

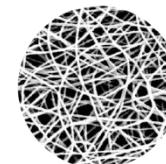
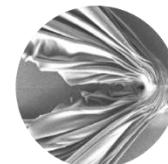
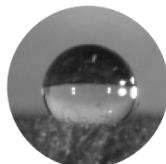
Tactile tribology: bulk materials and surfaces

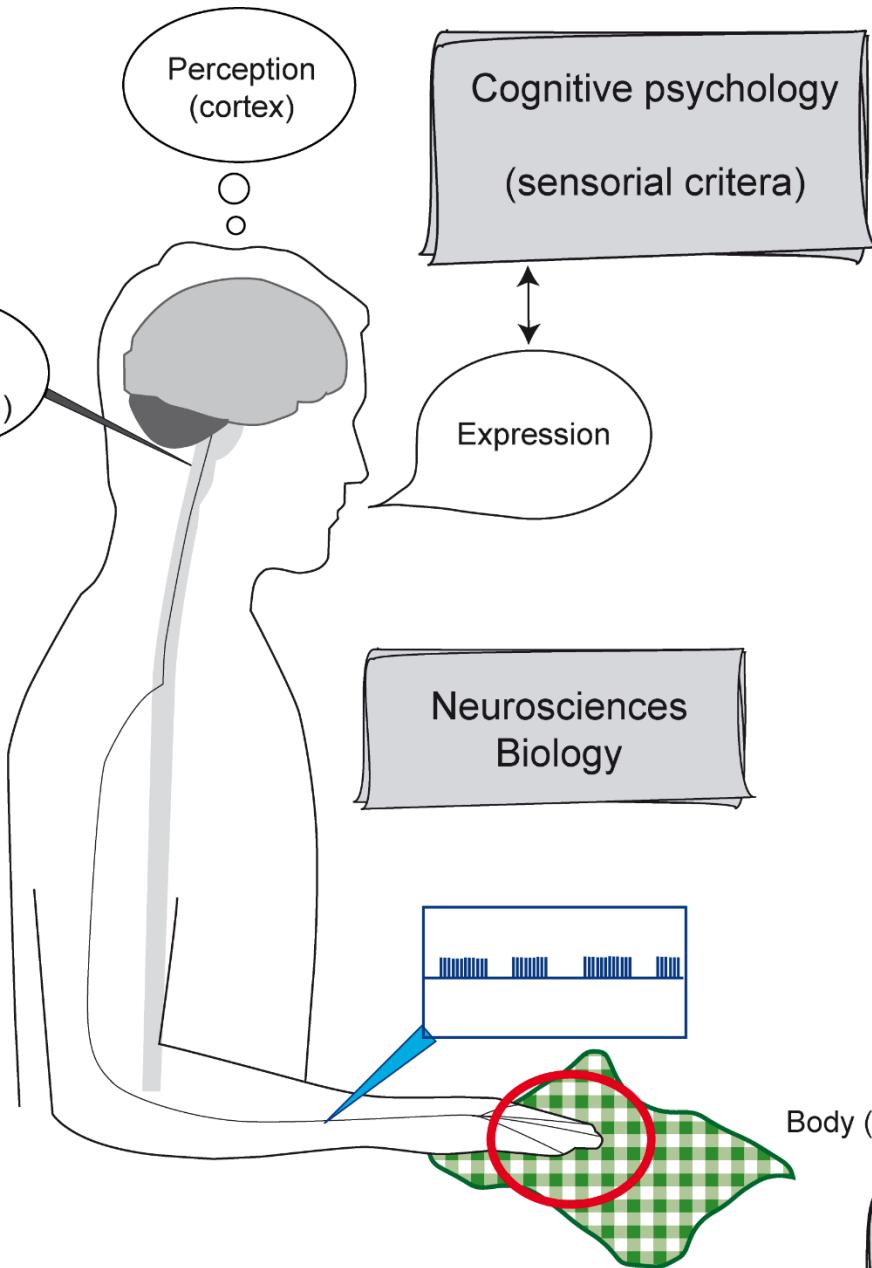
Marie-Ange Bueno

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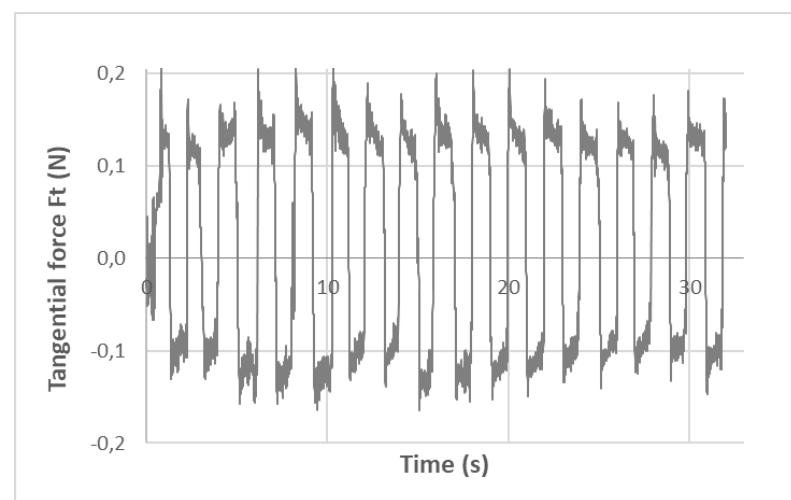
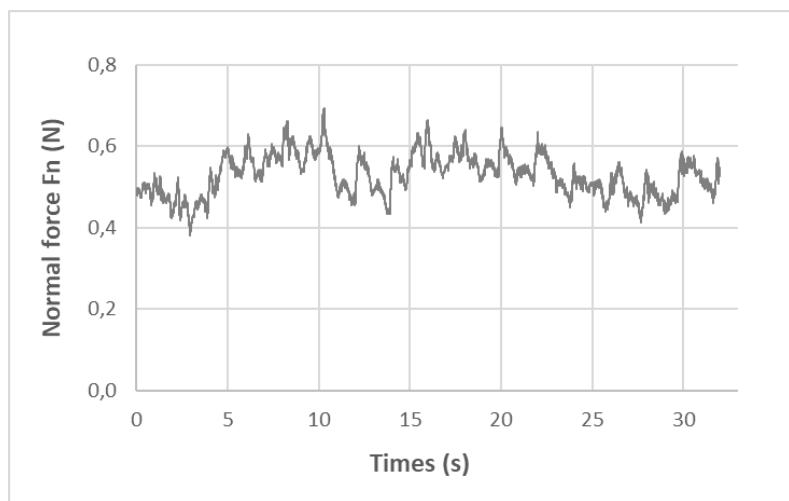
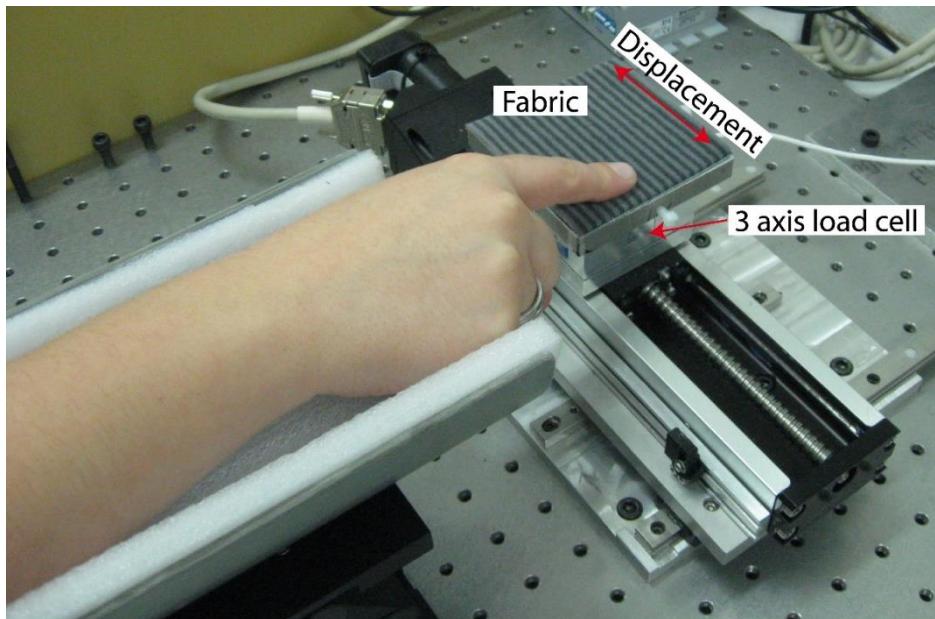
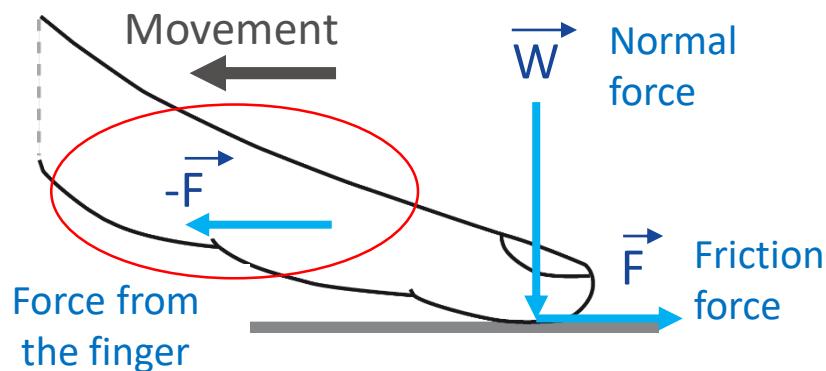
Interaction
Body (skin, finger ...) / Material (surface, volume)

Tribology

Heat and mass transfer

What can we extract from friction
measurement?

Tribological features (during rubbing)

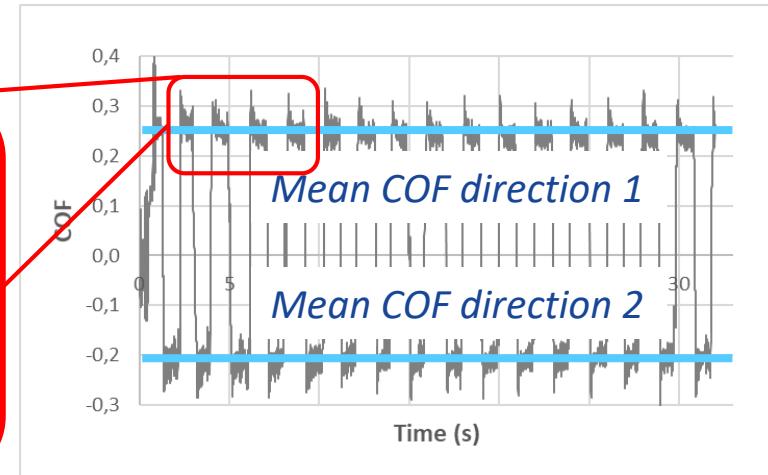
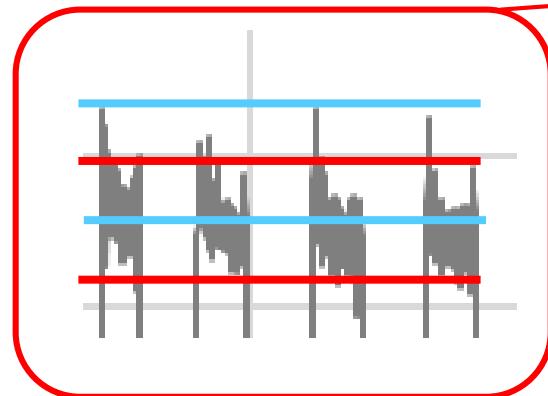


Tribological features (during rubbing)

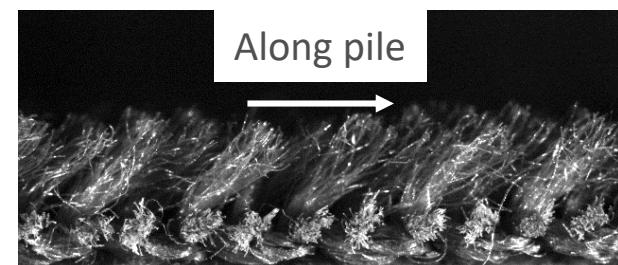
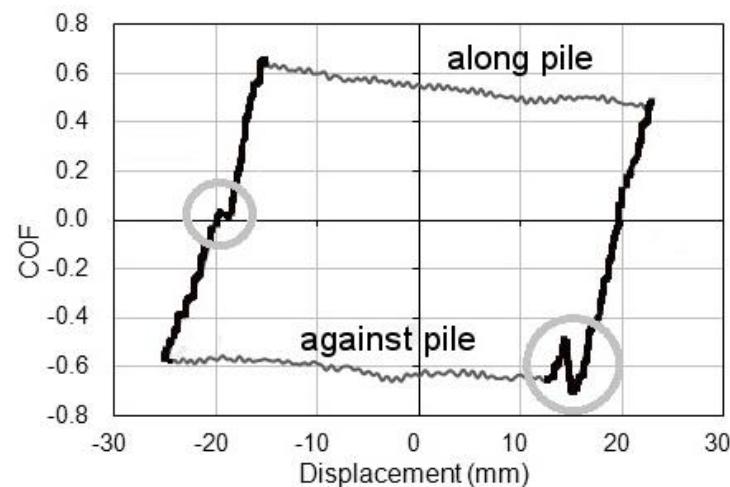
$$\text{Coefficient of friction (COF)} = \frac{\text{Friction force}}{\text{Normal force}}$$

COF Static and dynamic

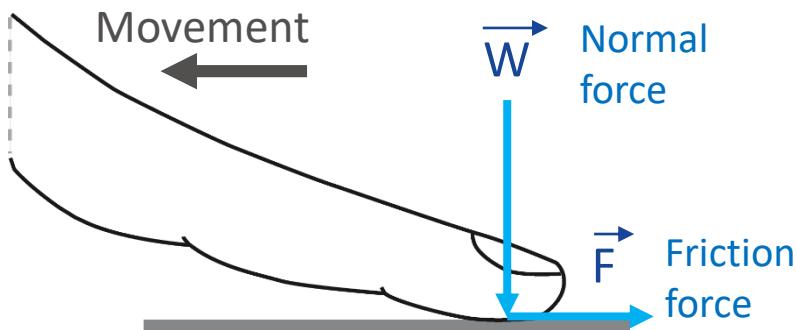
COF dispersion:
 → SD, MMD, ...



