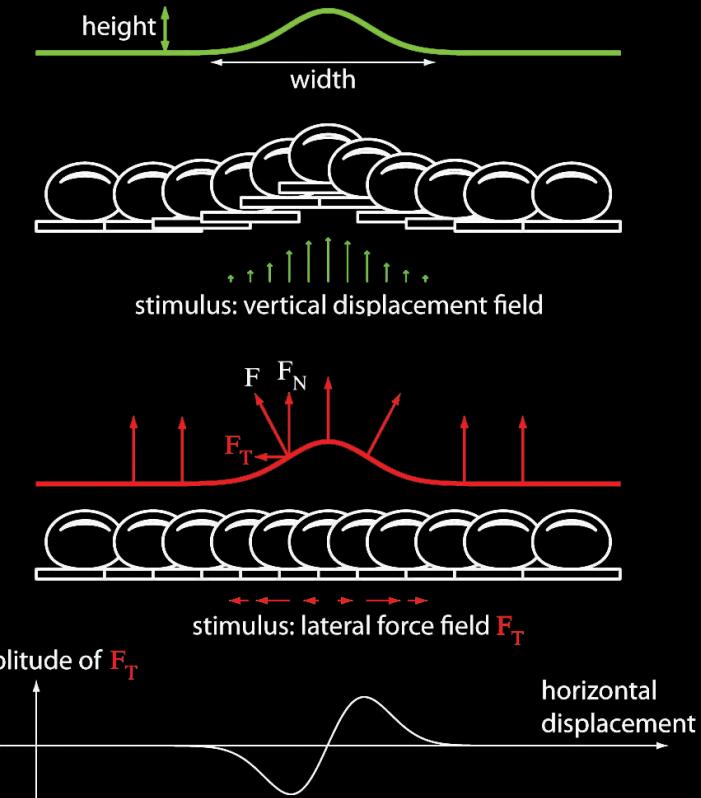
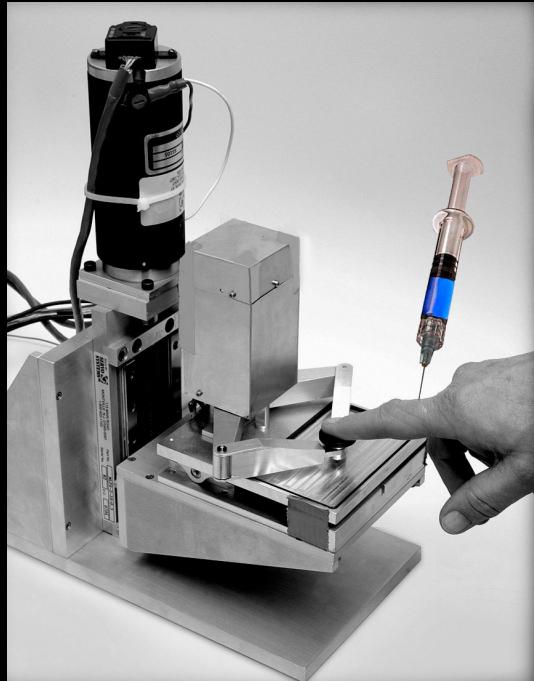
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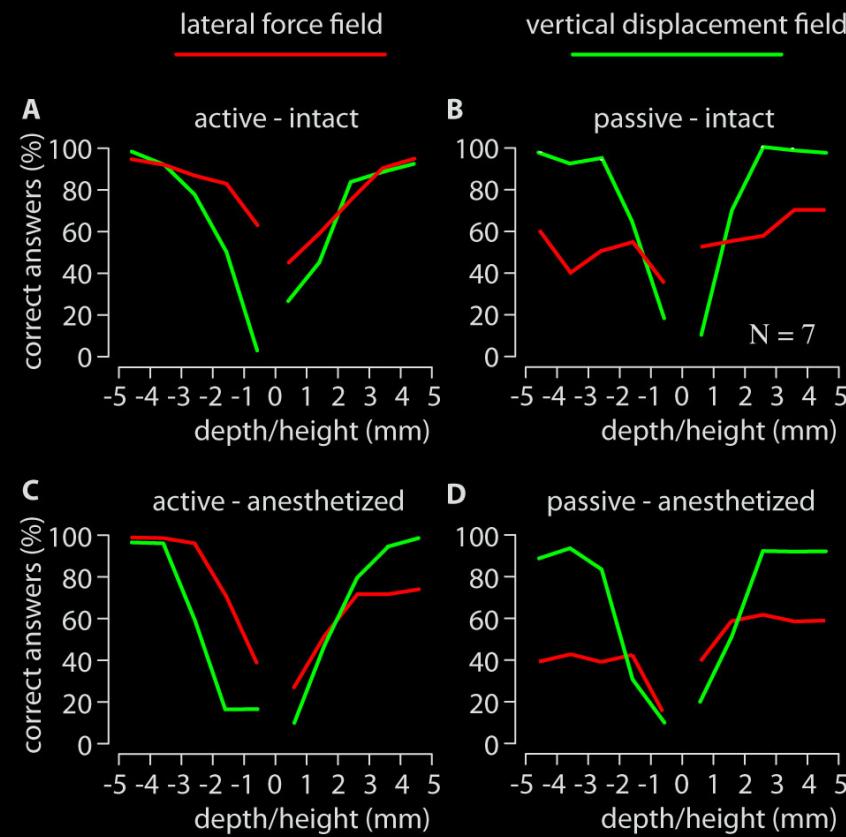


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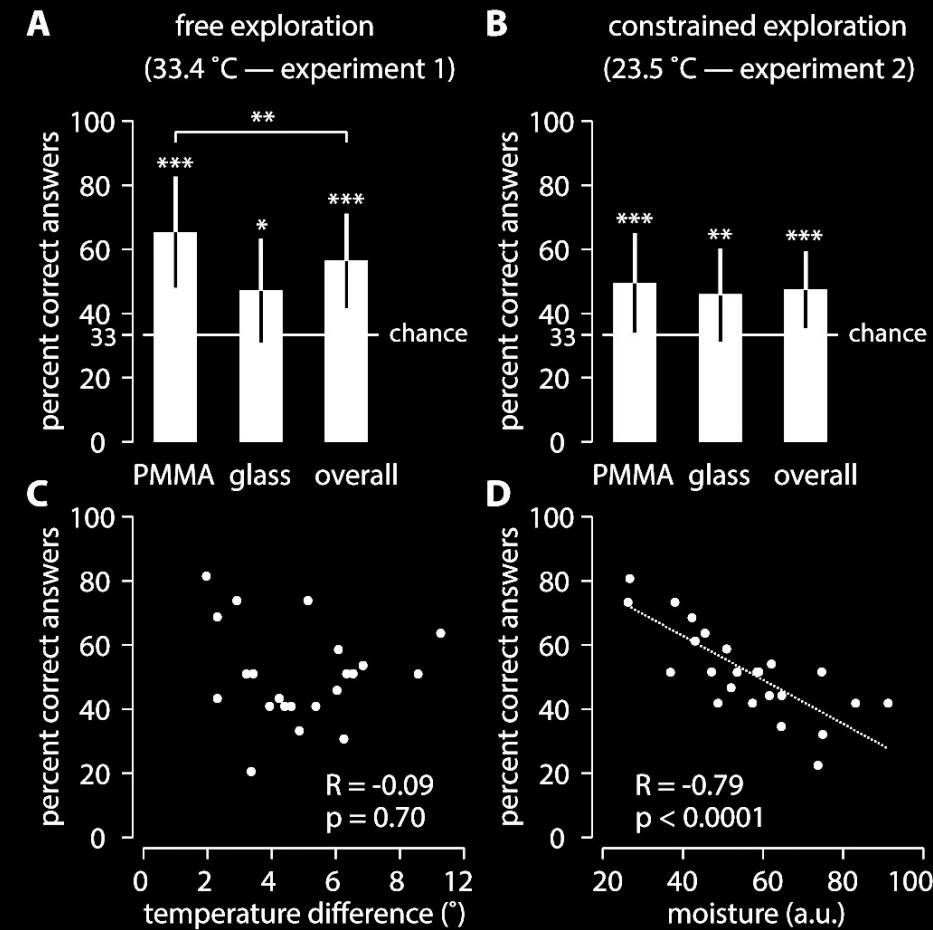


