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➤ Quantitative ultrasound to explore tactile perceptions of food elicited by tongue-palate friction: a biomimetic approach

Miodrag Glumac, Véronique Bosc, Paul Menut, Marco Ramaioli, Frédéric Restagno, Sandrine Mariot, Vincent Mathieu*

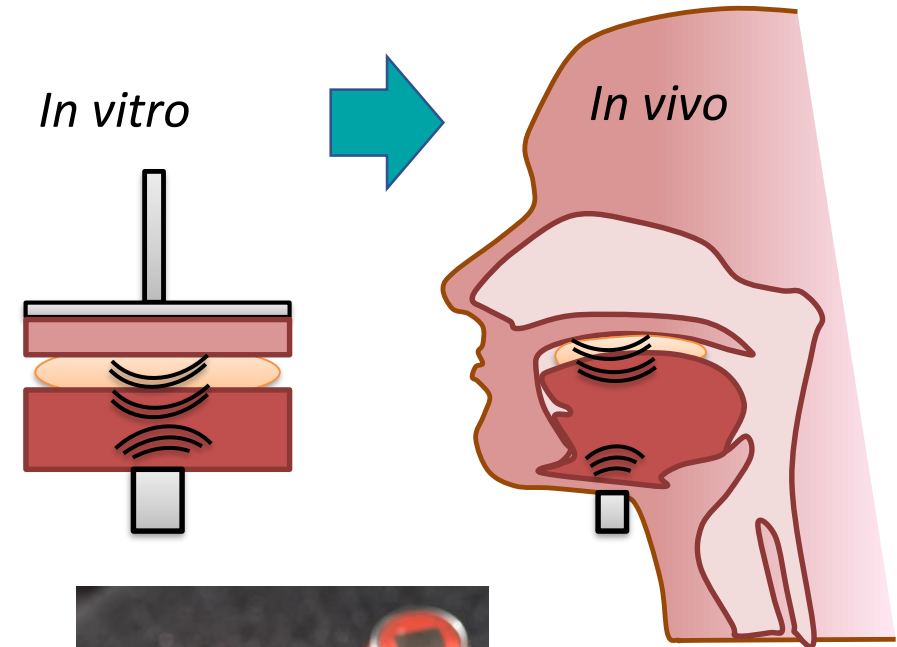
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Science & Technology of Milk & Eggs (STLO)
Rennes, FRANCE
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➤ Unravelling the mechanisms of texture perception

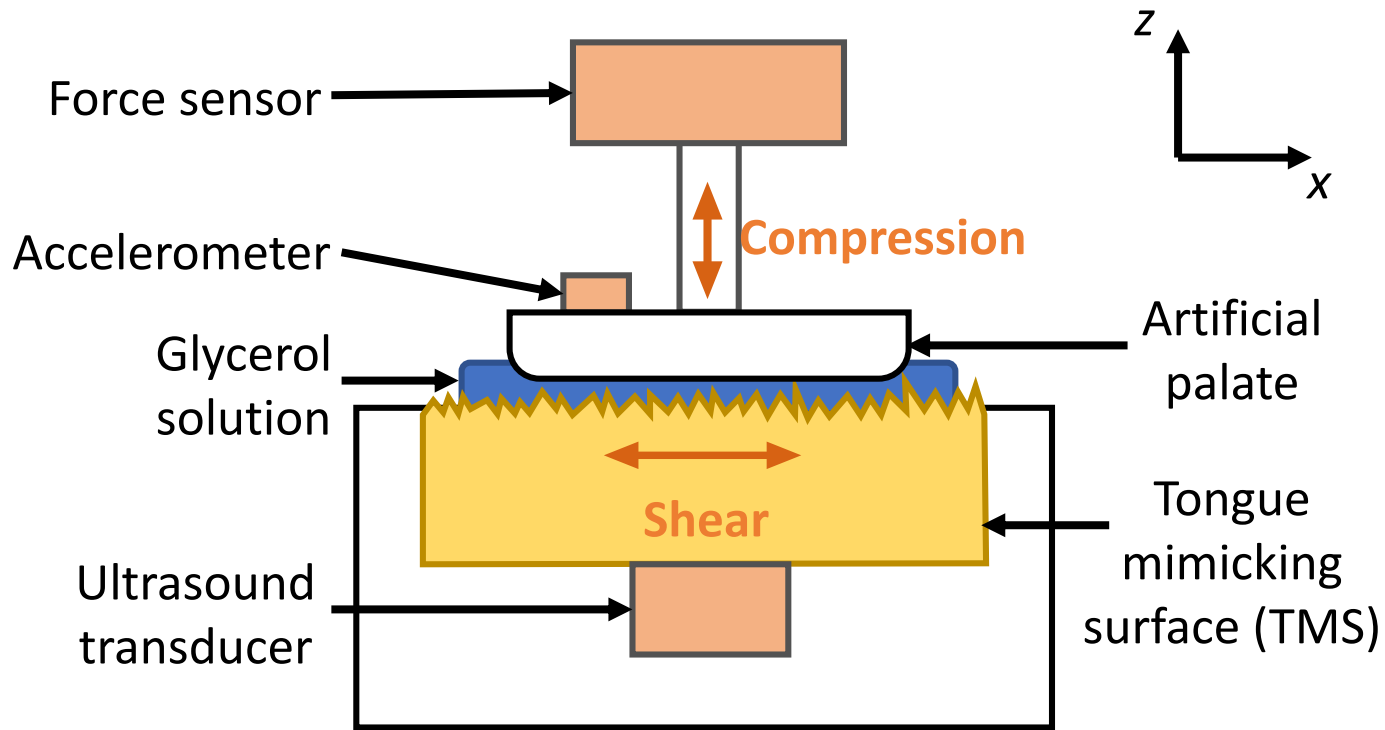
Towards the development of innovative methods in physiologically relevant environments