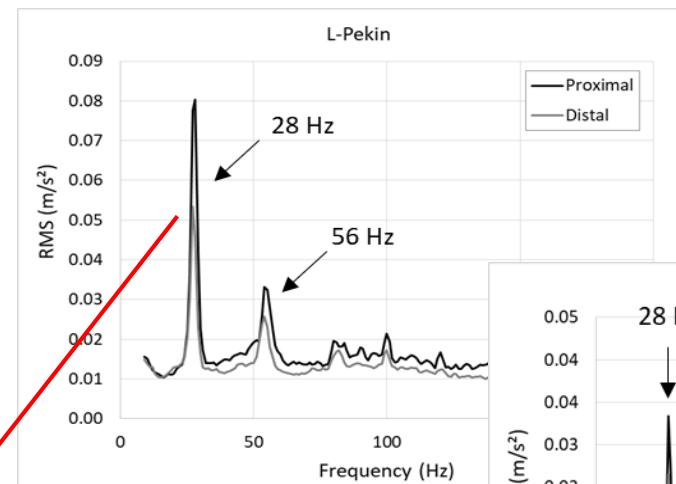
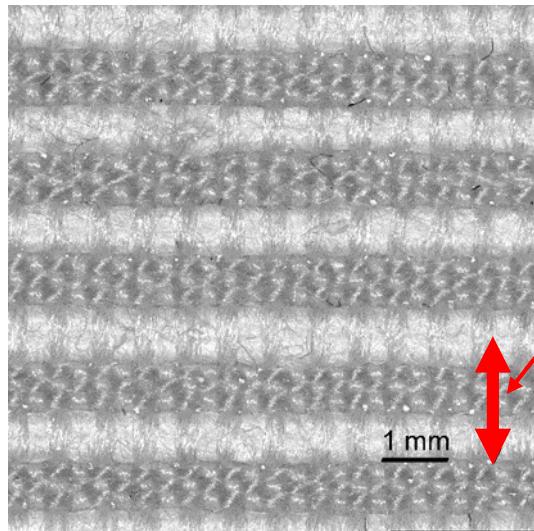
COF evolution
 → steady state
 → transition



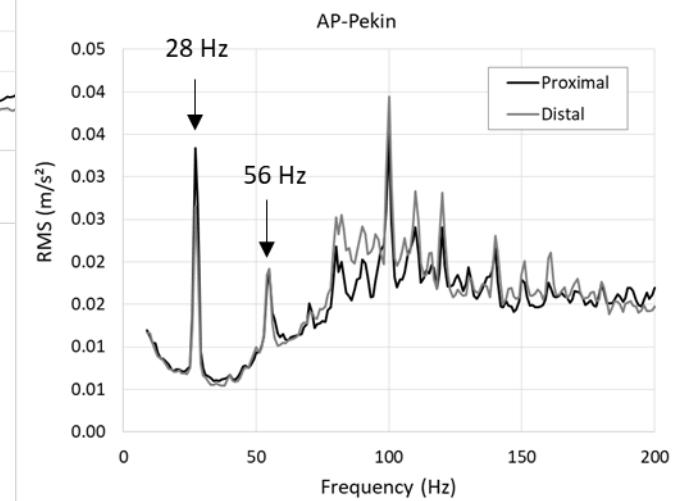
Tribological features (during rubbing)



$$\sum \overrightarrow{F_{ext}} = m \vec{a}$$



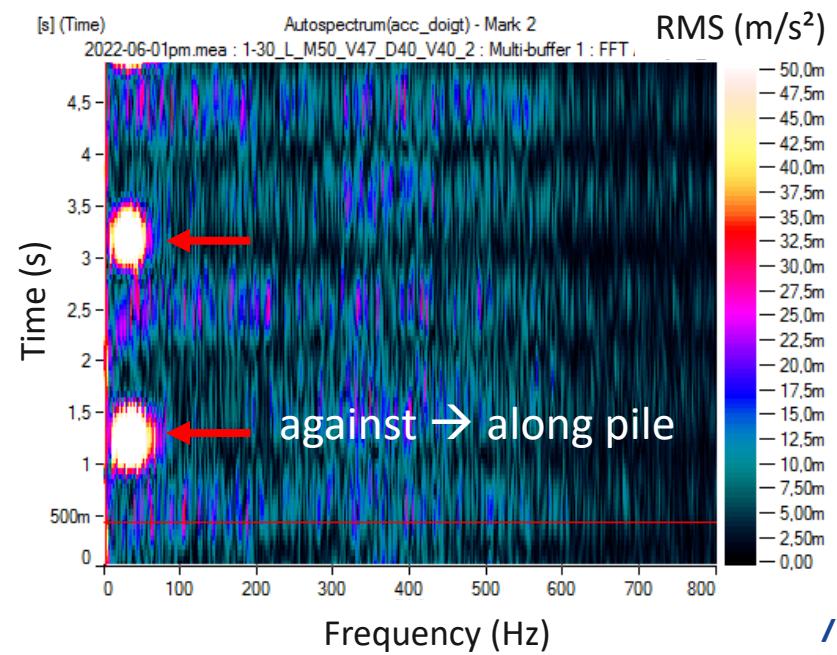
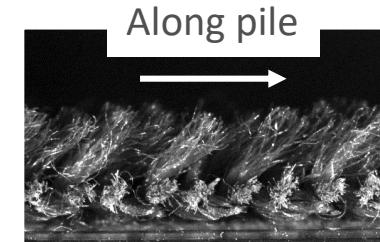
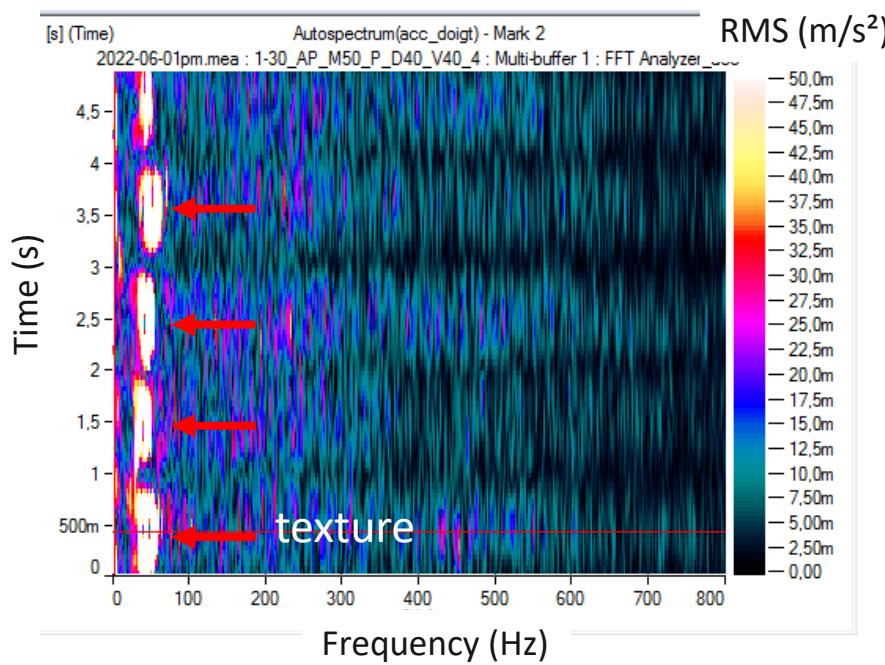
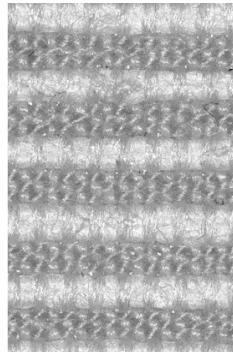
*Mean spectrum
(autospectrum)*



Tribological features (during rubbing)

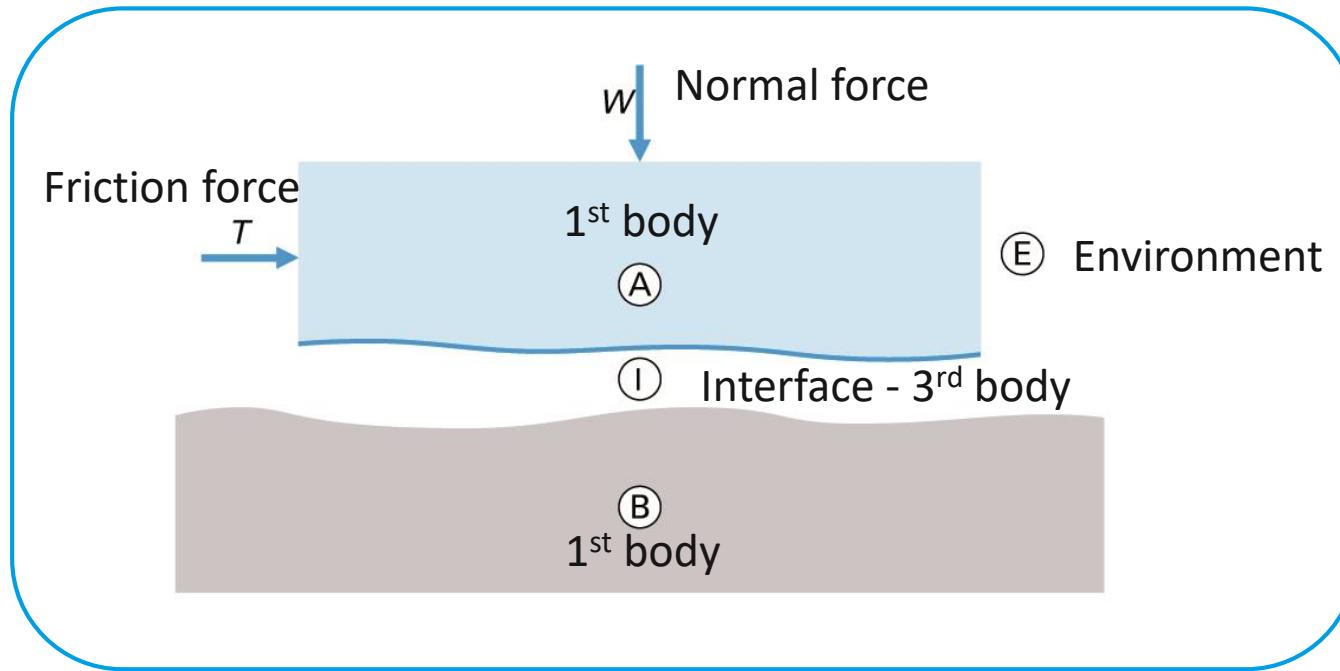
$$\sum \overrightarrow{F_{ext}} = m\vec{\gamma}$$

Time-frequency



What are the influencing parameters on
friction?

Tribological system



1st bodies: material (chemical, physical and mechanical properties), surface (texture, roughness), shape

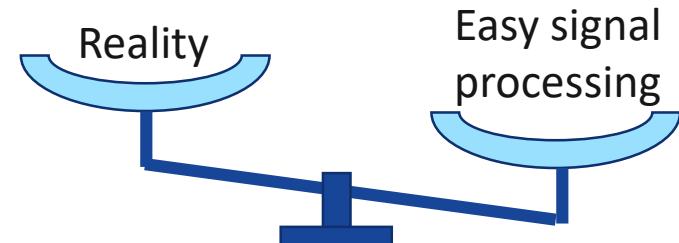
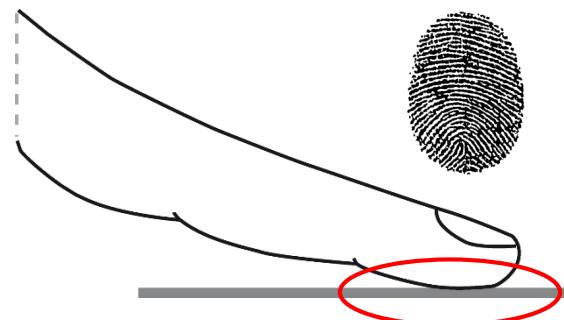
Movement: kinematics, dynamics, trajectory

Surface contaminants: water, oil, grease, ...

Multifactorial

Environment: RH%, temperature, ...

Tribological system for study

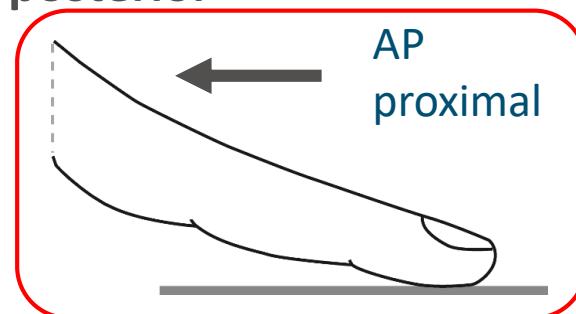


1st bodies:

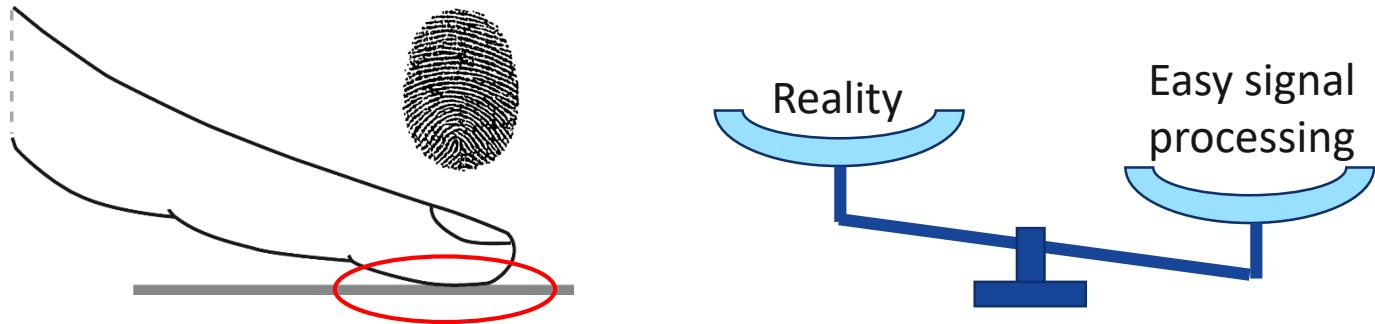
- **fingers** → natural variability but after cleaning
- **material** (chemical, physical and mechanical properties), **surface** (texture, roughness), **shape**

Movement:

- **active or touch passive** (displacement, speed, normal force)
- **linear, reciprocating or not lateral or anteroposterior**



Tribological system for study



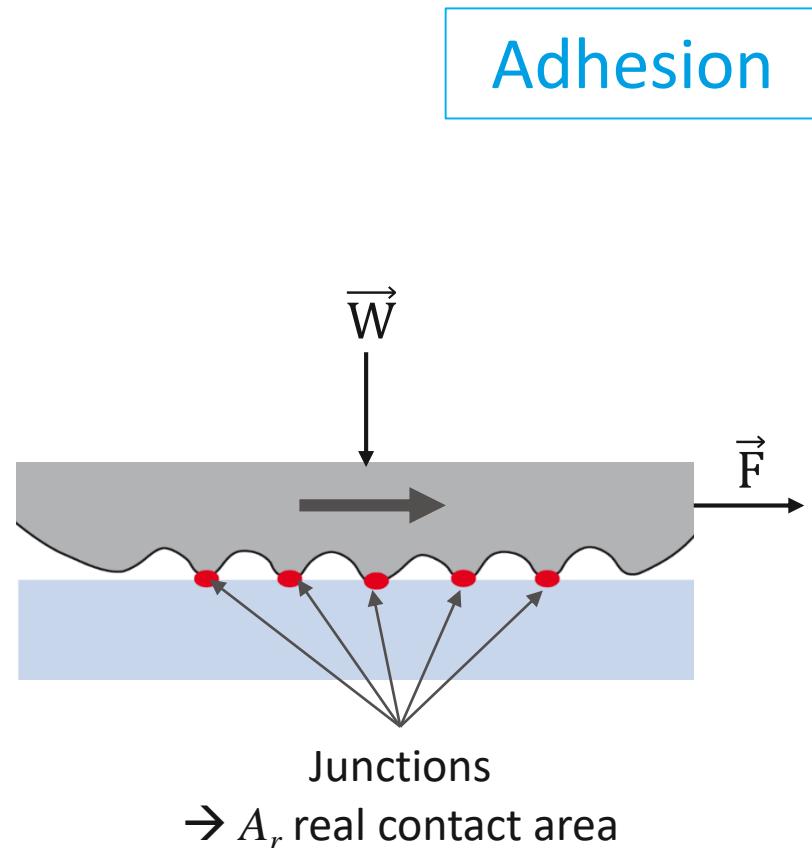
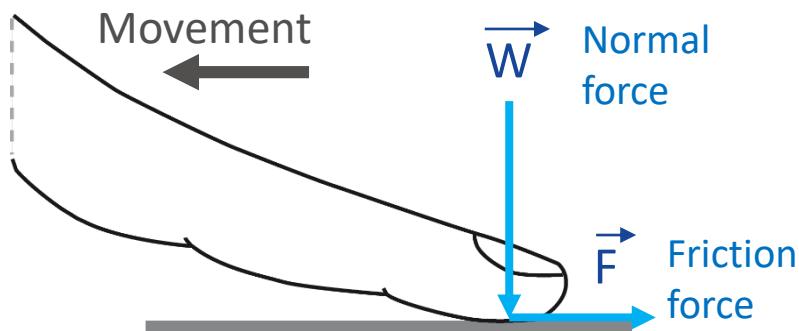
Surface contaminants:

- Water or humidity
- Hydro-lipidic film, sweat → cleaning protocol
- material cleaning protocol (if possible) or change of sample

Environment: RH%, temperature controlled.