Smith, A. M., Chapman, C. E., Donati, F., Fortier-Poisson, P. and Hayward, V. 2009.  
**Perception Of Simulated Local Shapes Using Active And Passive Touch.**  
*Journal of Neurophysiology*, 102:3519–3529

# Overcoming Proprioception

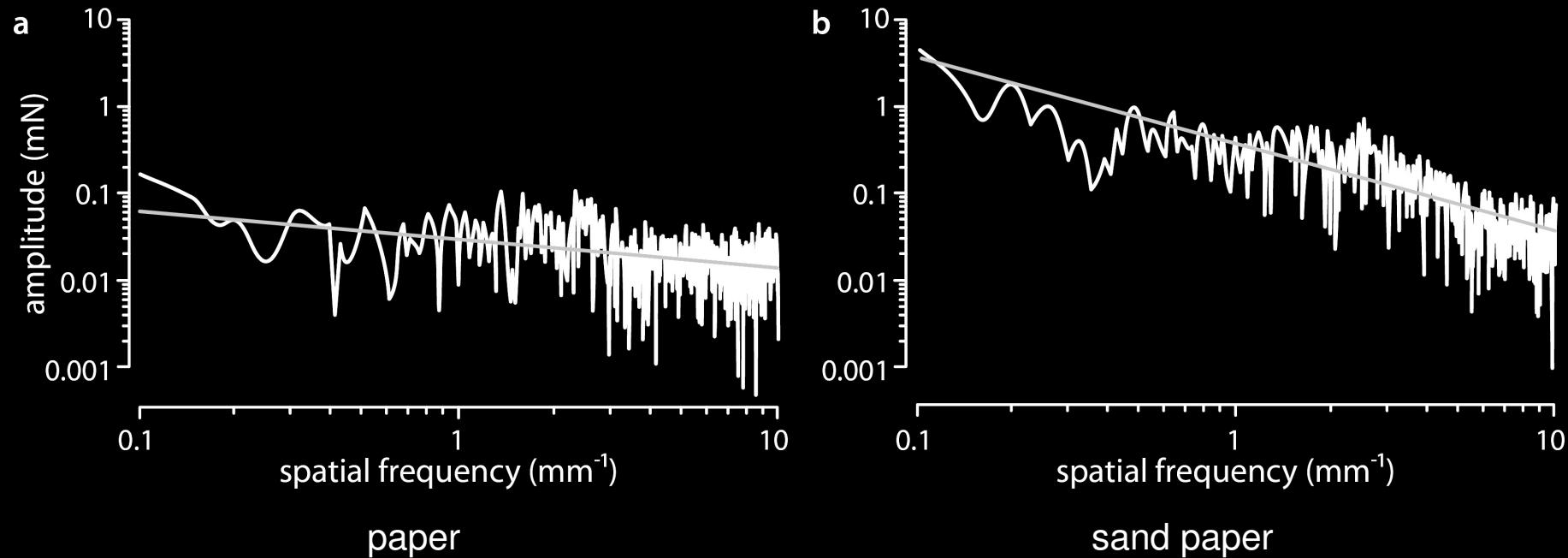


# Tactile Cognition: What



Gueorguiev, D., Bochereau, S., Mouraux, A., Hayward, V. and Thonnard, J-L. 2016.  
**Touch uses frictional cues to discriminate flat materials.**  
*Scientific Reports*, 6 :25553.

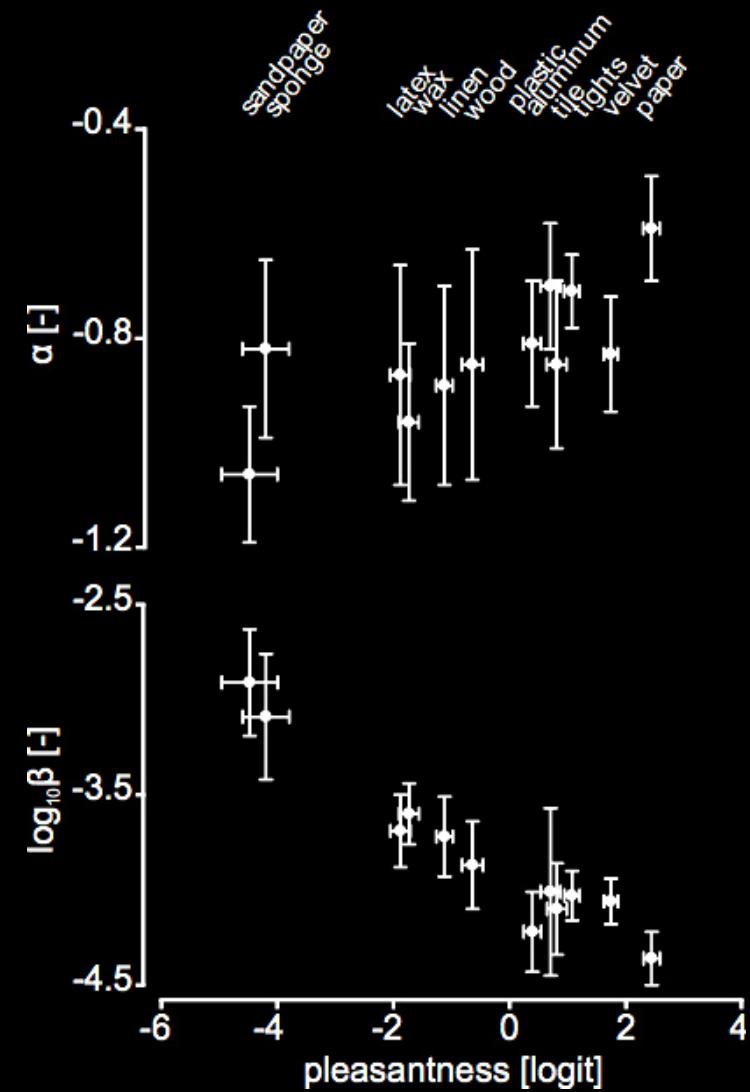
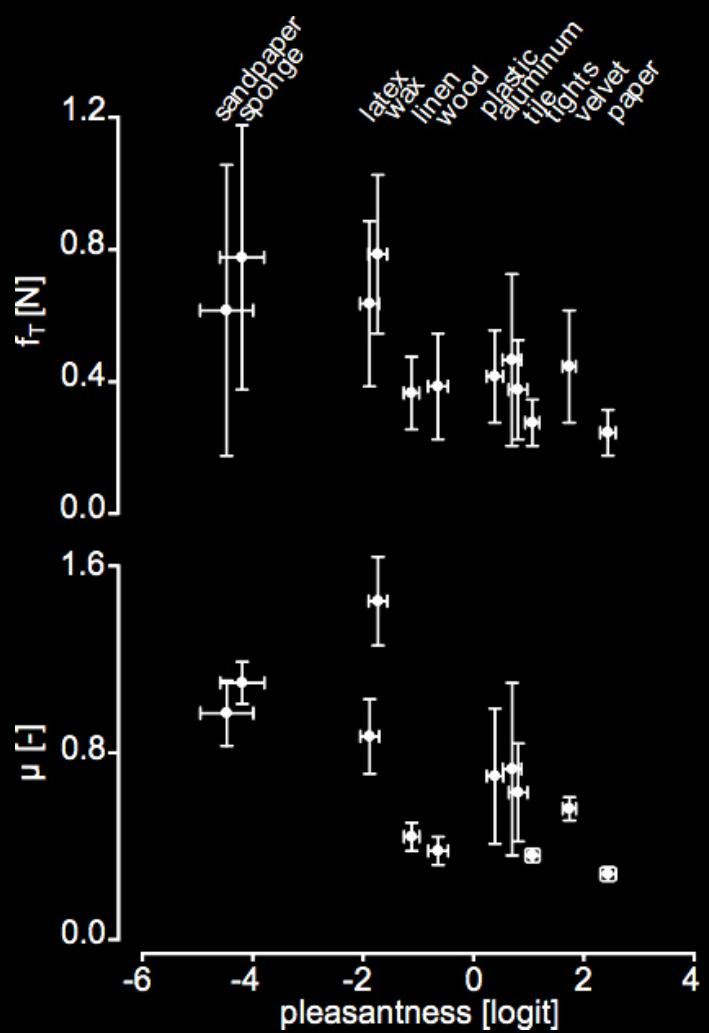
## Tactile Cognition: How