- Tongue has a central role in texture perception of food
- Mechanoreceptors with varied ranges of sensitivity (amplitude & frequency)
- Critical needs :
 - Physiologically relevant testing environments
 - Original techniques to monitor the mechanical interactions between the tongue, the food and the palate
- What about the potential of Ultrasound methods ?

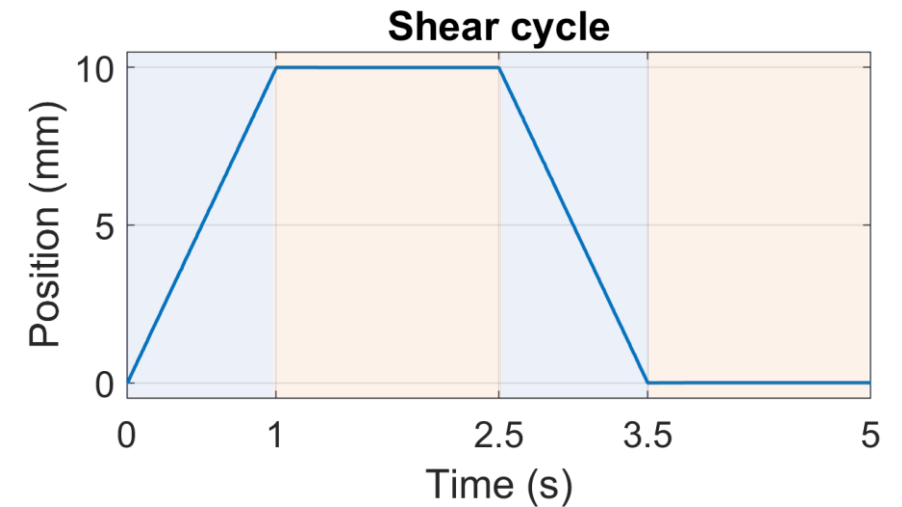
Let's see what we can get from them on a tongue-palate biomimicking testing bench...