What are the origin of friction?

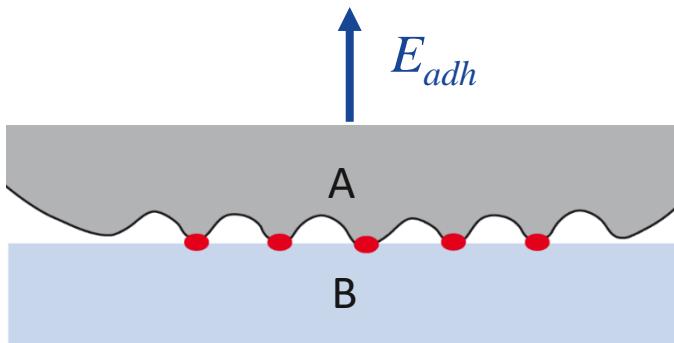
Friction definition and origin



$$\rightarrow F = F_{adh} = \tau \cdot A_r$$

τ : shear strength (Pa)

Friction definition and origin



Adhesion

Physics

τ depends on adhesion energy E_{adh} :

$$E_{adh} = \gamma_A + \gamma_B - \gamma_{AB}$$

γ_A and γ_B : surface tension for A and B (J/m^2)

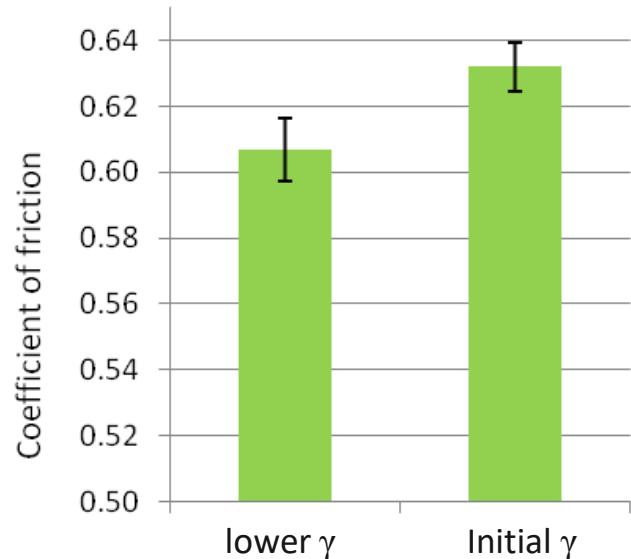
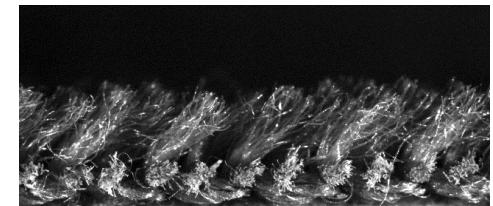
γ_{AB} : interface surface tension (J/m^2)

$$\gamma_{AB} \approx \beta \cdot (\gamma_A + \gamma_B)$$

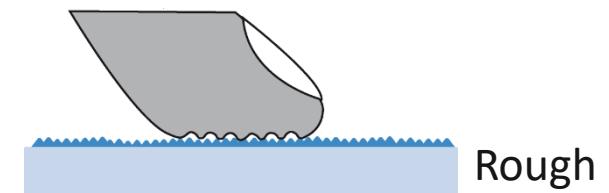
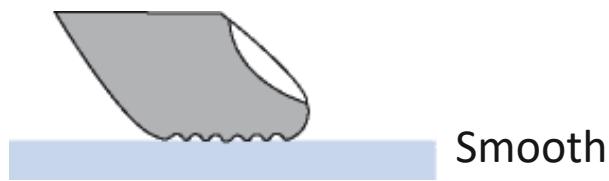
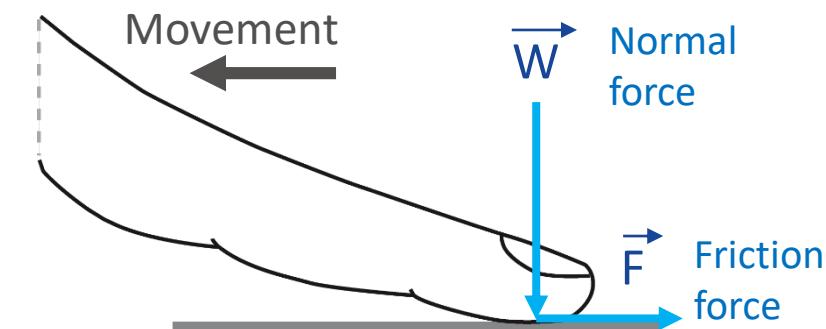
$\beta = 1/4$ for soluble materials

$\beta = 1/2$ for insoluble materials

$$\rightarrow E_{adh} \searrow \rightarrow \tau \searrow \rightarrow F_{adh} \searrow$$

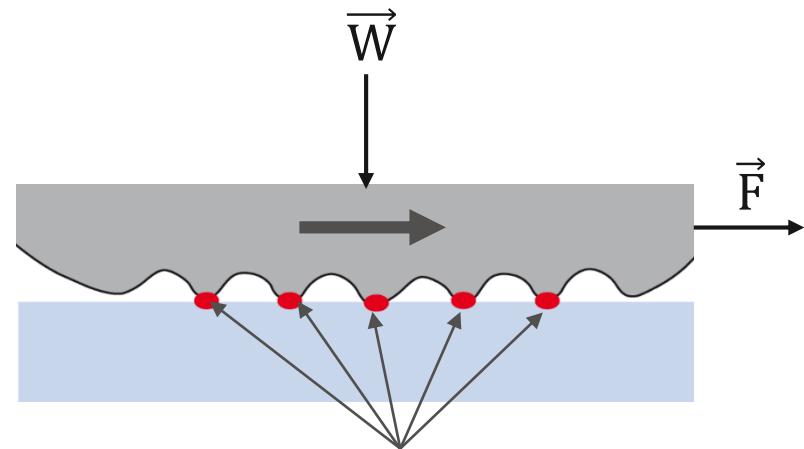


Friction definition and origin



$A_r \searrow$

$F_{adh} \searrow$

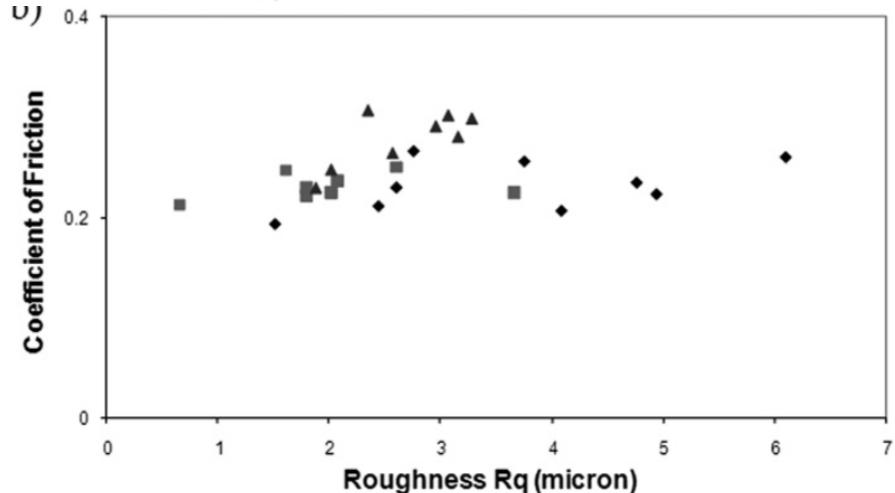
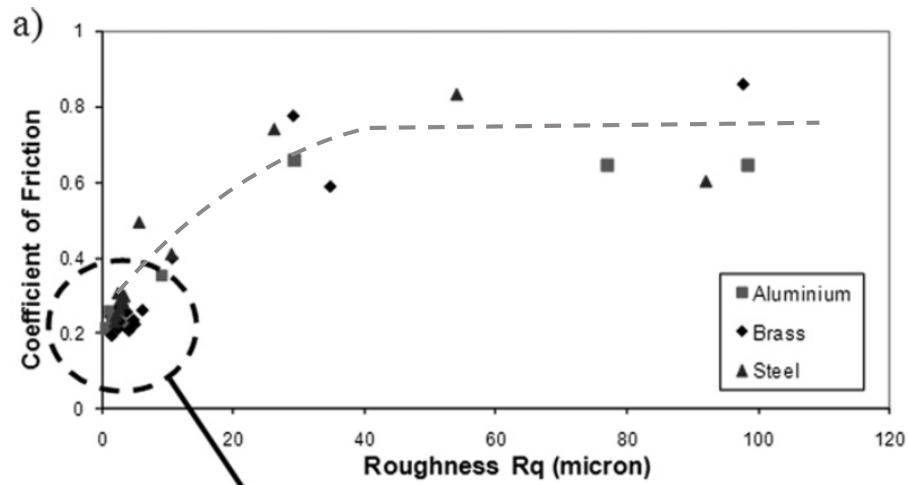
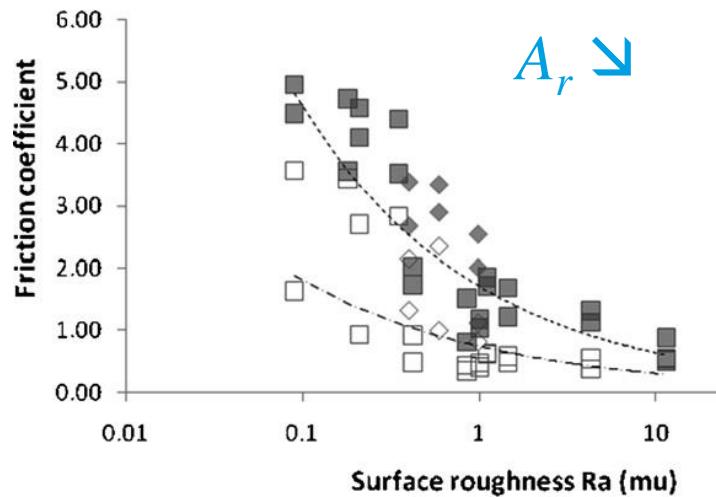


$\rightarrow A_r$ real contact area

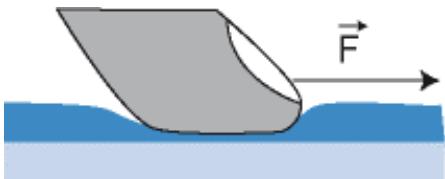
$$\rightarrow F = F_{adh} = \tau \cdot A_r$$

τ : shear strength (Pa)

Friction definition and origin



Friction definition and origin



$$F = F_{adh} + F_{def}$$

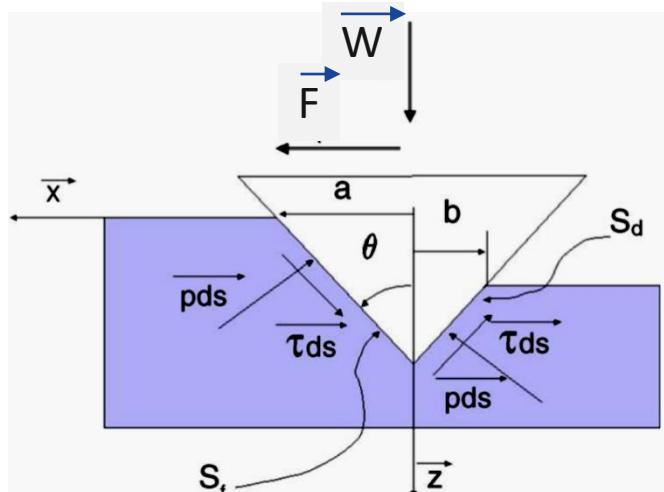
Viscoelasticity

Roughness

Deformation

Viscoelasticity

- Skin viscoelasticity can be considered as negligible
- What about touching a viscoelastic material?



$$W = p.(S_f + S_d) \sin \theta + \tau.(S_d - S_f). \cos \theta$$

$$F = p.(S_f - S_d) \cos \theta + \tau.(S_f + S_d). \sin \theta$$

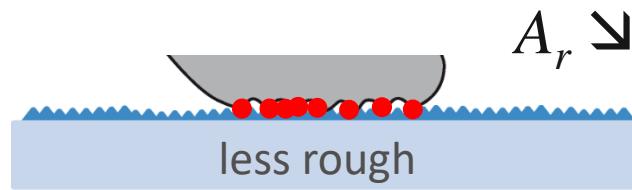
→ $\mu_{global} = \frac{F}{W}$ and $\mu_{local} = \frac{\tau}{p}$

Adams MJ, Briscoe BJ, Johnson SA. Friction and lubrication of human skin. *Tribol Lett*. 2007;26(3):239-53.

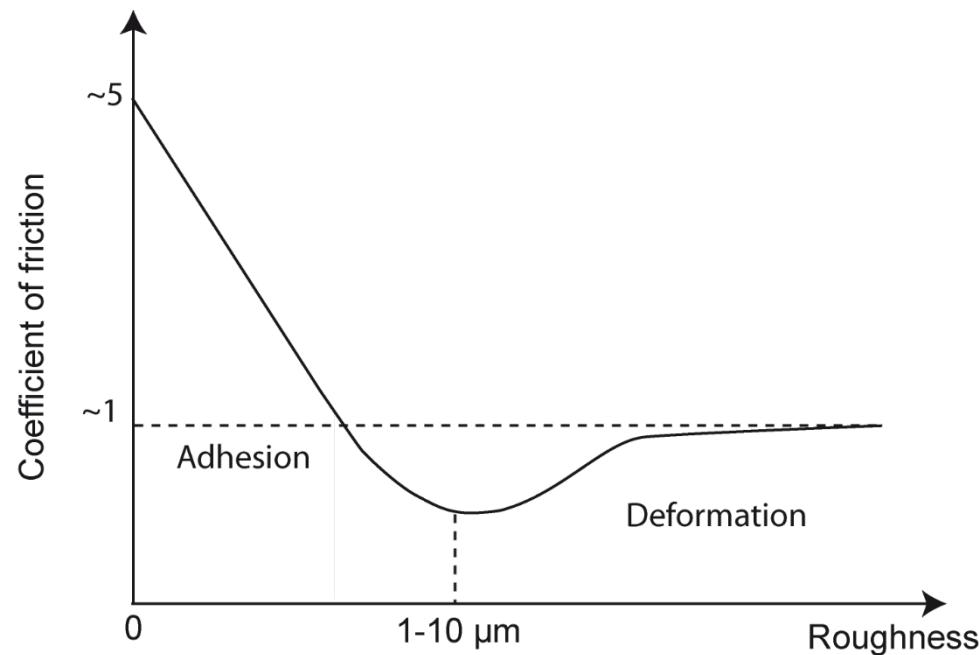
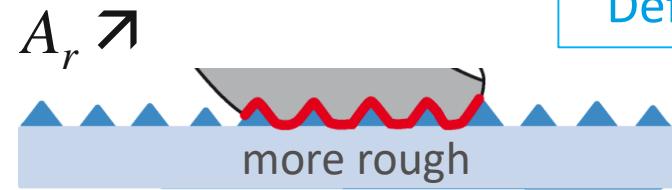
Lafaye S, Gauthier C, Schirrer R. A surface flow line model of a scratching tip: apparent and true local friction coefficients. *Tribology International*. 2005;38:113-27.