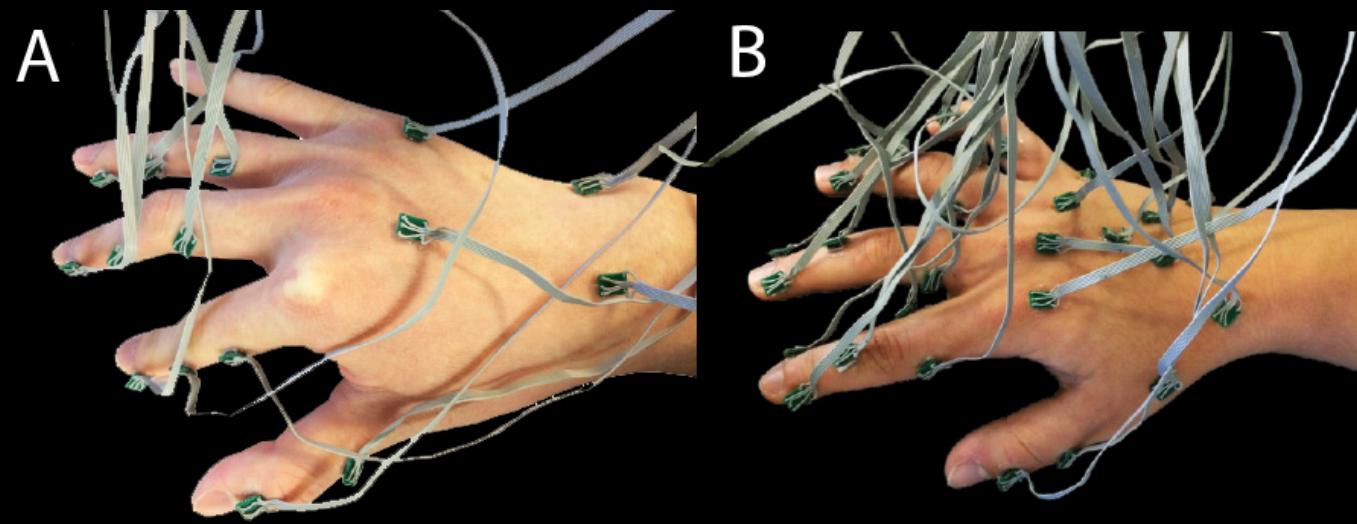
$$f_T = \beta \eta^\alpha$$

Klöcker, A., Wiertlewski, M., Théate, V., Hayward, V., Thonnard, J.-L. 2013.  
**Physical Factors influencing pleasant touch during tactile exploration.**  
*PloS ONE*, 8(11):e79085.