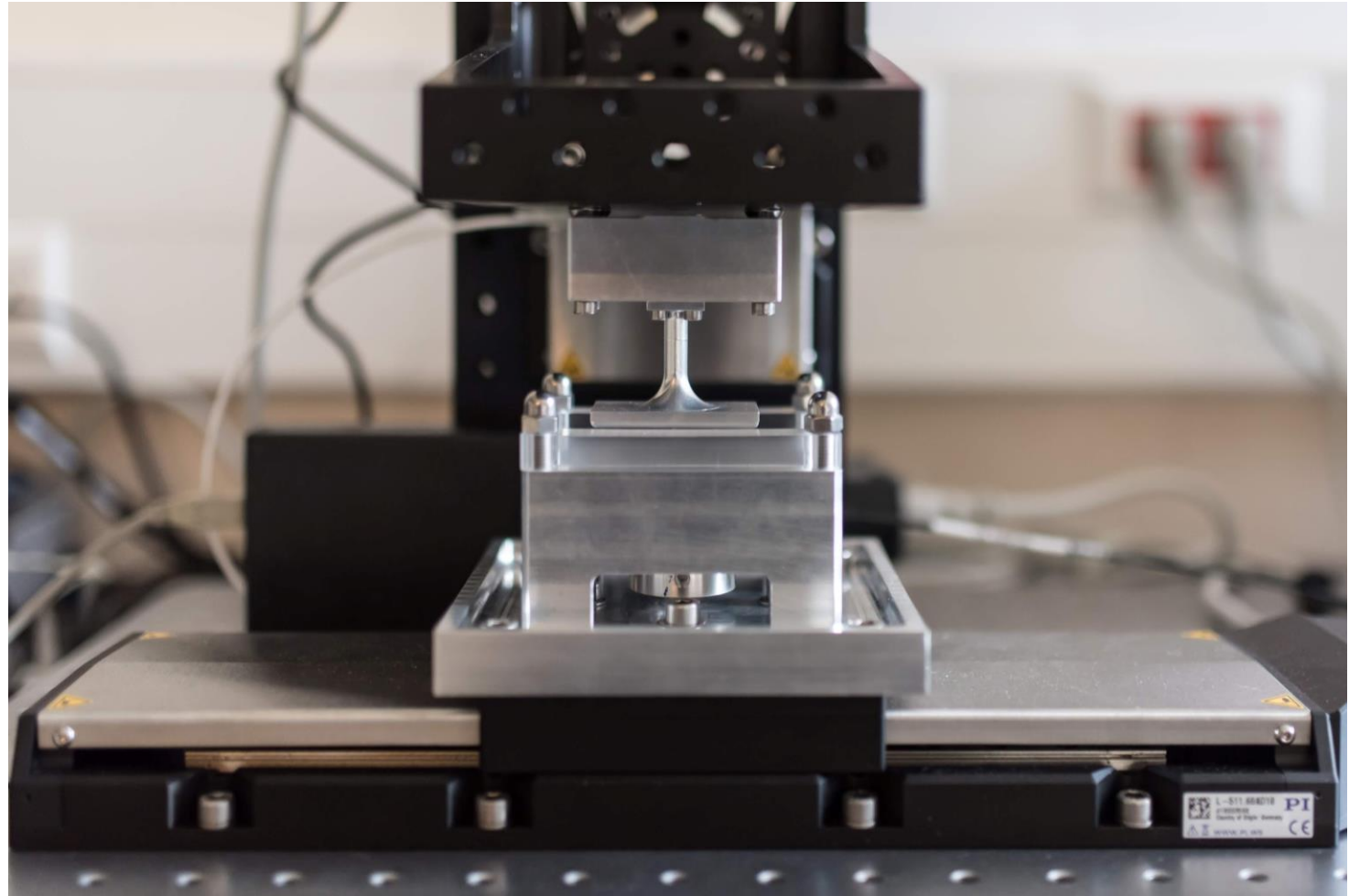
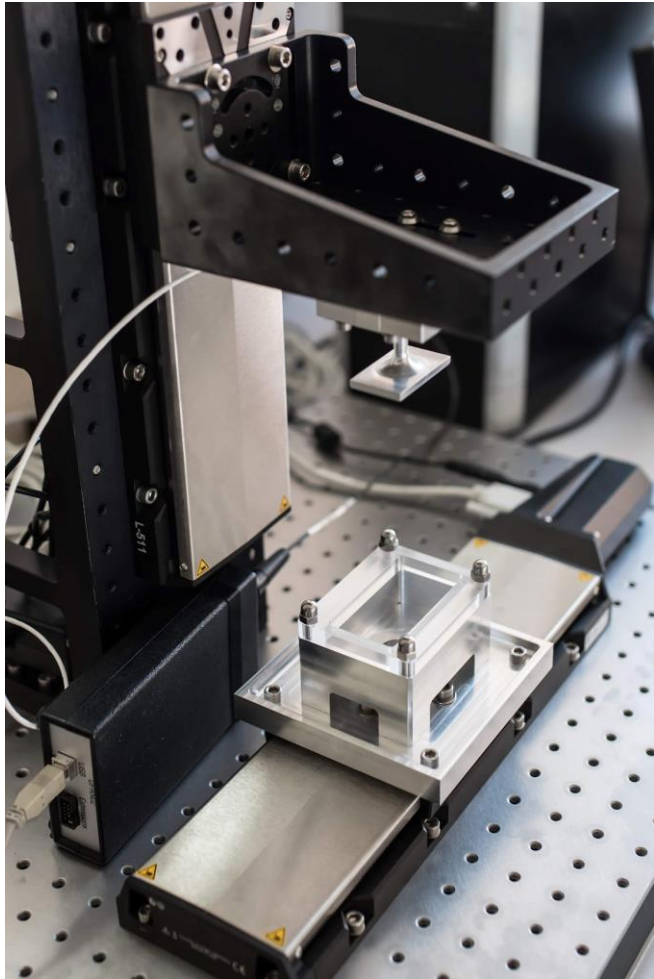
➤ Tongue palate biomimicking system



- Contact area : $45 \times 25 \text{ mm}^2$
- Imposed initial normal load : 10 N (around 9kPa)
- 5 cycles of shearing motions : Amplitude 10 mm; Velocity $10 \text{ mm}\cdot\text{s}^{-1}$