Friction definition and origin

Roughness

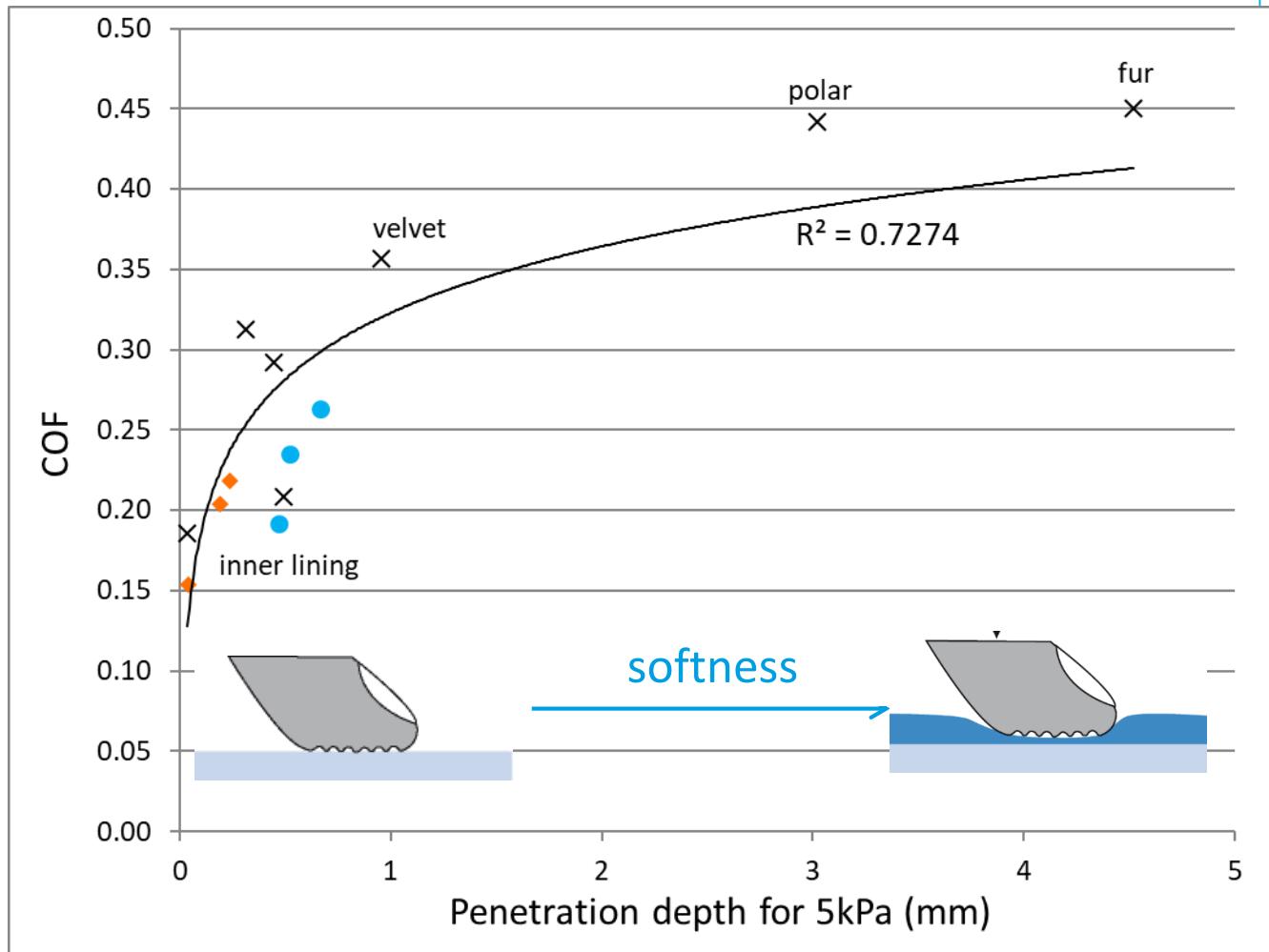


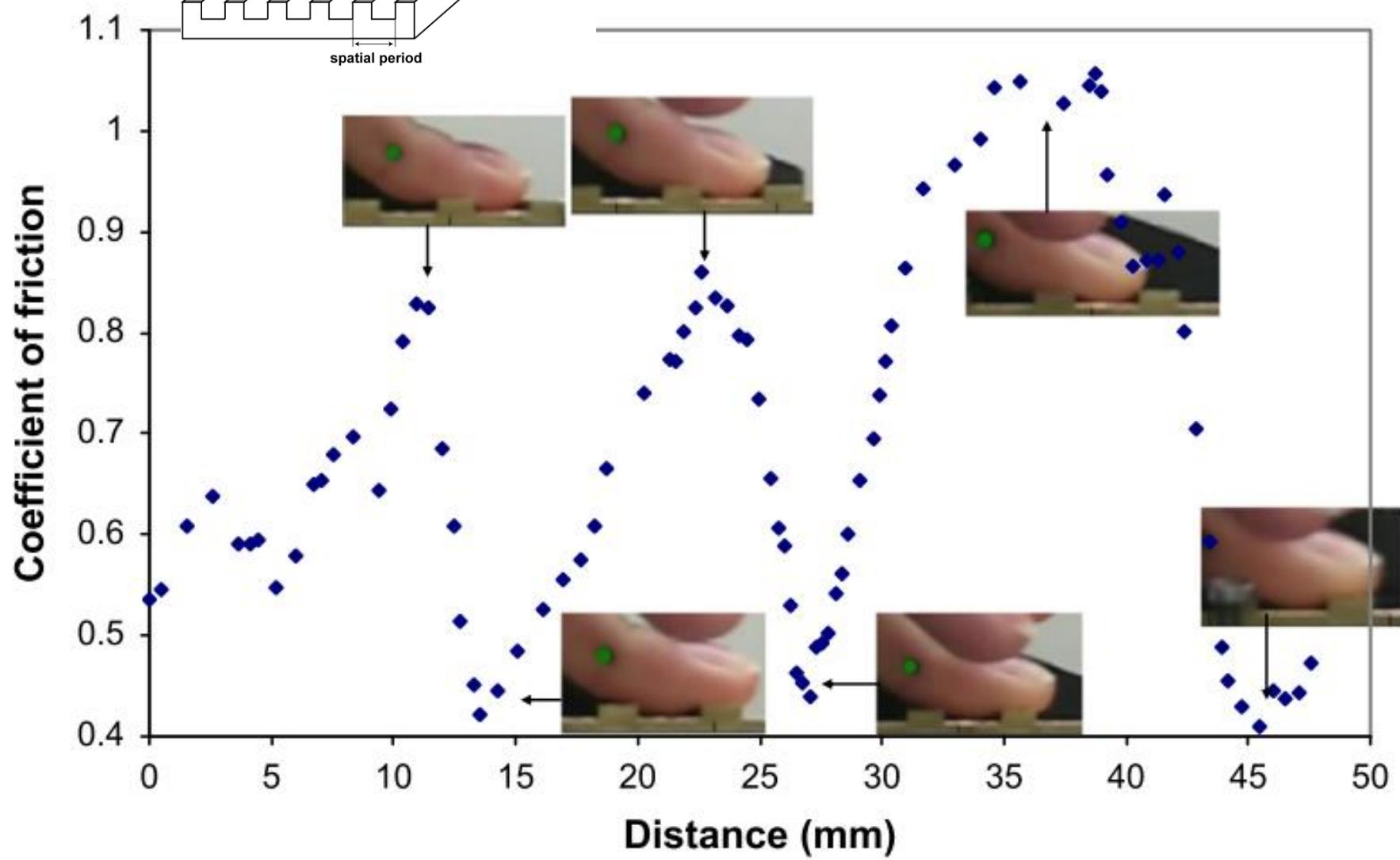
Adhesion
Deformation



Friction definition and origin

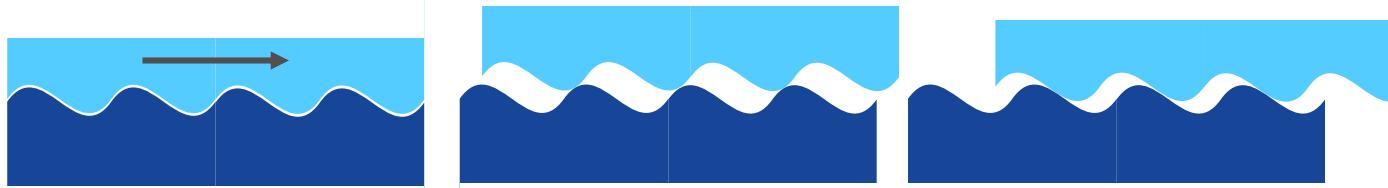
Adhesion
Deformation





Friction definition and origin

Imbrication with dermatoglyphs



$$F = F_{adh} + F_{def} + F_{imbrication}$$

“Ratchet” Imbrication



Arch



5%

Loop



60%

Whorls

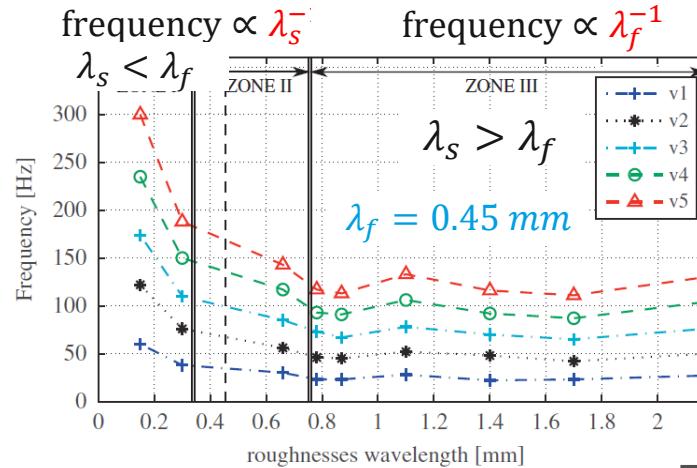
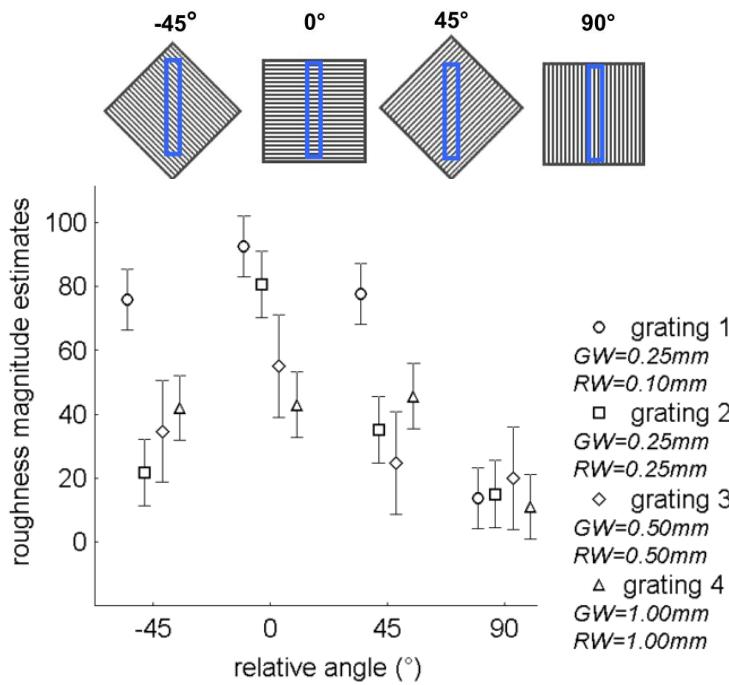


30%

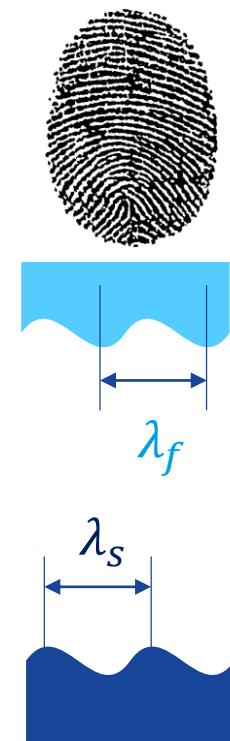
Hoover JE. *The Science of Fingerprints: Classifications and Uses*: United States Dept. of Justice, Federal Bureau of Investigation; 1985.

van Mensvoort M. *FINGERPRINTS WORLD MAP - global distribution of whorls, loops & arches!* Hand reading research & scientific hand analysis.
<http://fingerprintsandresearch.com/dermatoglyphics/fingerprints-world-map-whorls-loops-arches.htm>

Friction definition and origin



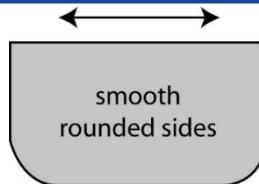
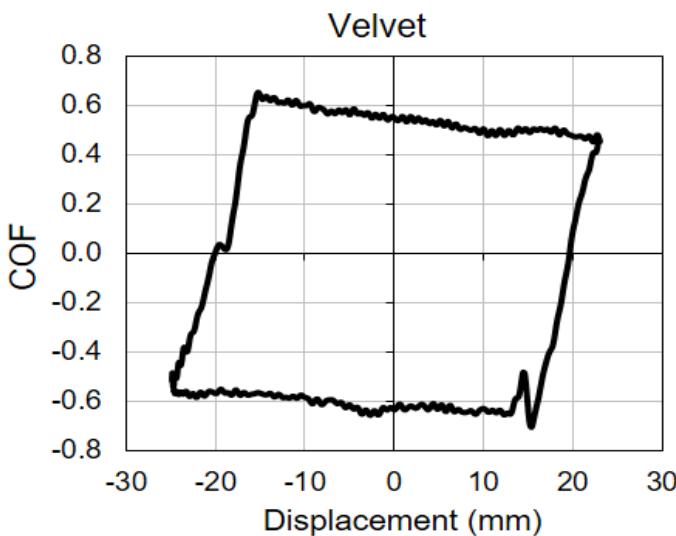
“Ratchet”
Imbrication