# Tactile Cognition: How



# Non Local Mechanics

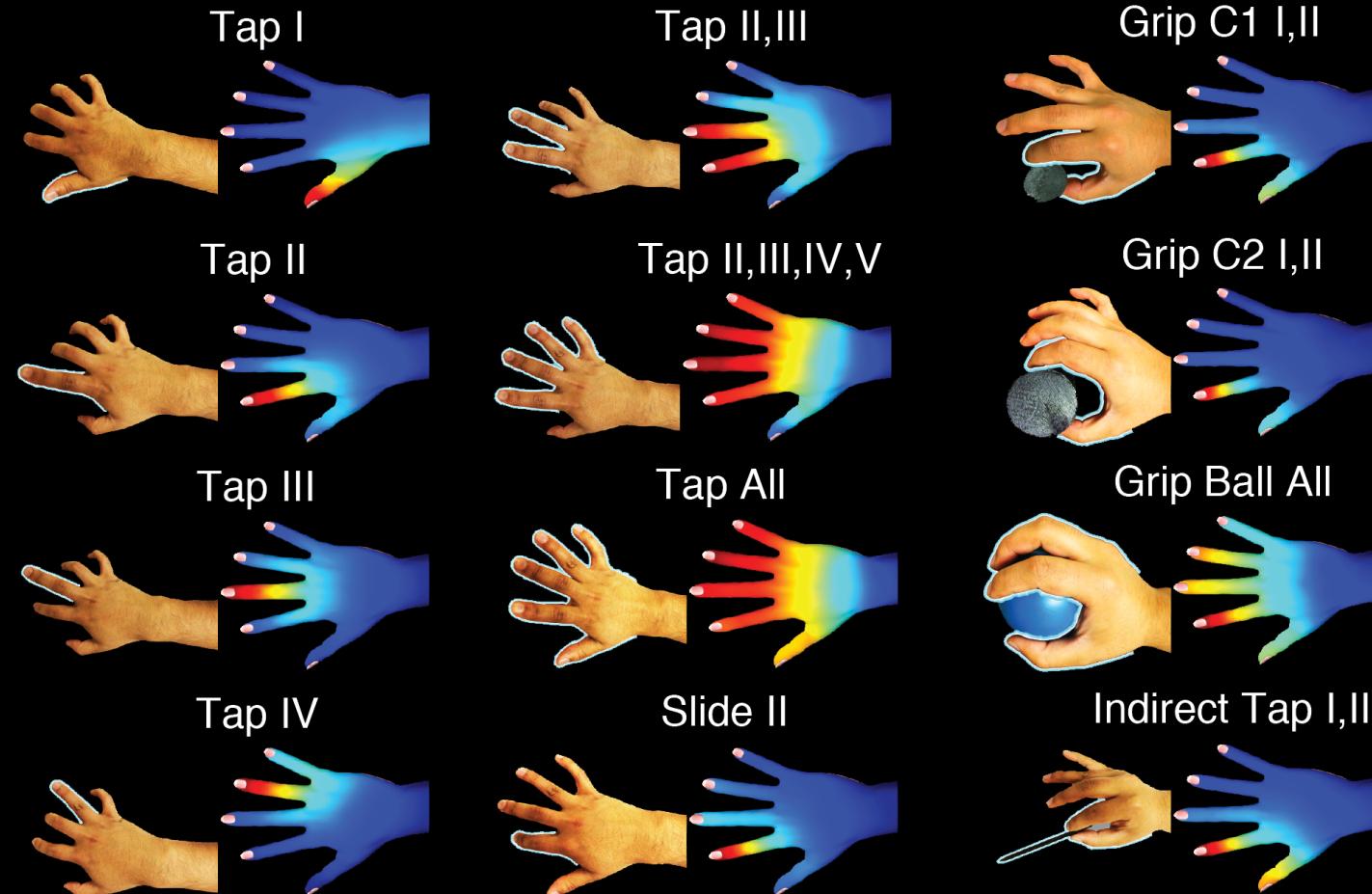


Y. Shao, V. Hayward, Y. Visell. 2016.

**Spatial patterns of cutaneous vibration during whole-hand haptic interactions.**

*Proceedings of the National Academy of Sciences*, 113(15):4188–4193

# Non Local Mechanics



# Non Local Mechanics

## Characteristic parameters for viscoelastic waves in the hand

Tactile frequencies	$f_{\min}$	0 Hz
	$f_{\max}$	1000 Hz
Group velocity, $c(f)$	$c_{\min}$	1 m/s
	$c_{\max}$	10 m/s
Wavelength, $\lambda=c(f)/f$	$\lambda_{\min}$	3 mm
	$\lambda_{\max}$	150 mm
Decay time, $\tau$	$\tau_{\min}$	10 ms
	$\tau_{\max}$	300 ms

# Non Local Mechanics

“Efficient encoding hypothesis”

Each estimated tactile stimulus:

$$\hat{v}(x, t) = \sum_{i=1}^M \sum_{\tau=0}^{T-1} h_i(t-\tau) w_i(x, \tau),$$

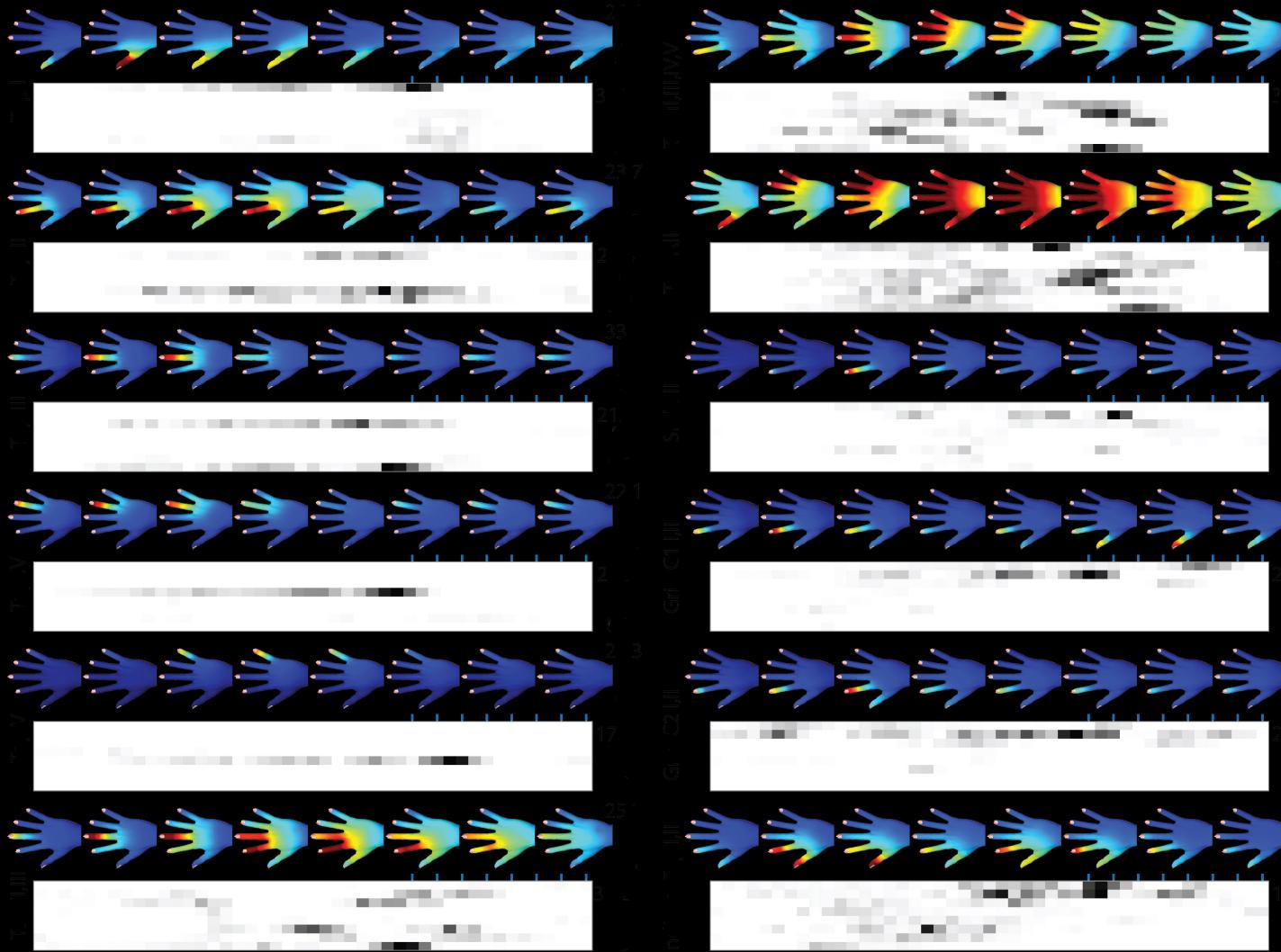
where,

$$w_i(x, t) \geq 0, \quad h_i(t) \geq 0.$$

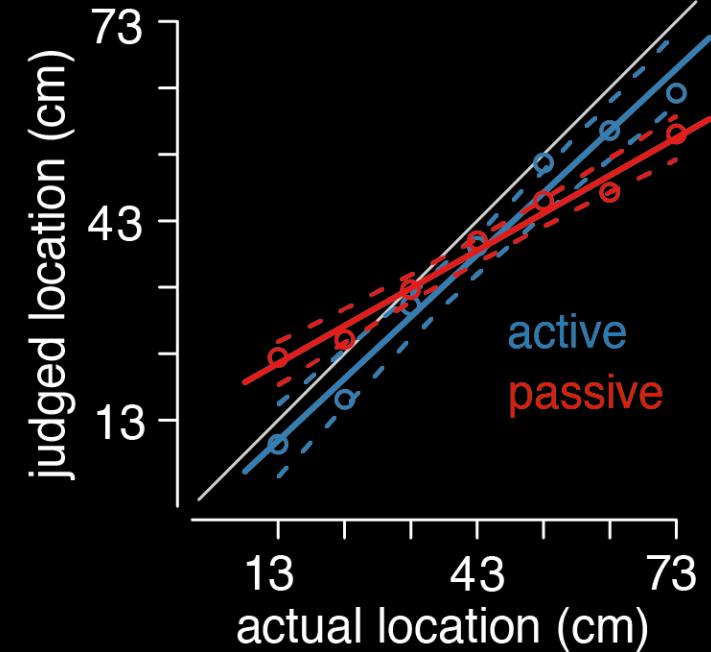
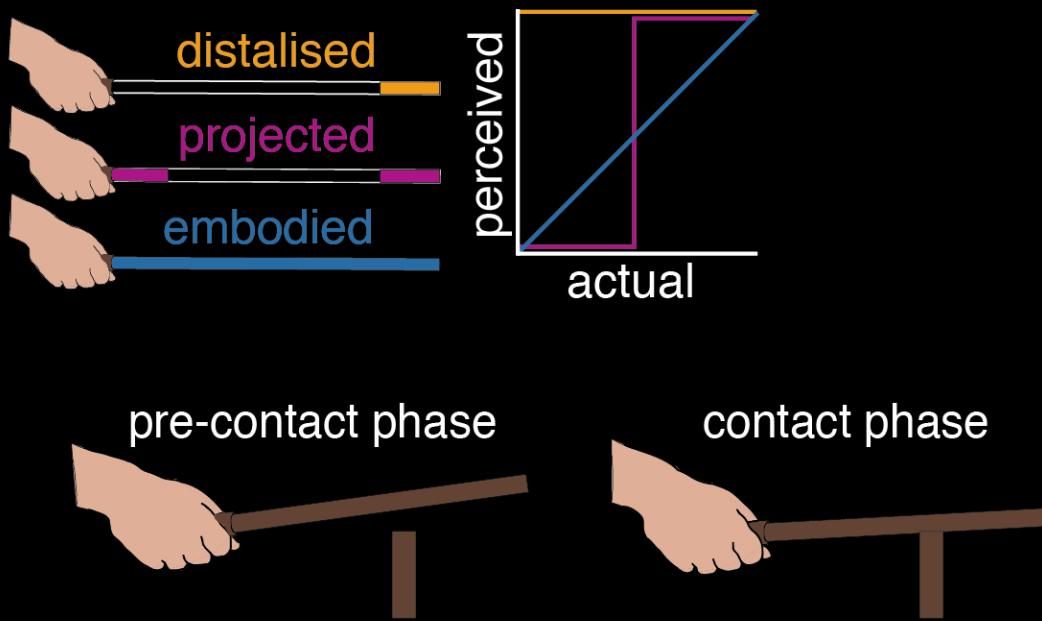
“Convulsive Non-negative Matrix Factorization”

Shao, Y., Hayward, V., Visell, Y. 2020.  
**Compression of dynamic tactile information in the human hand.**  
*Science Advances*, 6:eaaz1158.

## Non Local Mechanics

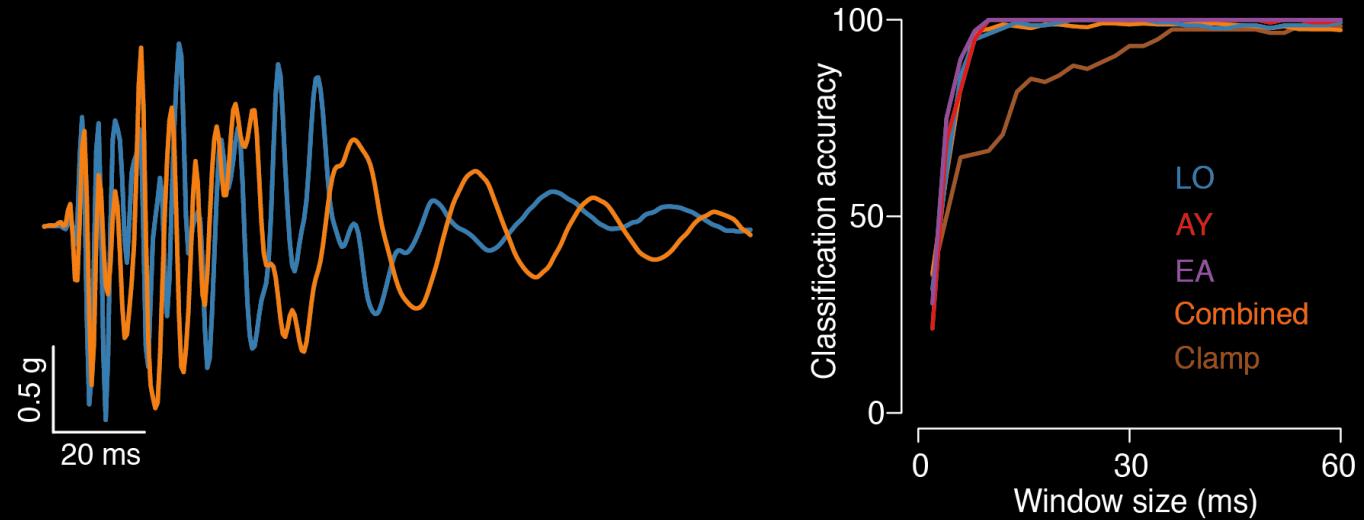


## Tactile Cognition: Where



Miller, L. E., Montroni, L., Koun, E., Salemme, R., Hayward, V., Farné, A. 2018.  
**Sensing with tools extends somatosensory processing beyond the body.**  
*Nature*, 561(7722):239-242.

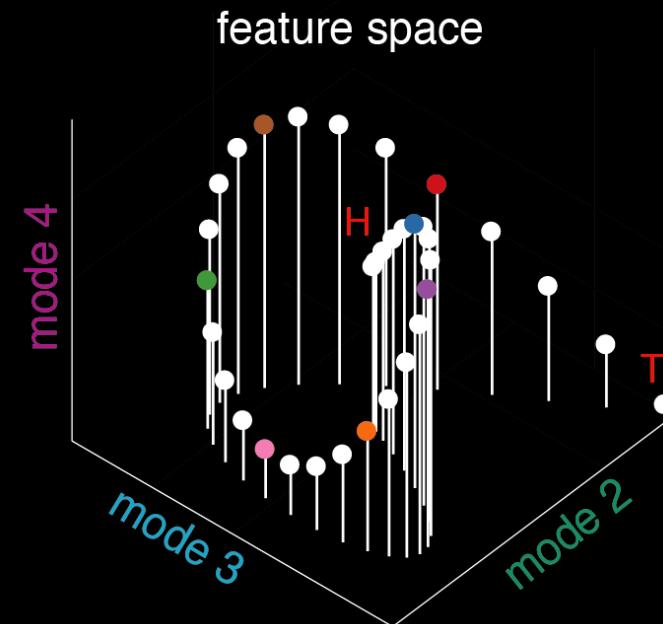
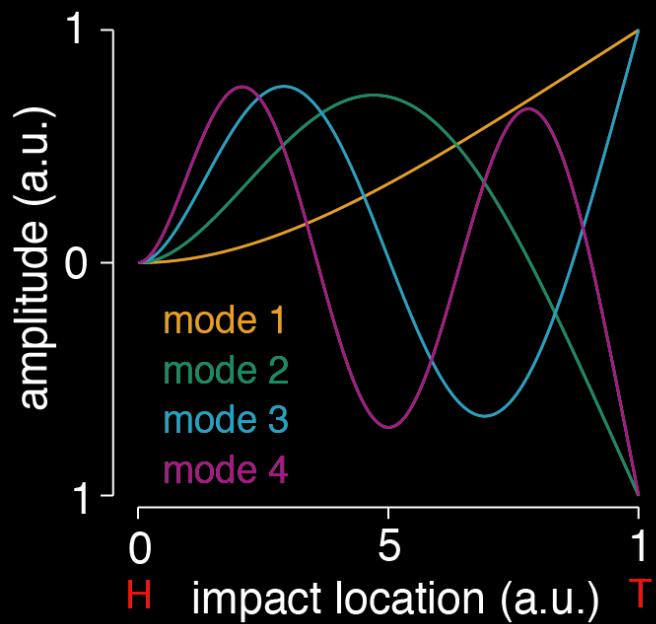
# Tactile Cognition: Where