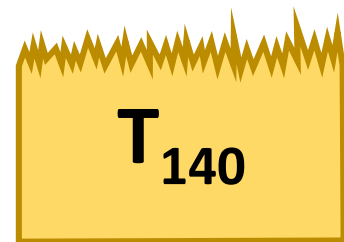
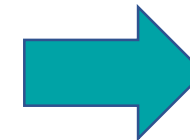
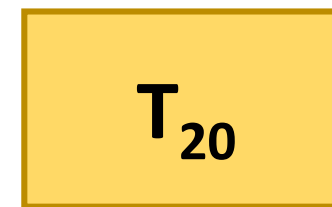
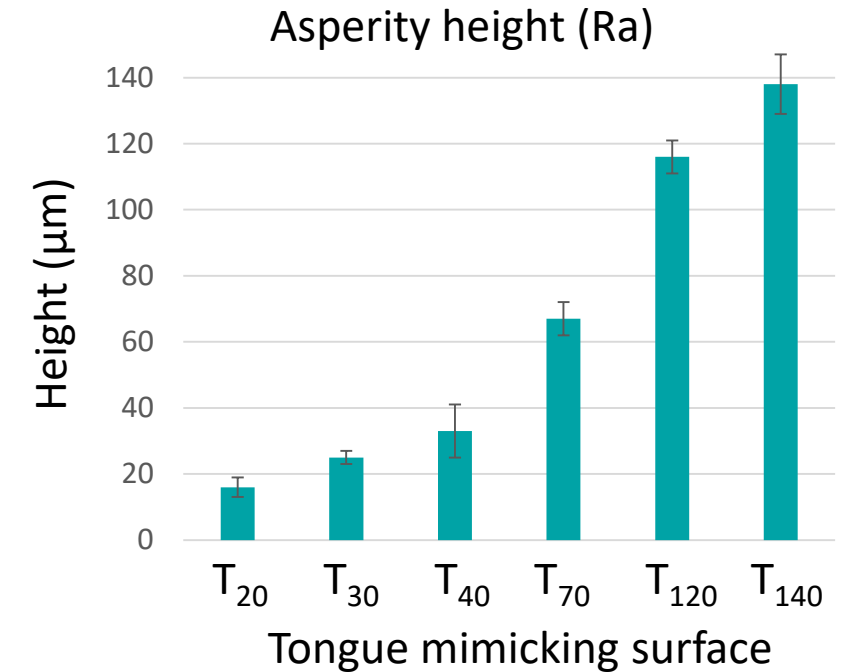
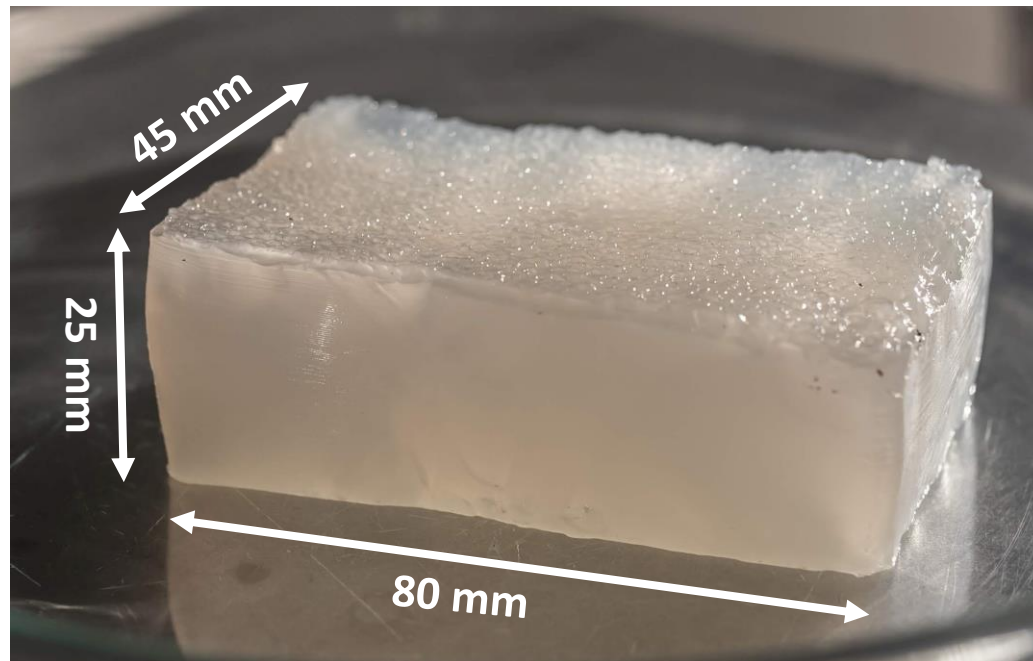
➤ Tongue palate biomimicking system



➤ Tongue mimicking surfaces

Design and characterization of 6 tongue mimicking surfaces (TMSs)