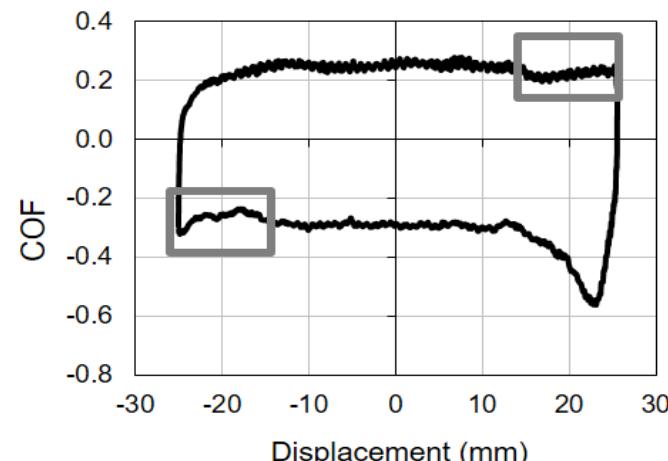
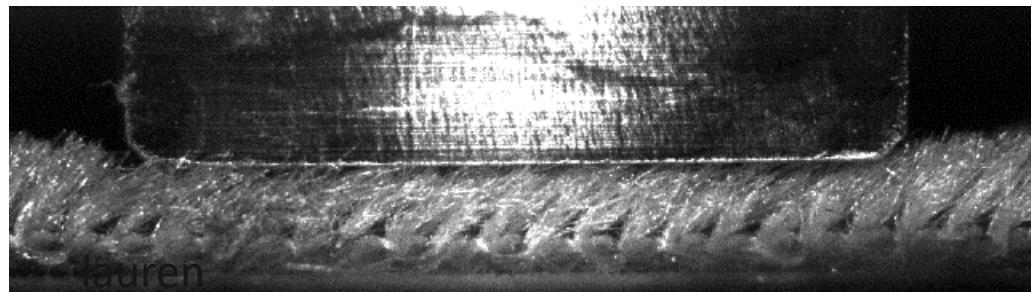
Touched surface

Friction definition and origin

Target : human finger

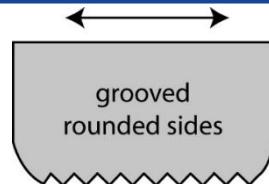
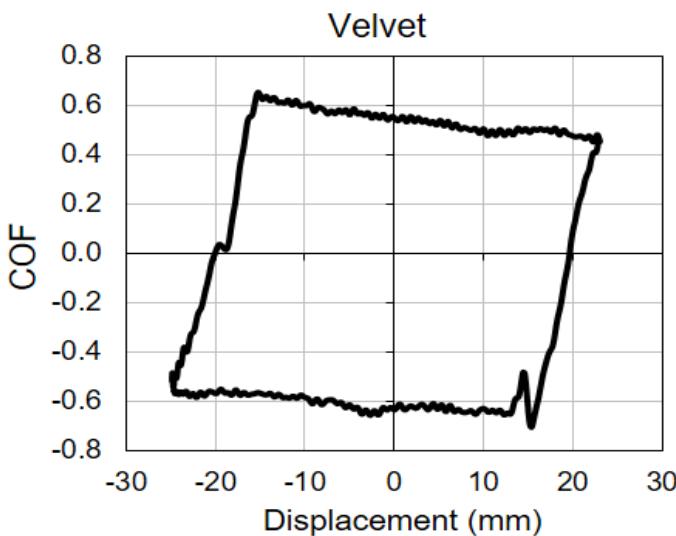


“Ratchet”
Imbrication

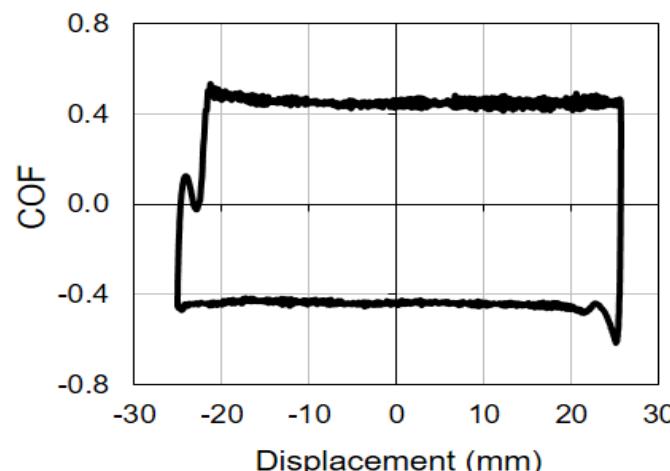
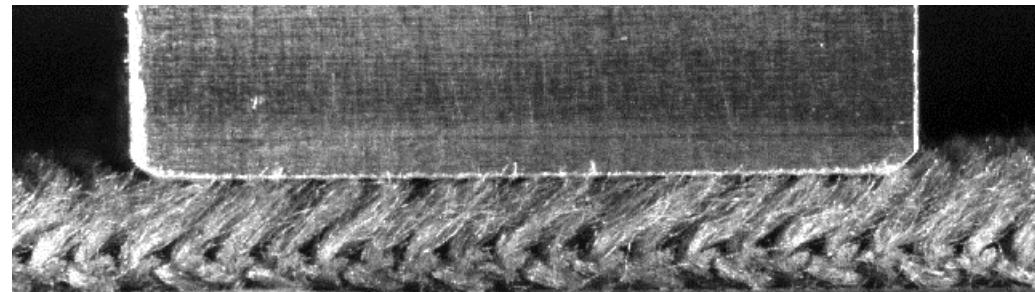


Friction definition and origin

Target : human finger

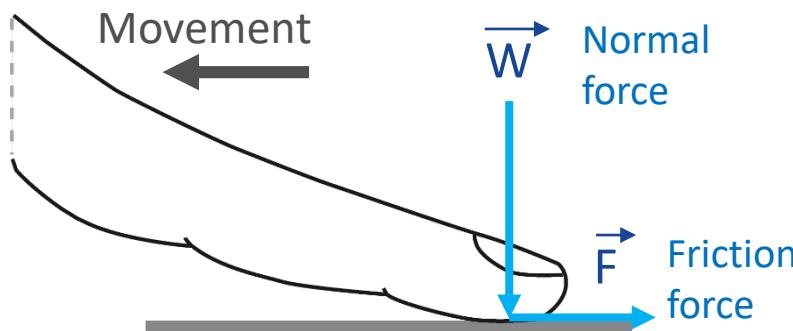


“Ratchet”
Imbrication



Influence of normal load on friction,
humidity or other contaminant

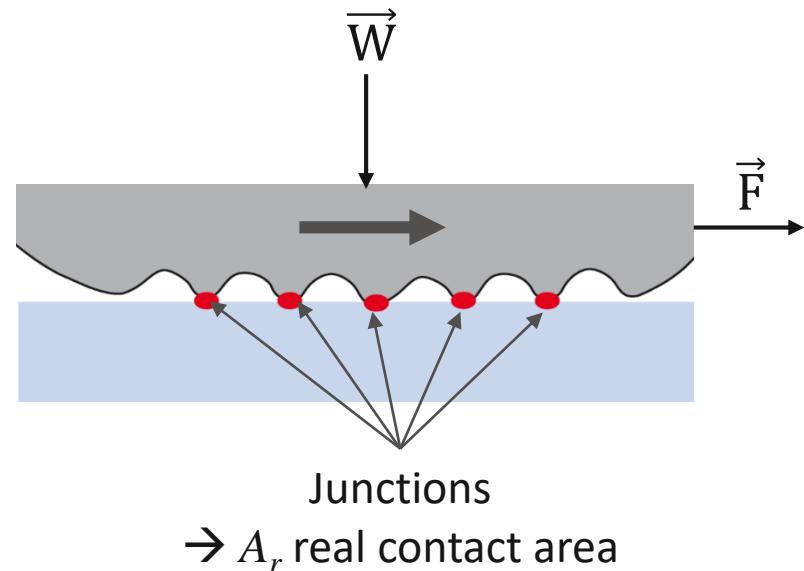
Influence of normal force



$$\tau: \text{shear strength (Pa)} \quad \tau = \tau_0 + \mu_0 \frac{W}{A_r}$$

$$A_r: \text{real contact area (m}^2\text{)} \quad A_r = k \cdot W^n$$

$$n \in [2/3, 1]$$



→ $F_{adh} = k' \cdot W^n + \mu_0 \cdot W$

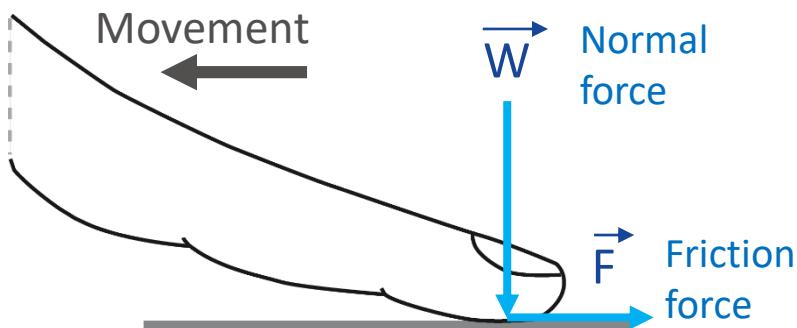
→ $F = F_{adh} = \tau \cdot A_r$

Bowden FP, Tabor D. *The Friction and Lubrication of Solids*. Oxford University Press ed. New York 1954.

Bowden FP, Young JE. *Proceedings of the Royal Society of London Series A*. 1951; 208, 444-55

Briscoe BJ, Tabor D. *Shear Properties of Thin Polymeric Films*. *The Journal of Adhesion*. 1978;9(2):145-55.

Influence of normal force



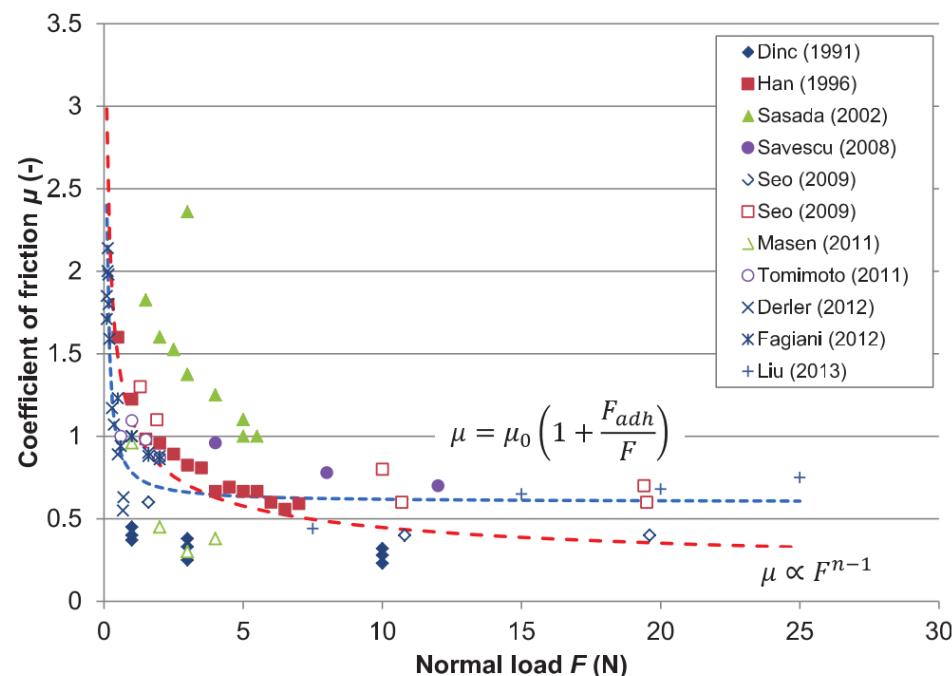
$$\mu_{adh} = \tau_0 \cdot \frac{A_r}{W} + \mu_0$$

$$\mu_{adh} = \tau_0 \cdot k \cdot W^{n-1} + \mu_0$$

$$n \in [2/3, 1]$$

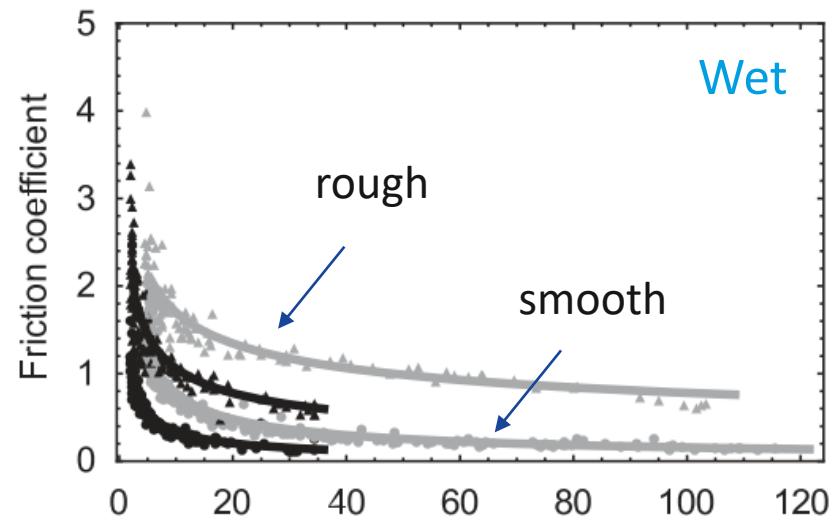
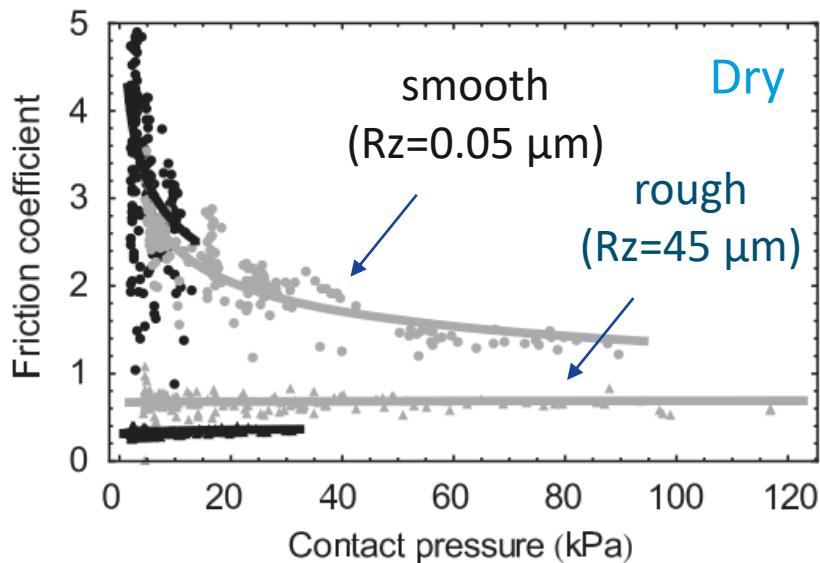
If $n = 1$ coefficient of friction $\mu = \text{constant}$

Adhesion



Influence of normal force and humidity

Finger on hard surface (glass)



Smooth surfaces $\rightarrow A_r = k \cdot W^n \quad n < 1 \quad \rightarrow \mu_{adh} = \tau_0 \cdot k \cdot W^{n-1} + \mu_0$

Rough surfaces $\rightarrow A_r = k \cdot W \quad n = 1 \quad \rightarrow \mu_{adh} = \text{constant}$