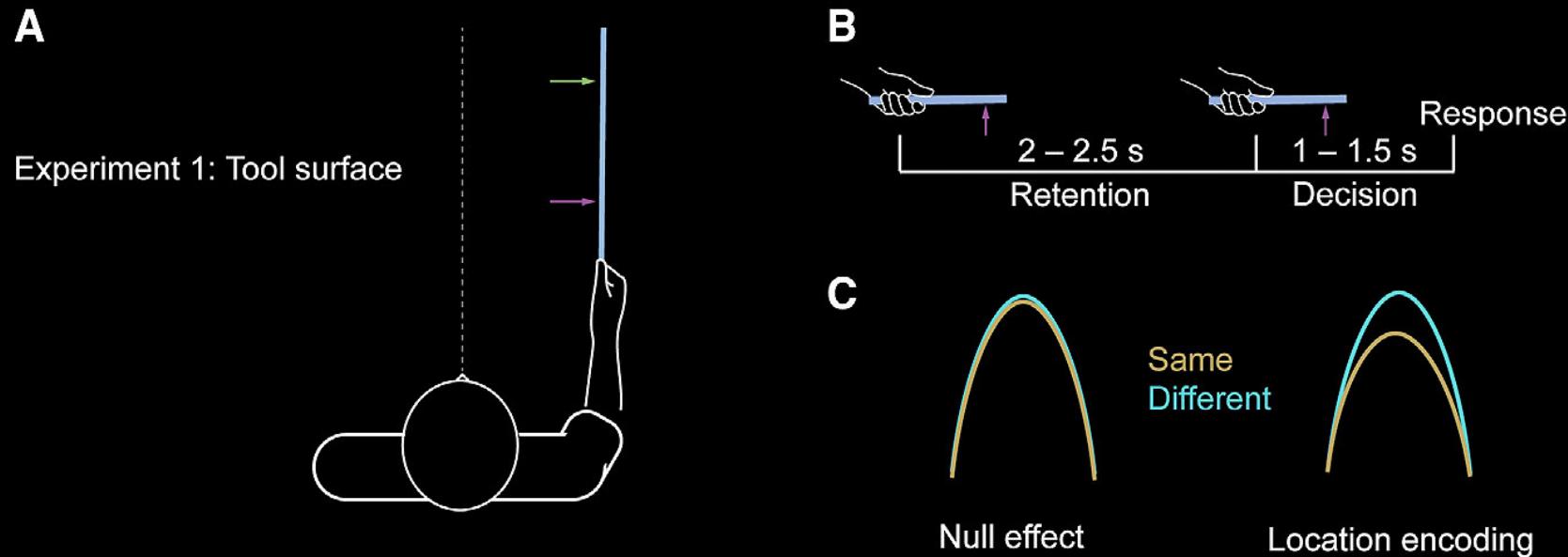
# Tactile Cognition: Where

$$EI \frac{\partial^4 u}{\partial x^4} + \mu \frac{\partial^2 u}{\partial t^2} + \lambda \frac{\partial u}{\partial t} = 0$$

natural frequencies  $\propto 1.5^2, 2.5^2, 3.5^2, 4.5^2$

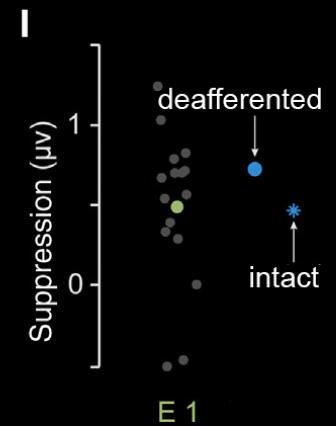
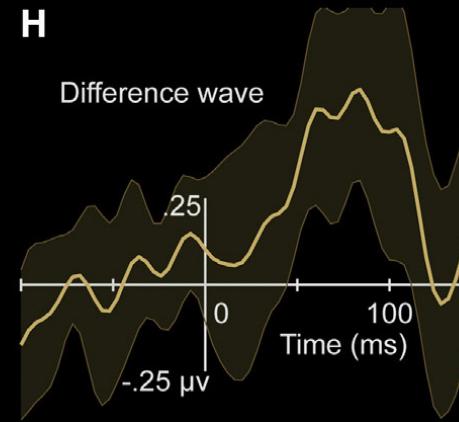
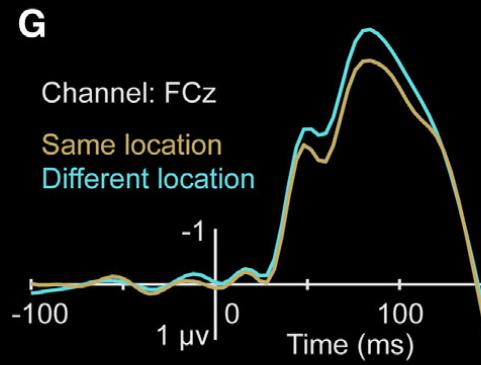
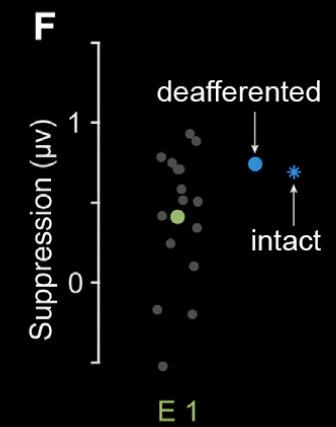
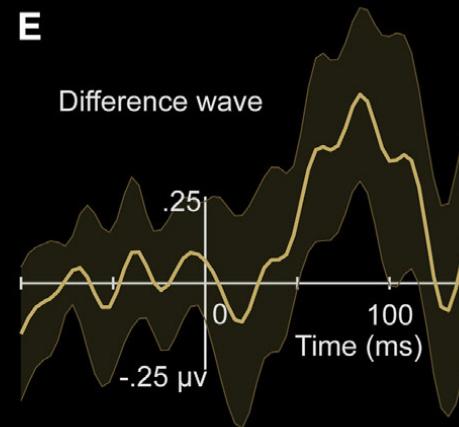
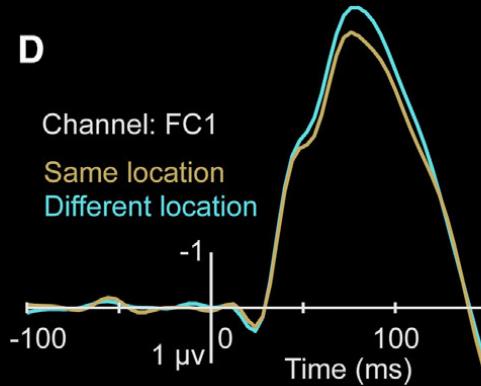