- 10% w/w Polyvinyle Alcohol cryogels
- Young's modulus : ~ 30 kPa
- US speed of sound : $1540 \text{ m}\cdot\text{s}^{-1}$
- Varied roughness



> Lubricants

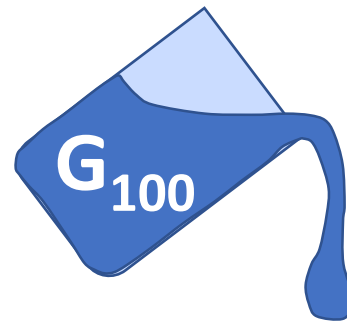
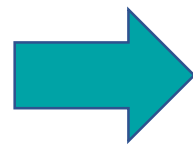
Preparation of 6 mixtures of water and glycerol

- Newtonian fluids
- Covering a wide range of viscosity

Solutions labels	G ₀	G ₅₀	G ₈₅	G ₉₃	G ₉₇	G ₁₀₀
Concentration (% w/w)	0	50	85	93	97	100

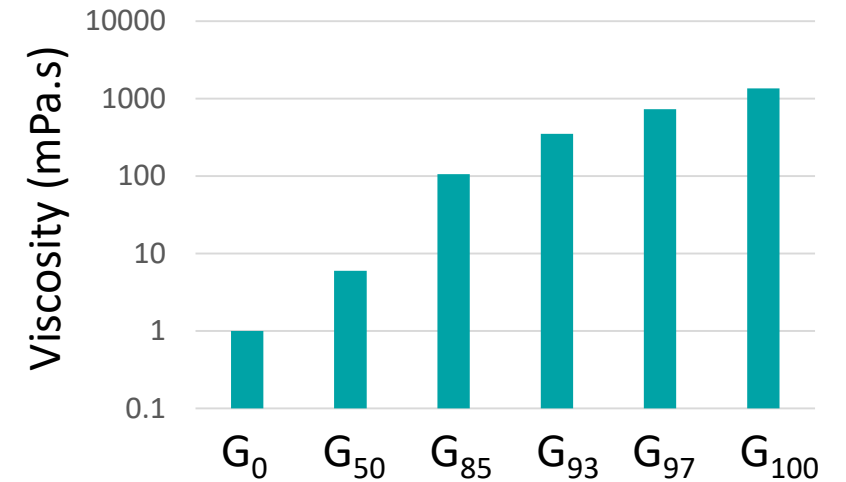


Pure water

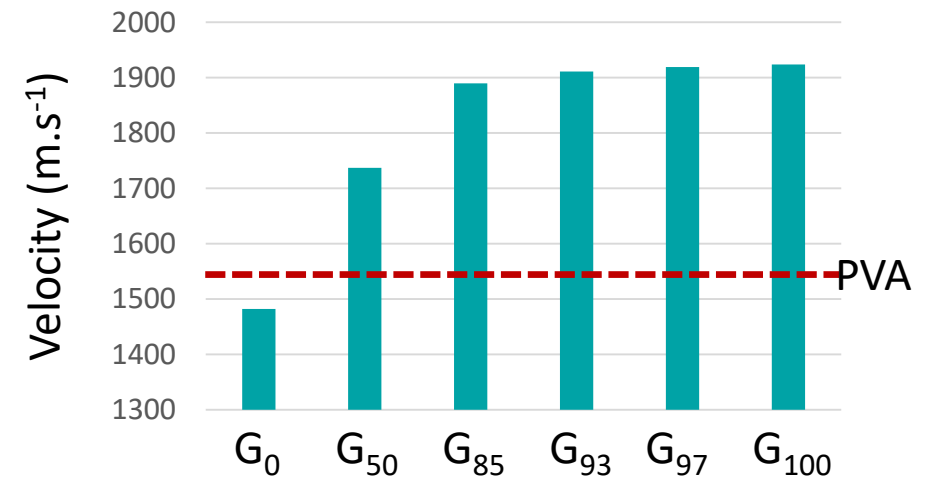


Pure glycerol

Viscosity of glycerol solutions

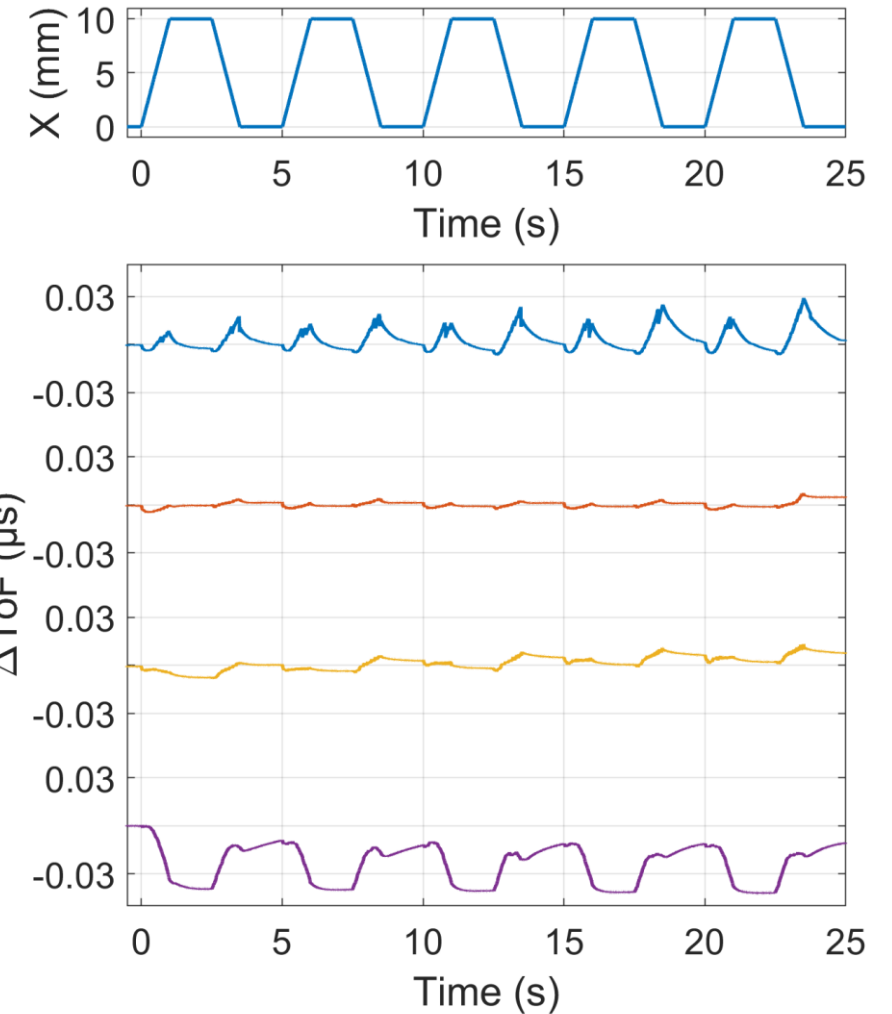
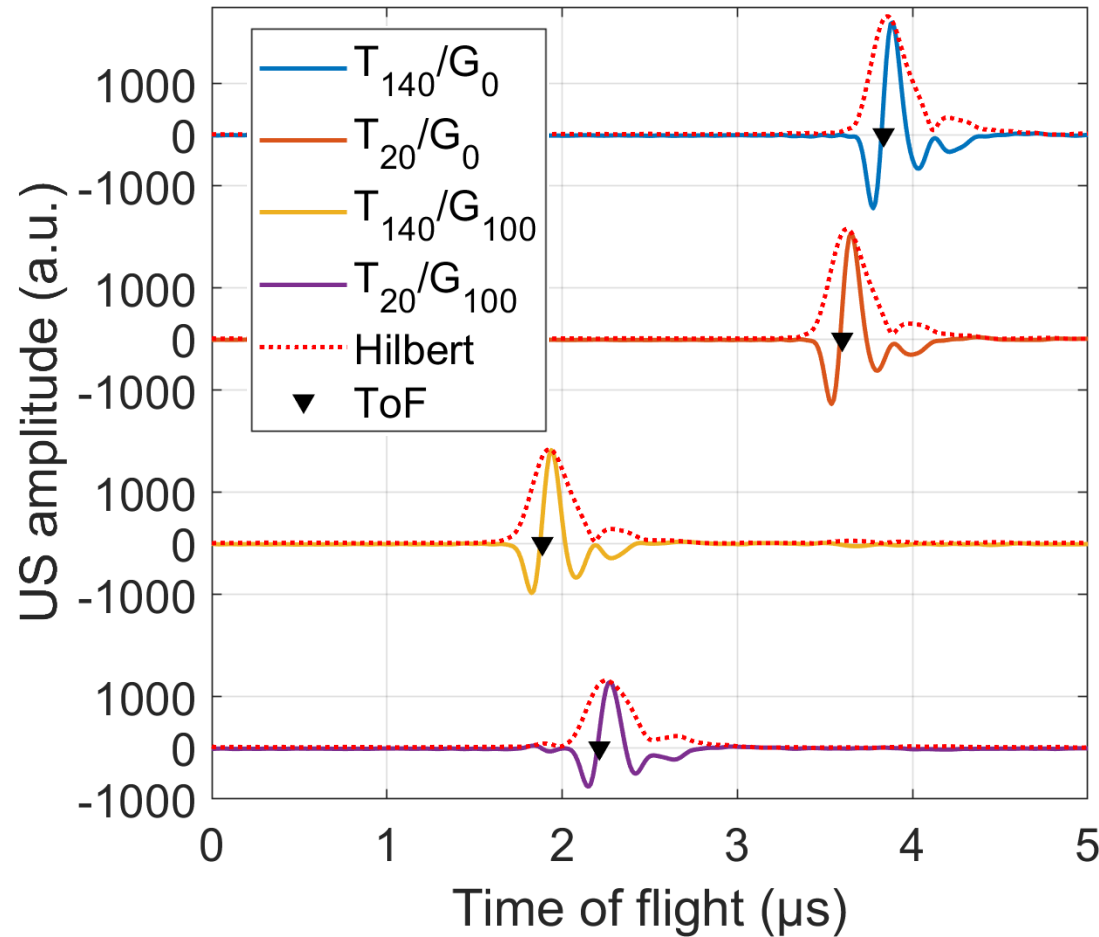
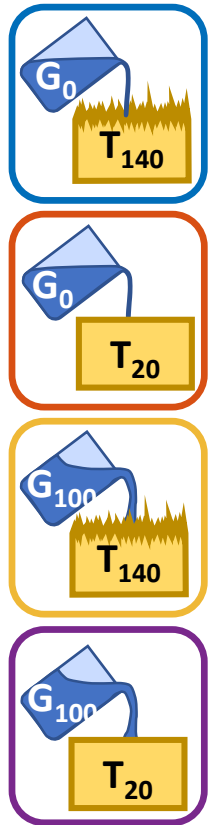