\rightarrow Water reduces the friction level \rightarrow acts as a lubricant

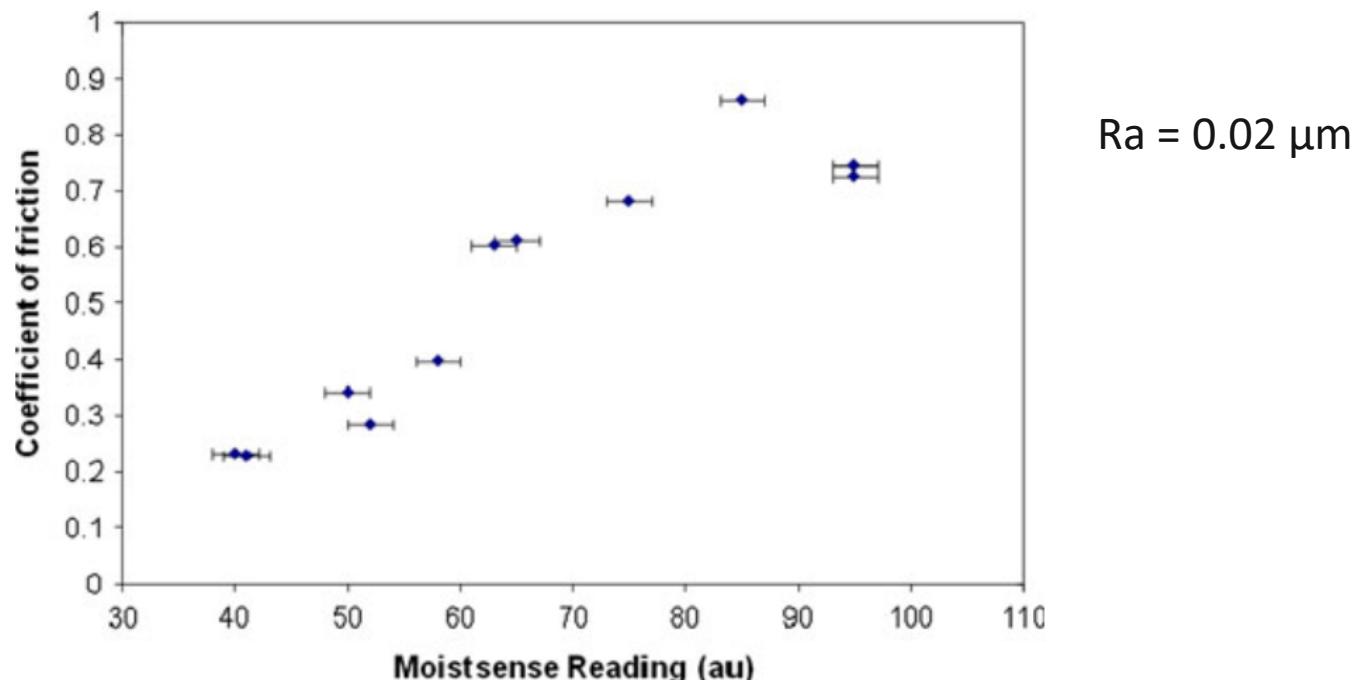
Archard JF, Allibone TE. Elastic deformation and the laws of friction. Proceedings of the Royal Society of London Series A Mathematical and Physical Sciences. 1957;243(1233):190-205.

Greenwood JA, Tripp JH. The Elastic Contact of Rough Spheres. Journal of Applied Mechanics. 1967;34(1):153-9.

Derler et al.. Friction of human skin against smooth and rough glass as a function of the contact pressure. Tribol Int. 2009;42:1565-74.

Influence of normal force and humidity

Finger on hard surface (PVC)

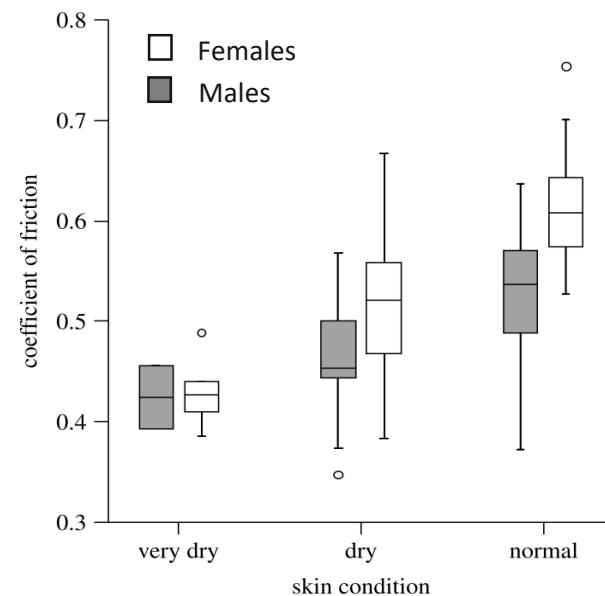
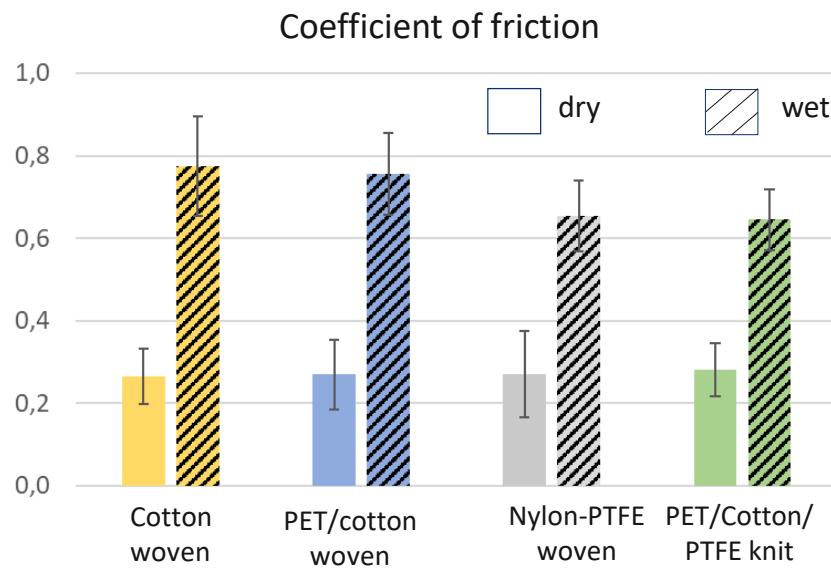


Water increases the friction level

Water increases or decreases friction level depending of the quantity

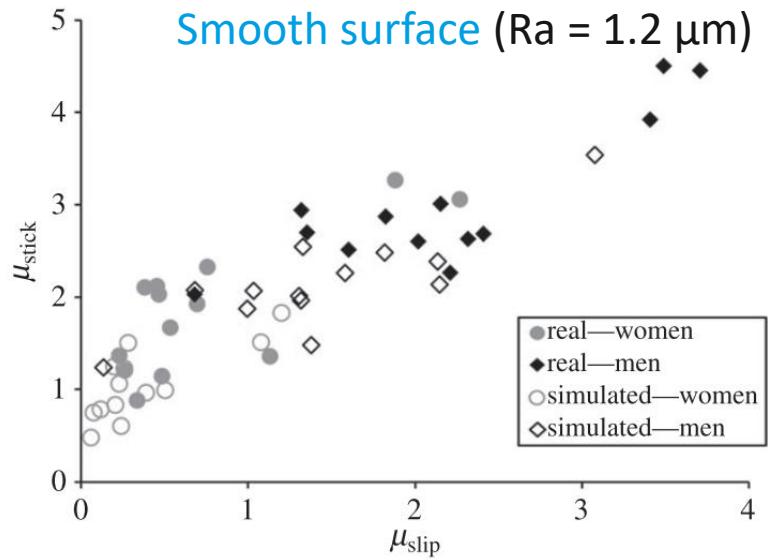
Influence of humidity

Skin on softer and porous surface (textiles)

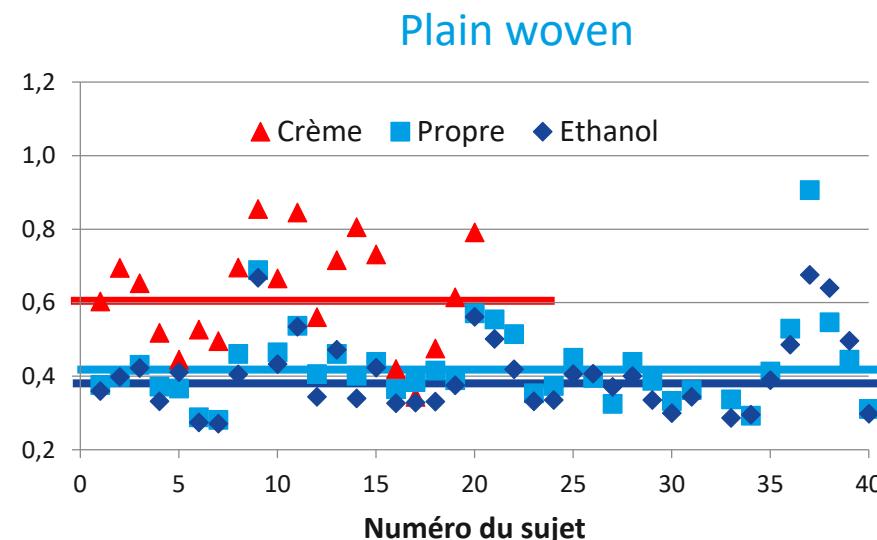


On textile fabrics (porous materials) water Increases the friction level

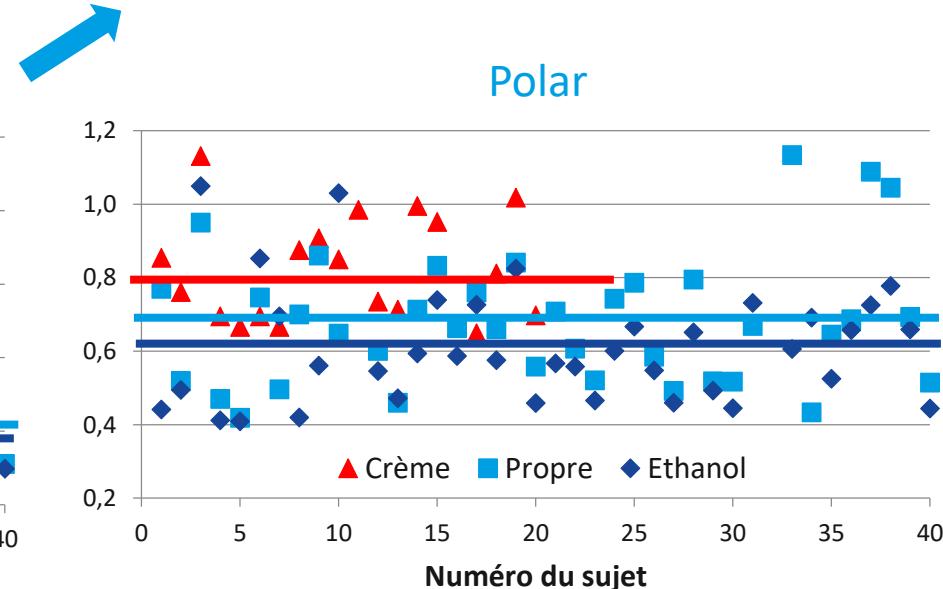
Influence of finger contaminants



Non porous materials
COF very sensitive to hydrolopidic film composition

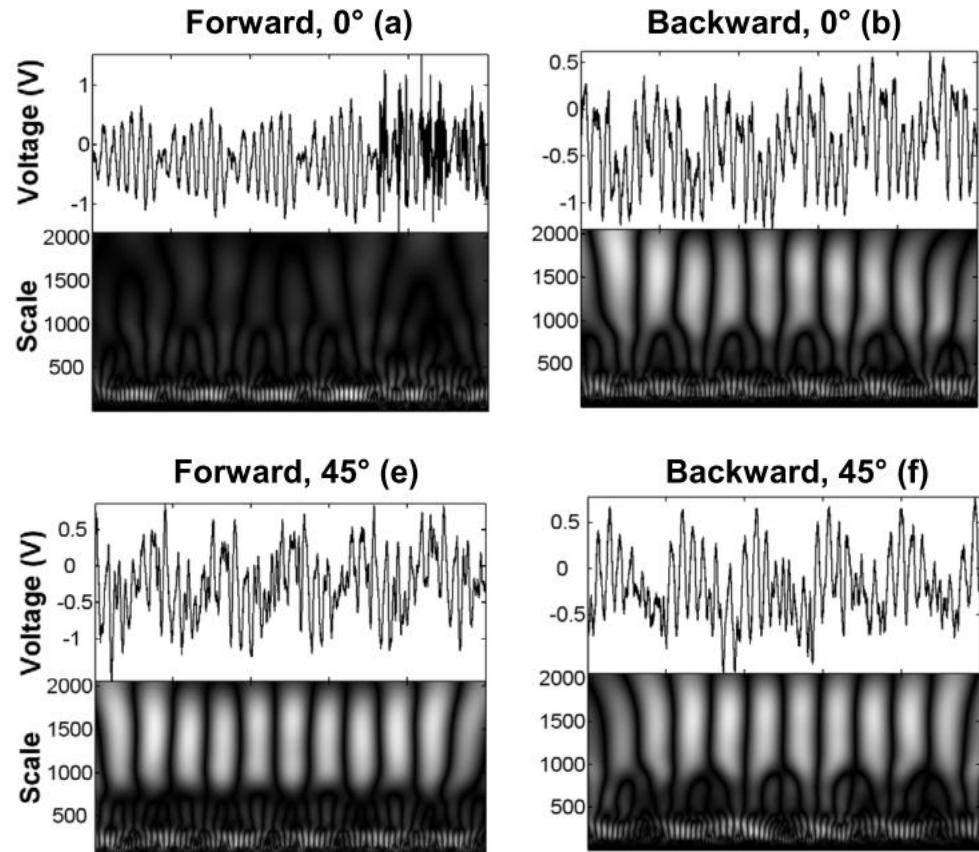
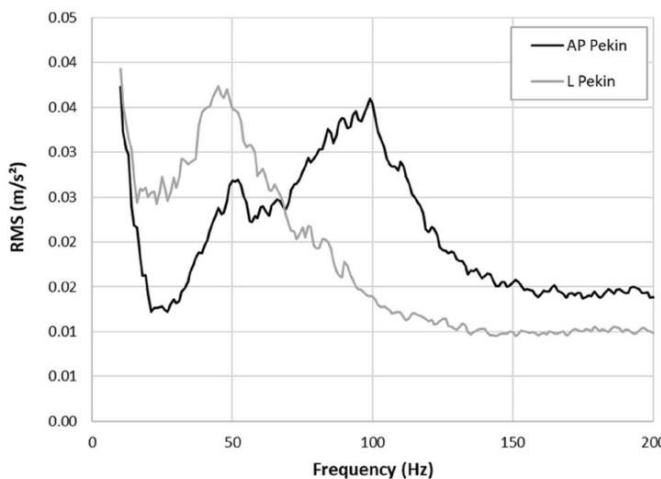
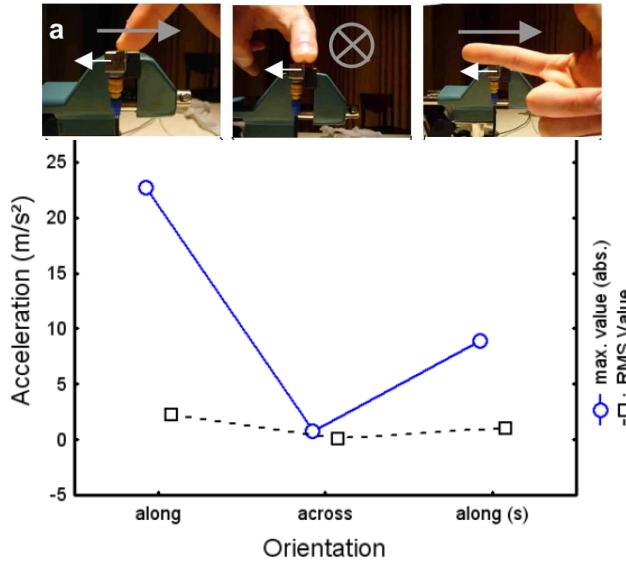