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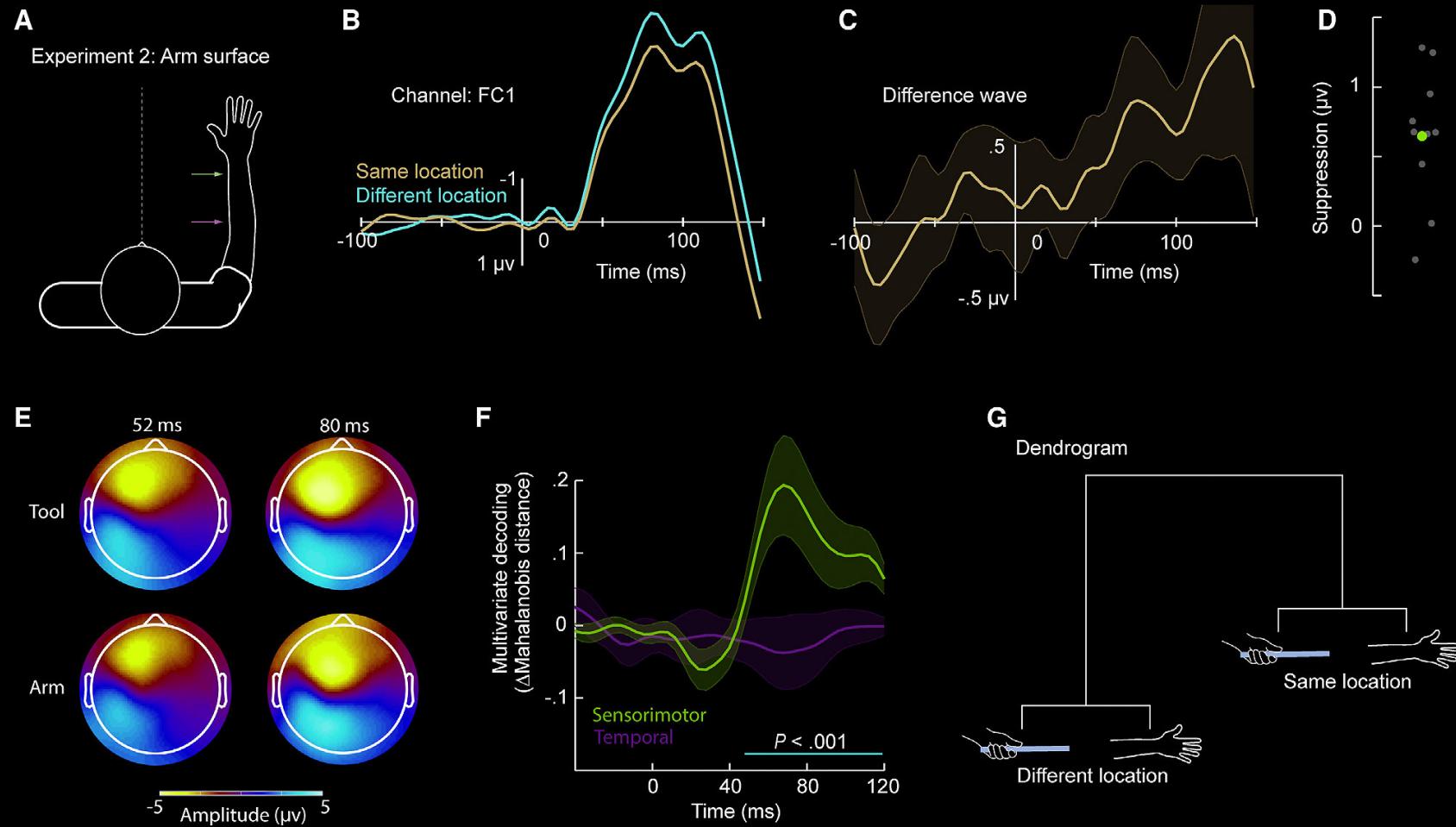


Miller, L. E., Fabio, C., Ravenda, V., Bahmad, S., Koun, E., Salemme, R., Luauté, J., Bolognini, N., Hayward, V., Farnè, A. 2019.  
**Somatosensory cortex efficiently processes touch located beyond the body.**  
*Current Biology*, 29(24):4276-4283.e5