US velocity in glycerol solutions



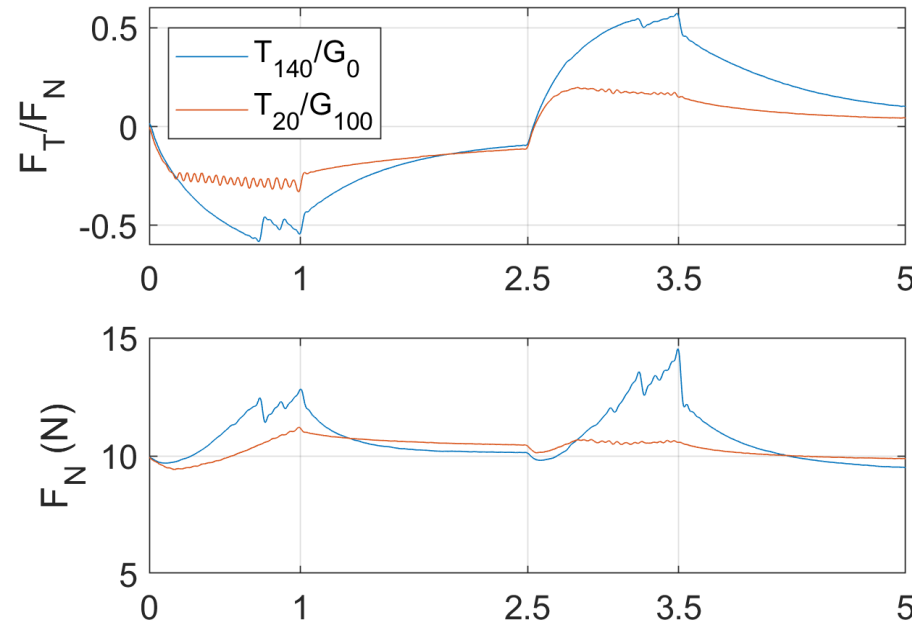
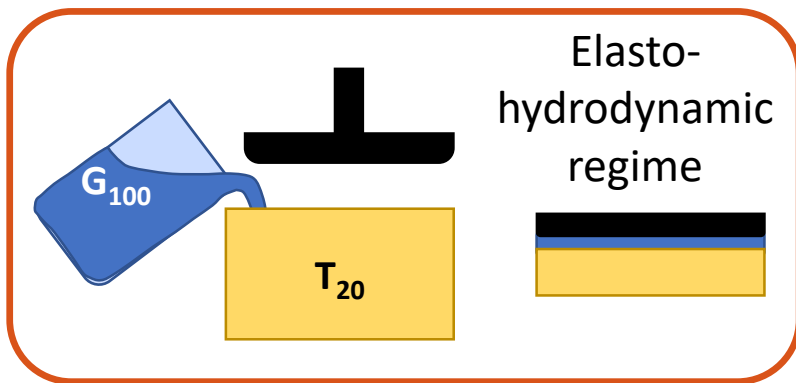
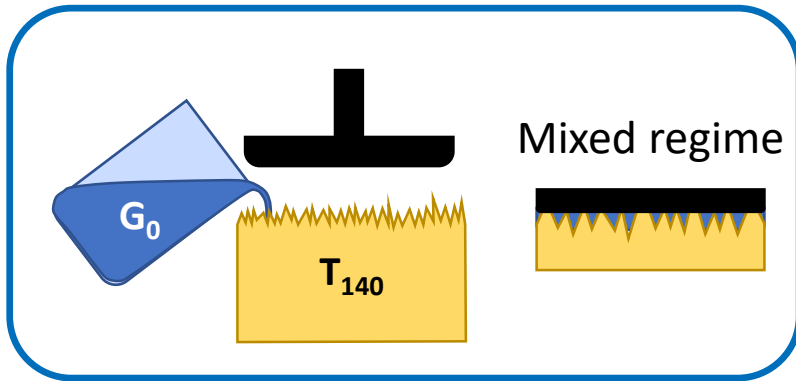
➤ Signal processing of ultrasound signals