Porous materials
COF is slightly higher with cream
Effect less significant with pile



Influence of finger movement

Influence of finger movement

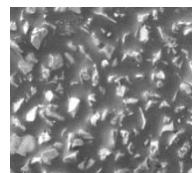


Influence of texture

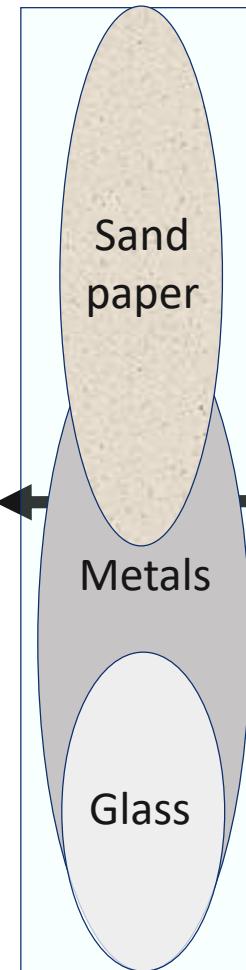
Influence of texture

Non porous materials

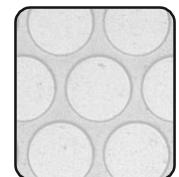
Rough Ra or SP > 1 mm



Stochastic



Smooth Ra or SP < 0.1 μm

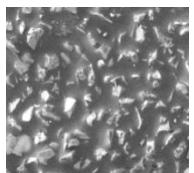


Deterministic

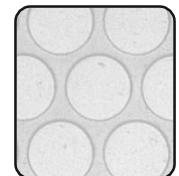
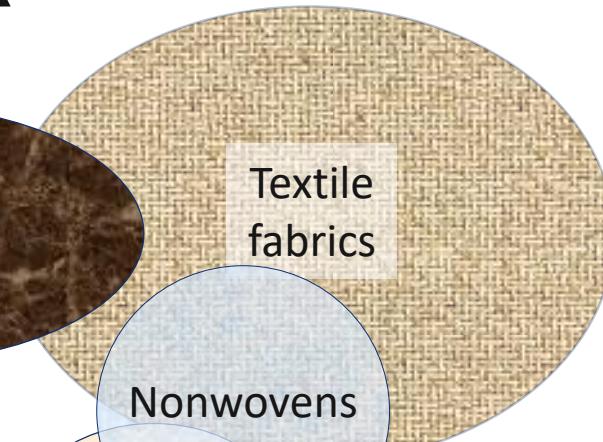
Influence of texture

Porous materials

Rough Ra or $SP > 1 \text{ mm}$



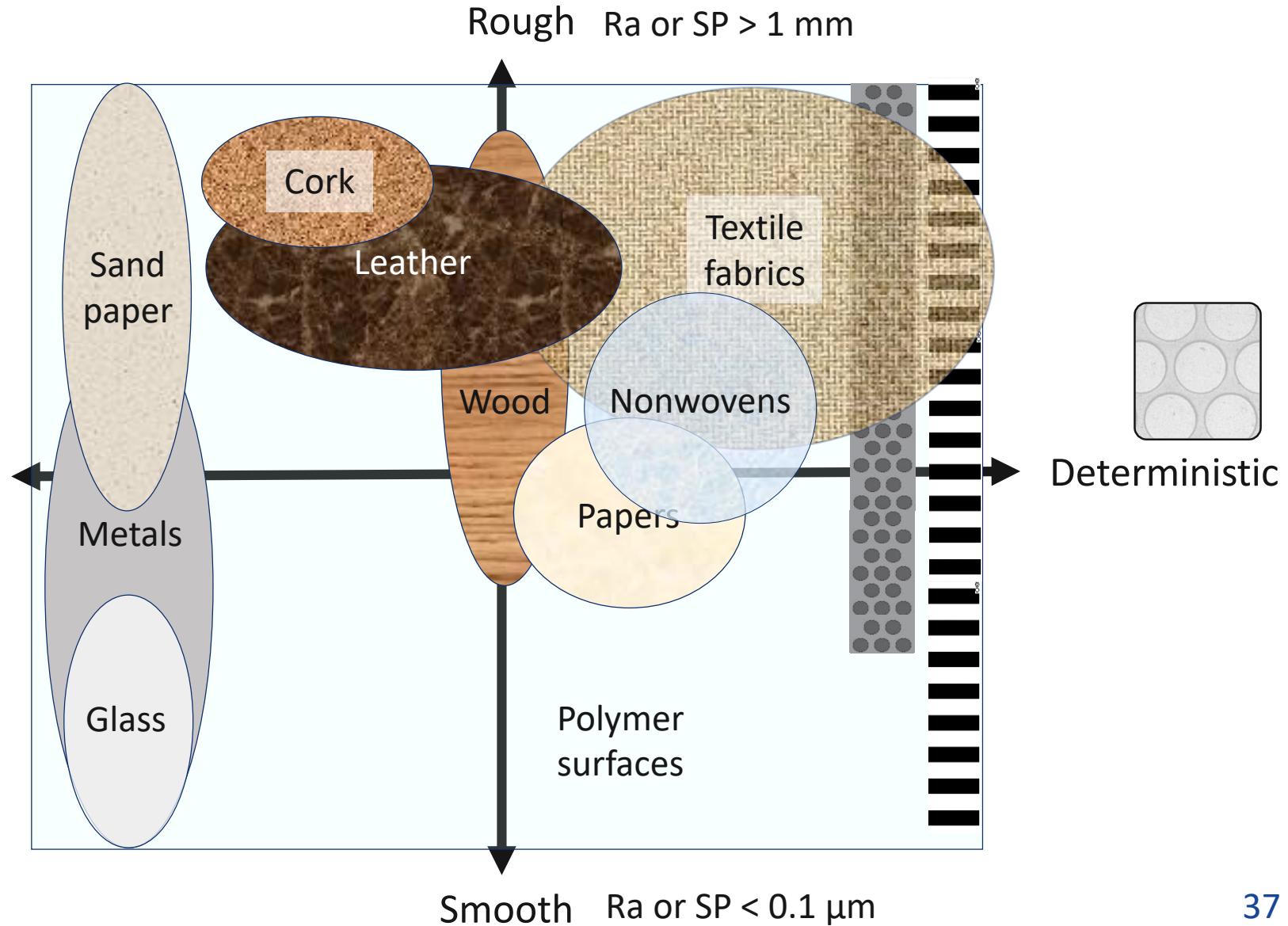
Stochastic



Deterministic

Smooth Ra or $SP < 0.1 \mu\text{m}$

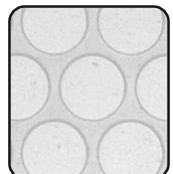
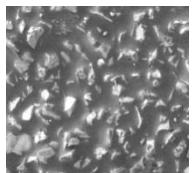
Influence of texture



Influence of texture

Non porous materials

Rough Ra or SP > 1 mm



Stochastic

Deterministic

Humidity

Real contact area

Material surface tension

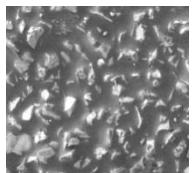
$$F = F_{adh} = \tau \cdot A_r$$

Smooth Ra or SP < 0.1 μm

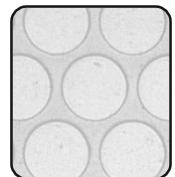
Influence of texture

Non porous materials

Rough $\text{Ra or SP} > 1 \text{ mm}$



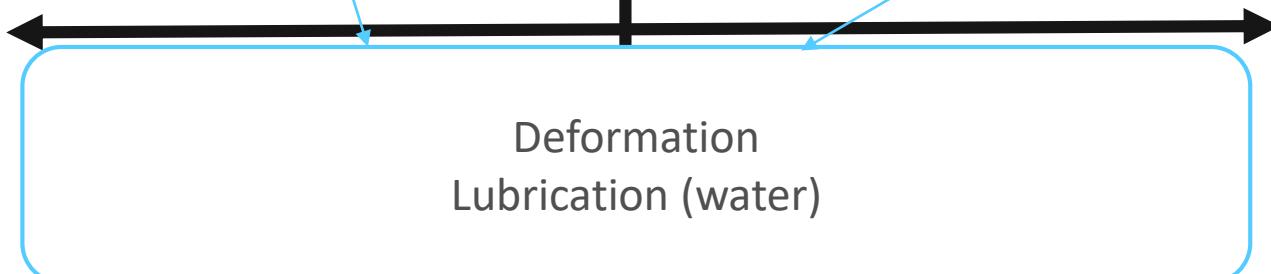
Real contact area



Contaminant property

Stochastic

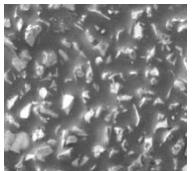
Deterministic



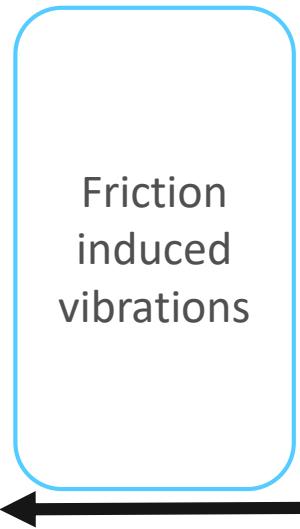
Smooth $\text{Ra or SP} < 0.1 \mu\text{m}$

Influence of texture

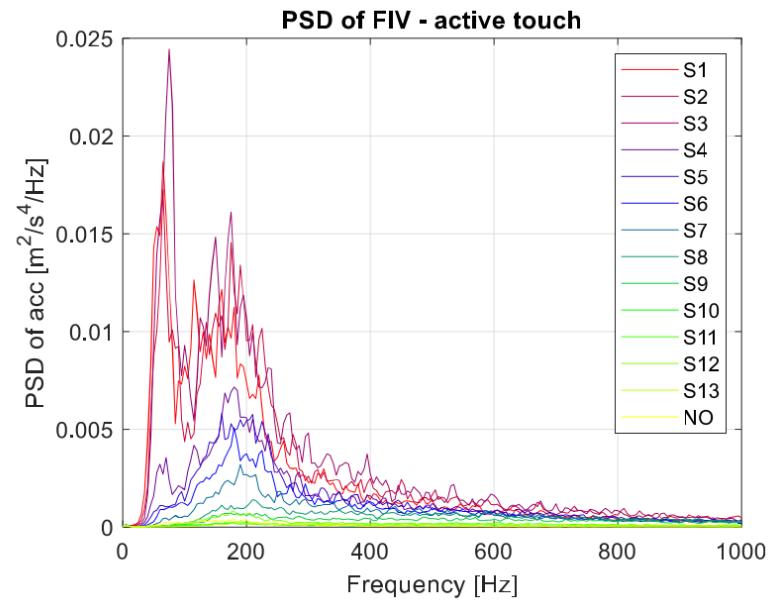
Non porous materials



Stochastic

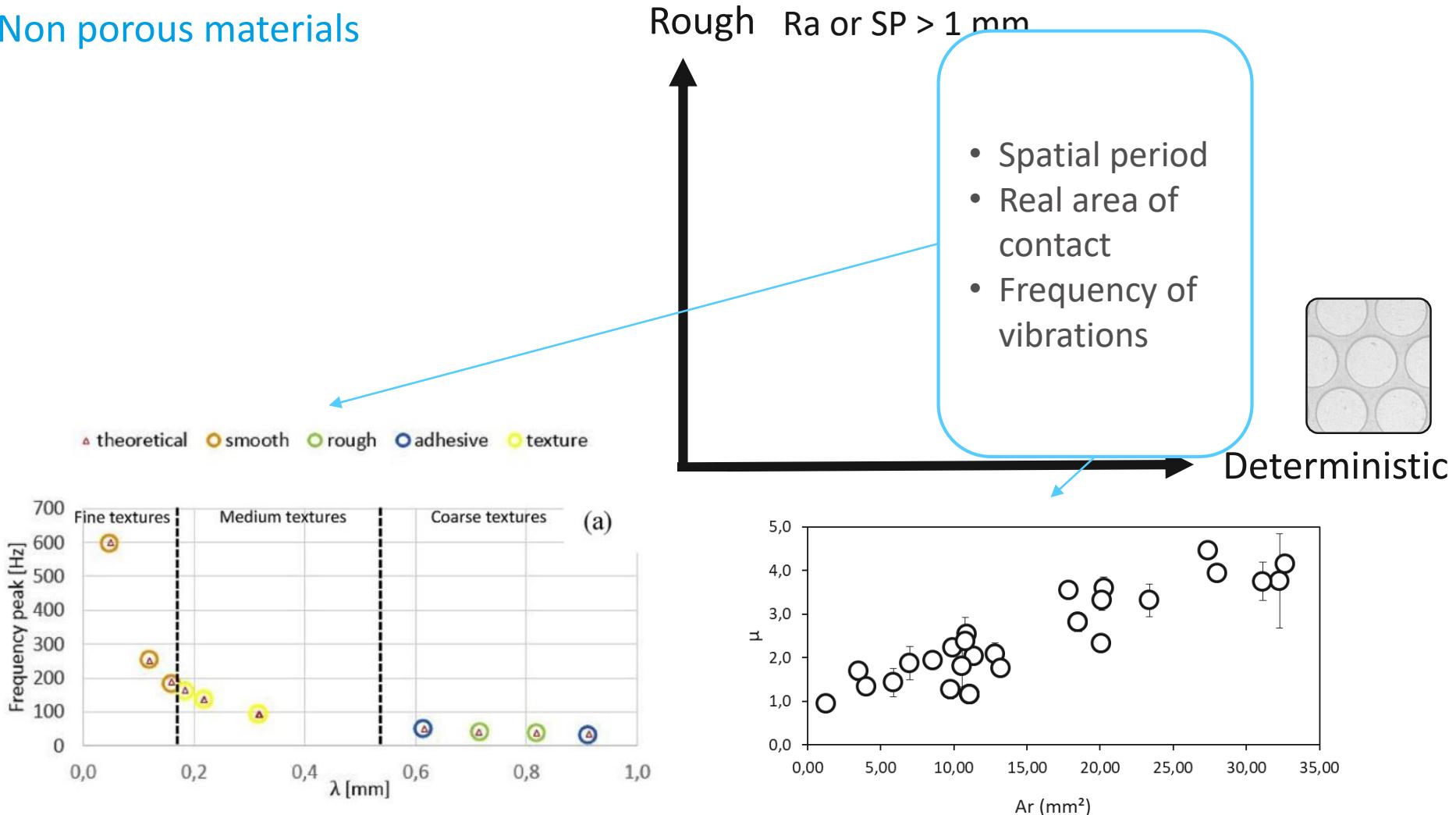


Rough Ra or SP > 1 mm



Influence of texture

Non porous materials



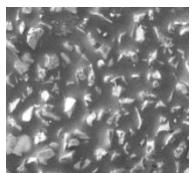
Weiland B. Tribologie et perception tactile de surface texturées [PhD thesis]: Université Bourgogne Franche-Comté; 2020.