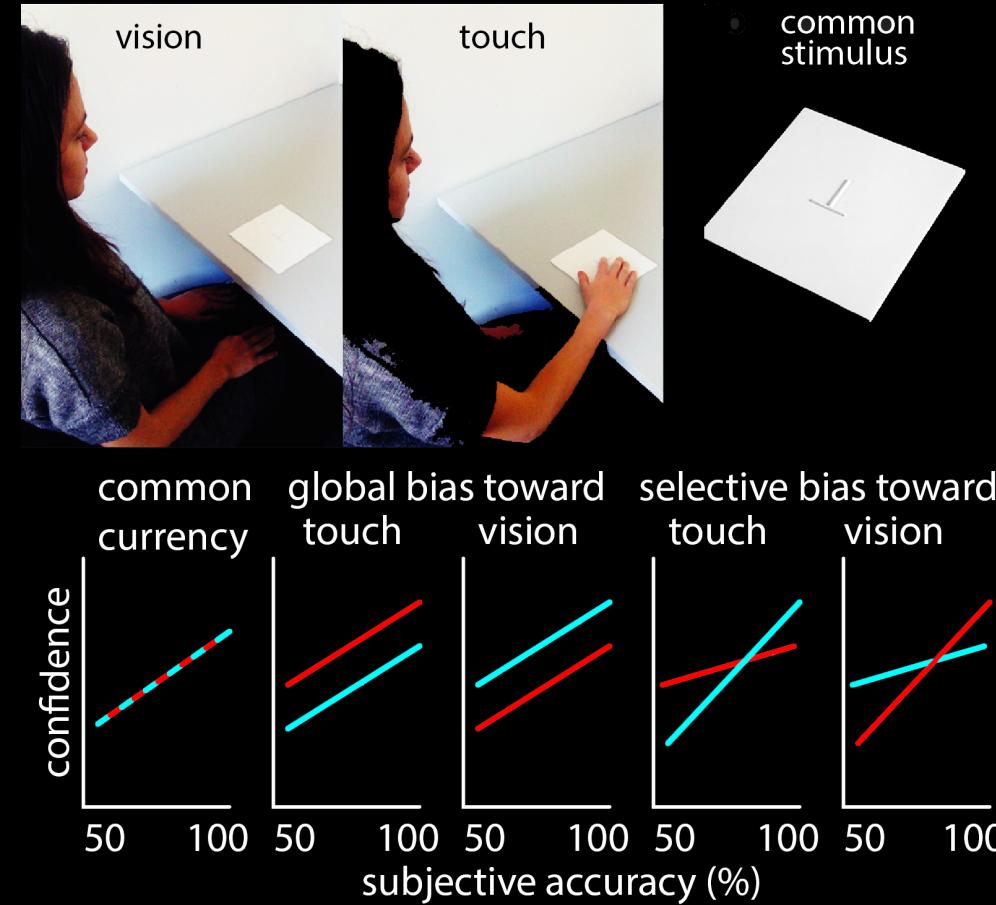
# Tactile Cognition: Where



# Tactile Cognition: Where

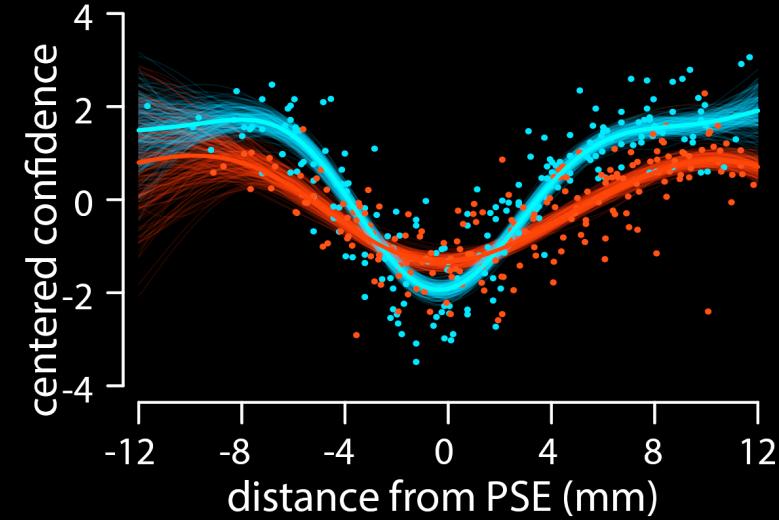
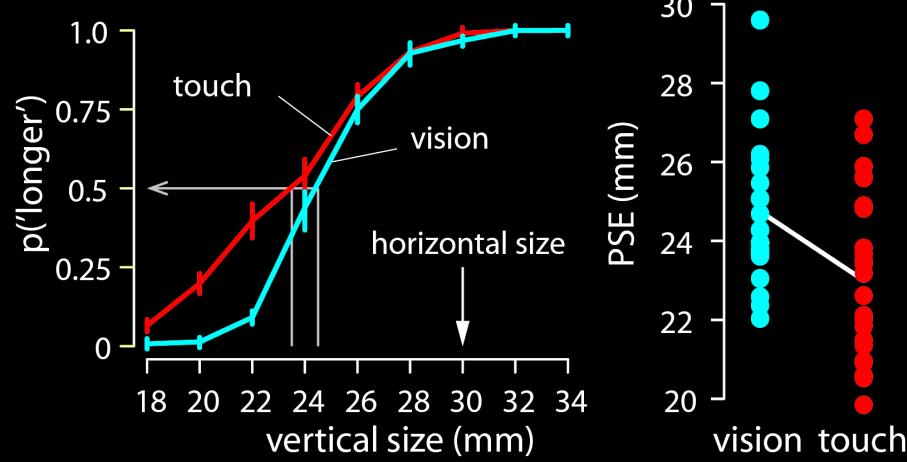
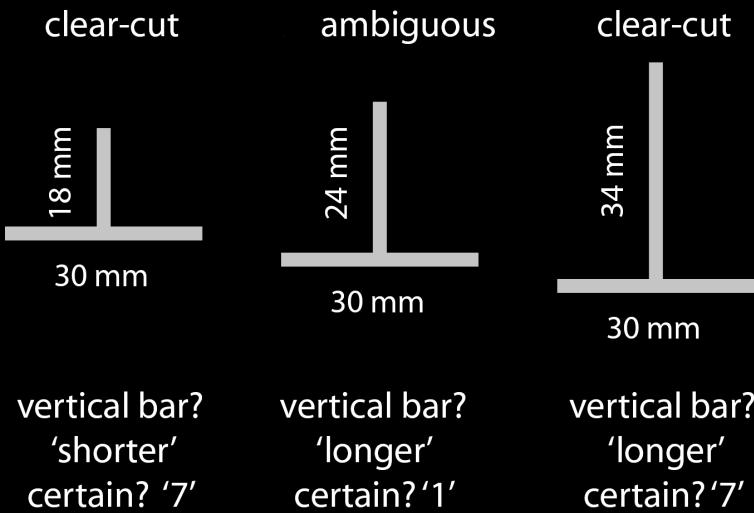


## Tactile Metacognition

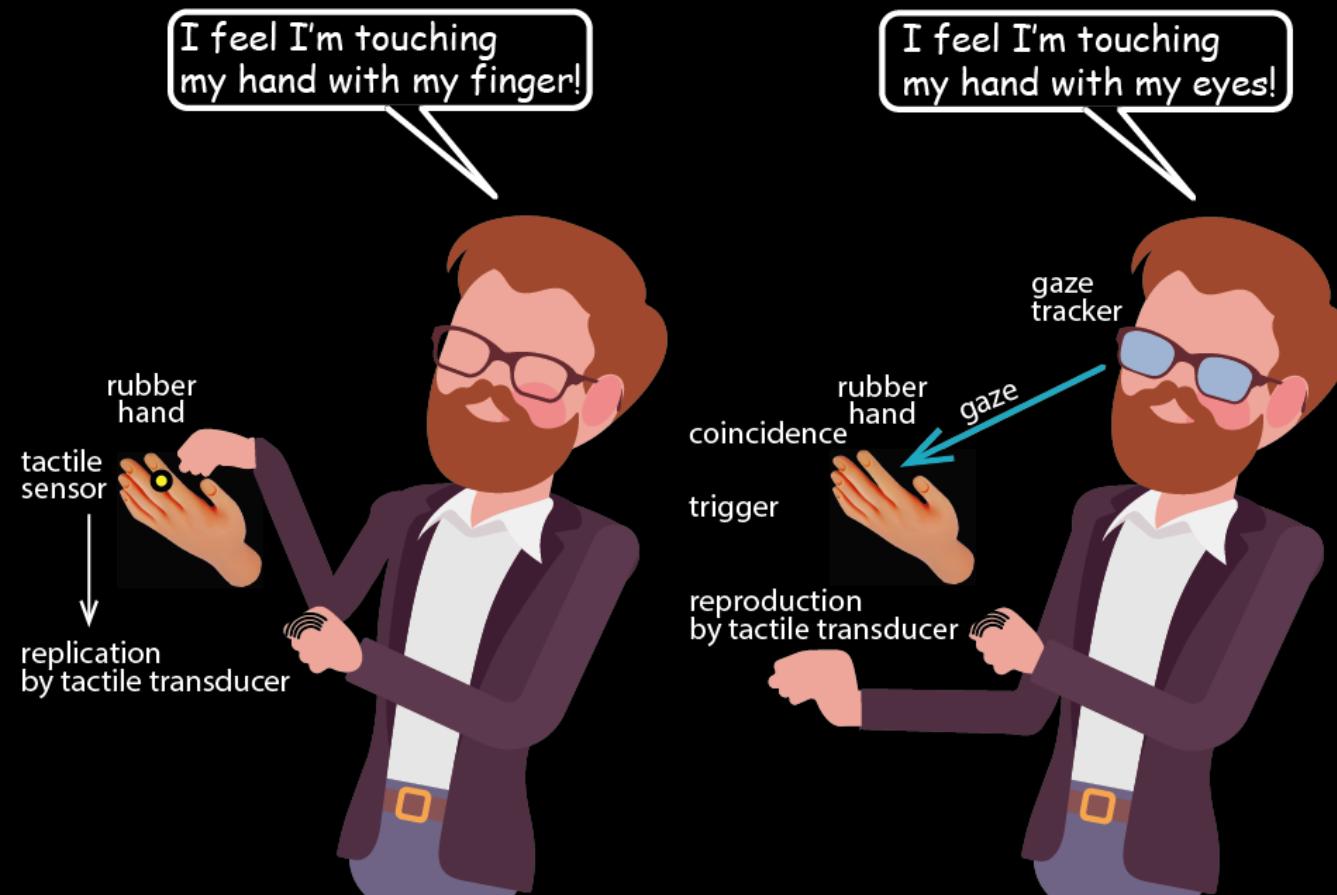


Fairhurst, M. T., Travers, E., Hayward, V., and Deroy, O. 2018.  
**Confidence Is Higher in Touch Than in Vision in Cases of Perceptual Ambiguity.**  
*Scientific Reports*, 8:15604

# Tactile Metacognition



## Tactile Cognition: Who



Cataldo, A., Di Luca, M., Deroy, O., Hayward, V. 2023.

Touching with the eyes: Oculomotor self-touch induces illusory body ownership.  
*iScience*, in press.

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