Massimiani V, Weiland B, Chatelet E, Cornuault P-H, Faucheu J, Massi F. The role of mechanical stimuli on hedonistic and topographical discrimination of textures. *Tribol Int*. 2020;143:106082.

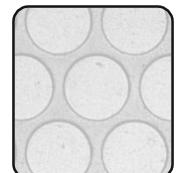
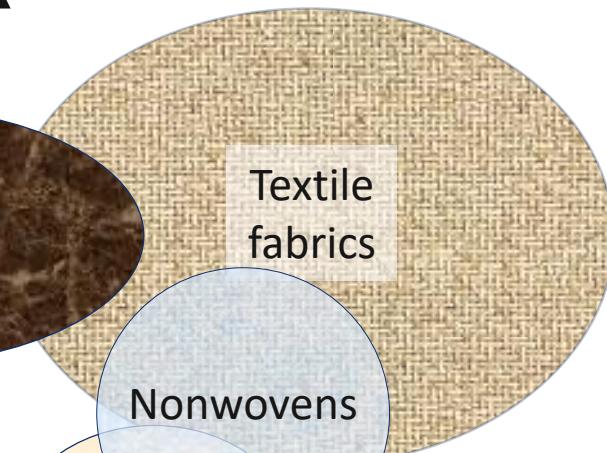
Influence of texture

Porous materials

Rough R_a or $SP > 1 \text{ mm}$



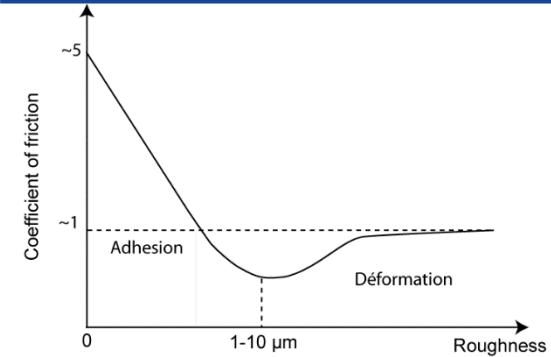
Stochastic



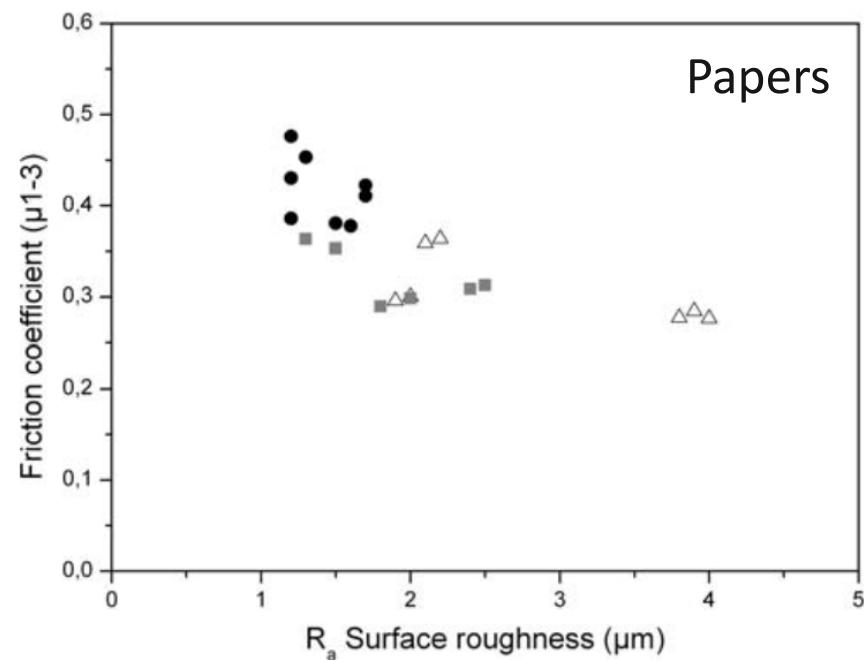
Deterministic

Smooth R_a or $SP < 0.1 \mu\text{m}$

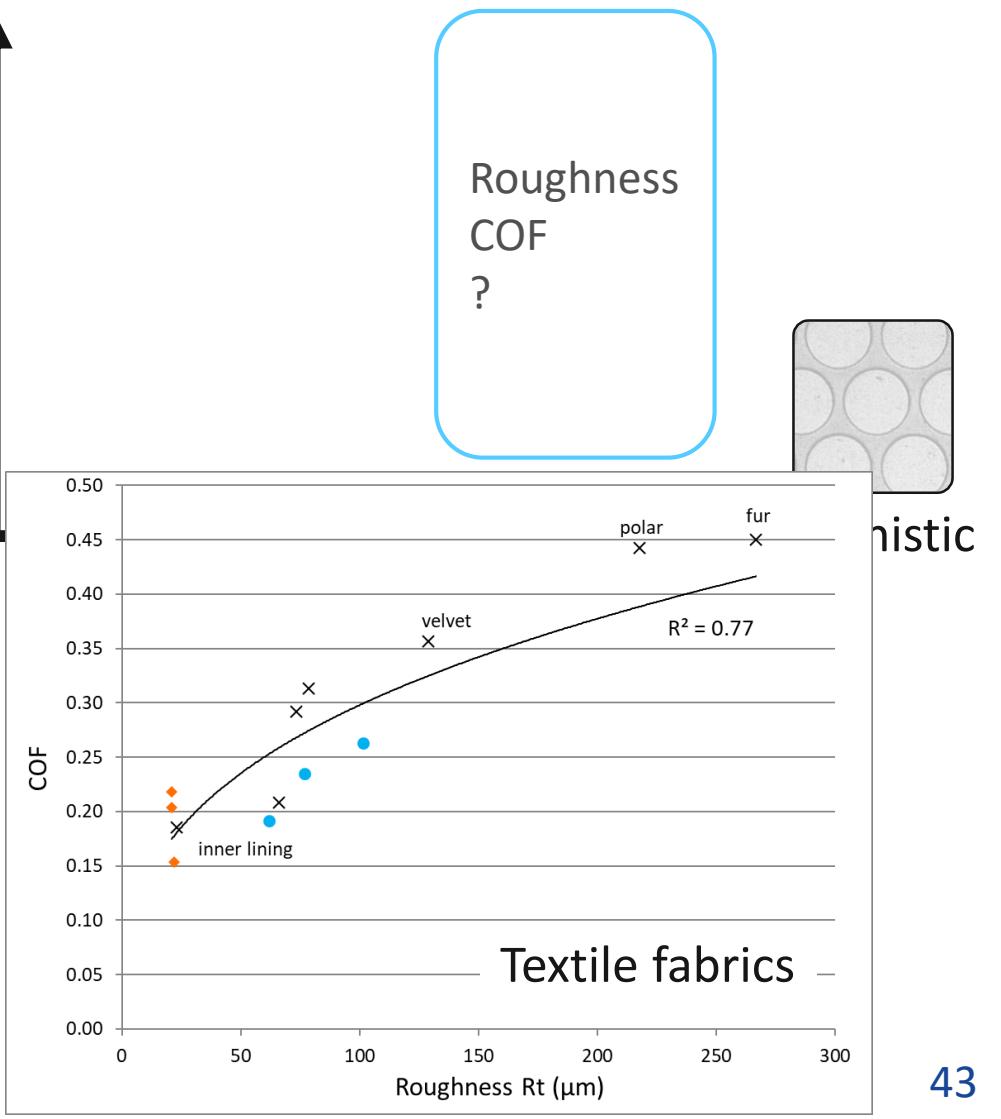
Influence of texture



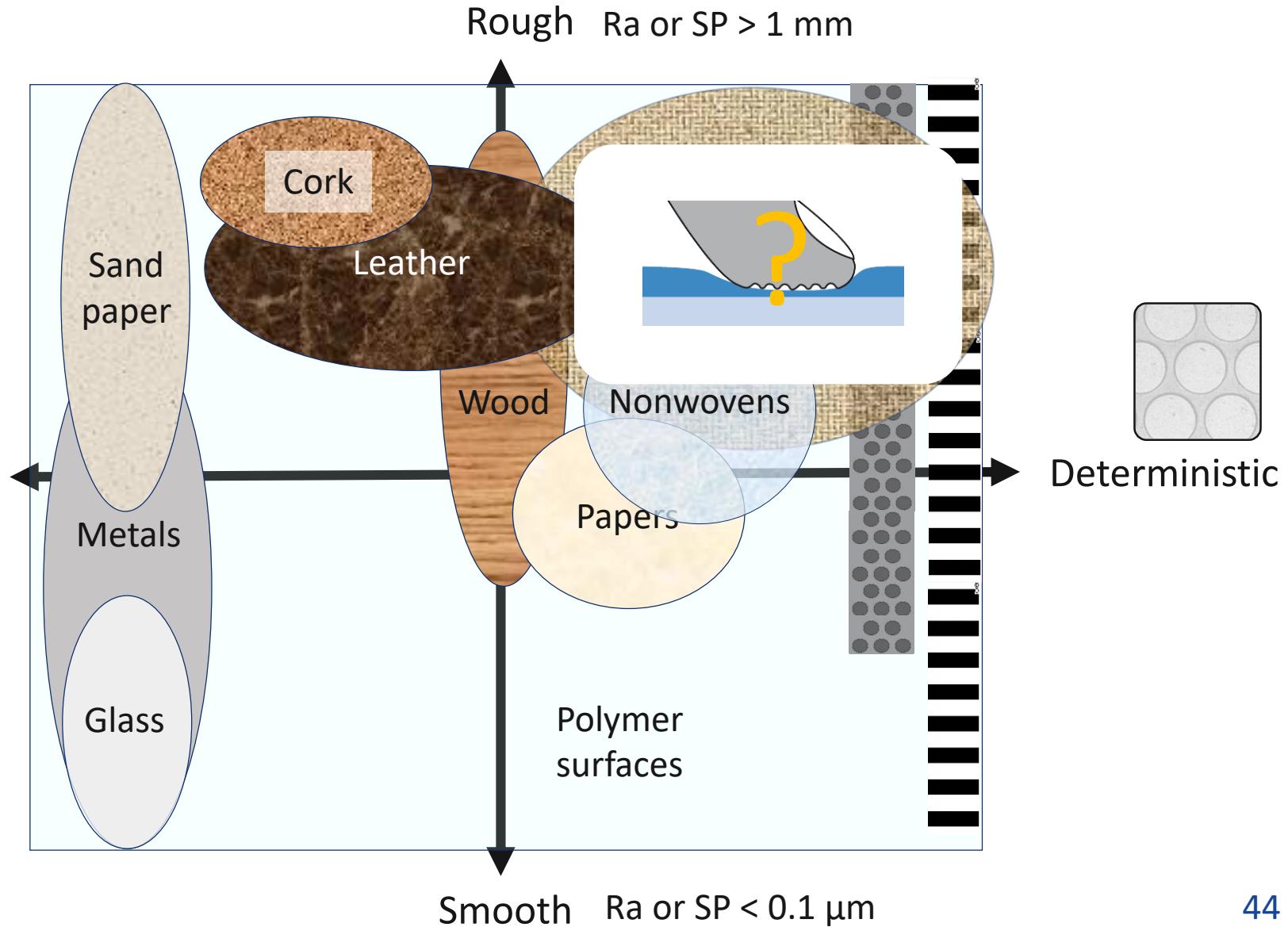
Skedung L, Danerlöv K, Olofsson U, Aikala M, Niemi K, Kettle J, et al. Finger friction measurements on coated and uncoated printing papers. *Tribol Lett*. 2010;37:389-99.



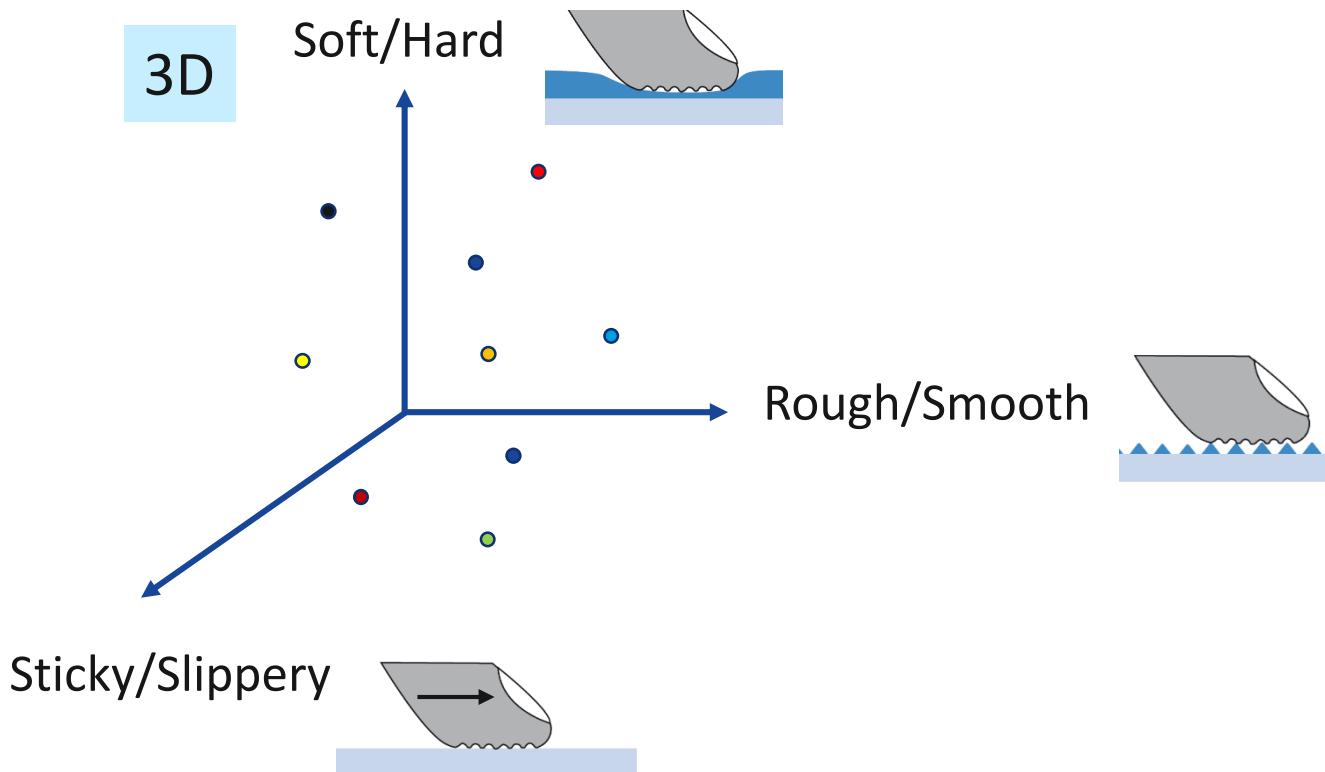
Rough Ra or SP > 1 mm



Influence of texture



Perceptual dimensions for tactile textures



Hollins M., Bensmaïa S., Karlof K. et Young F., "Individual differences in perceptual space for tactile textures: Evidence from multidimensional scaling" - Perception & Psychophysics, vol. 62, n°8, p.1534-1544, 2000.

Picard D., Dacremont C., Valentin D. et Giboreau A., "Perceptual dimensions of tactile textures" - Acta Psychologica, vol. 114, p.165-184, 2003.

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