Detecting & monitoring the time-of-flight of tongue-palate interface.



➤ US time-of-flight as a marker of lubrication regime

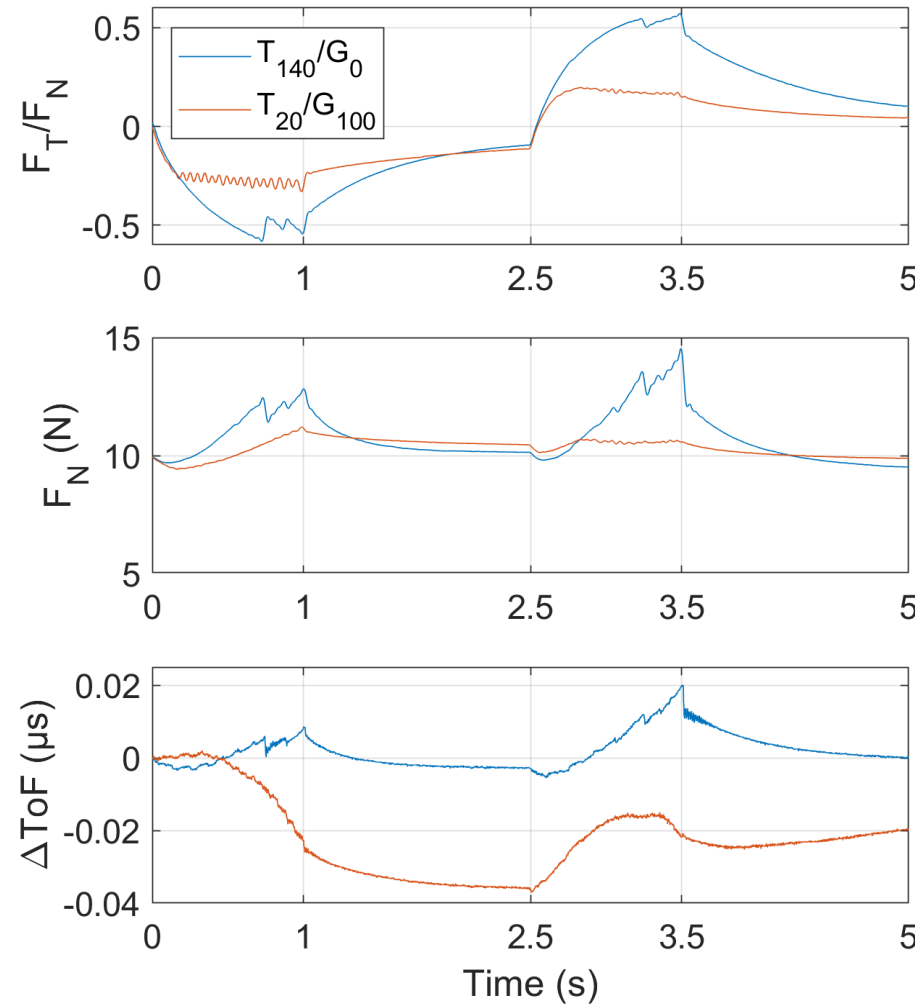
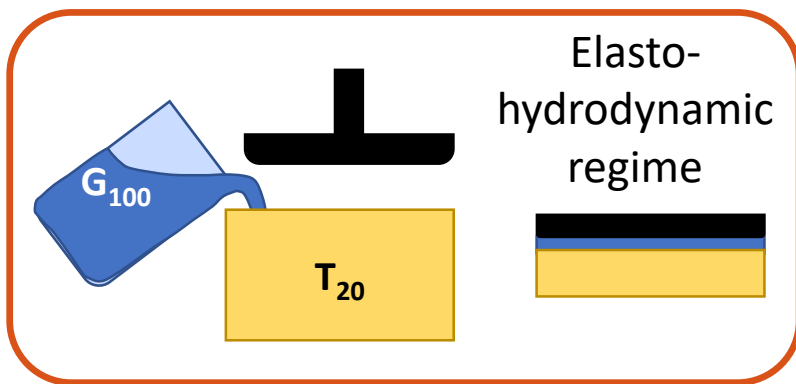
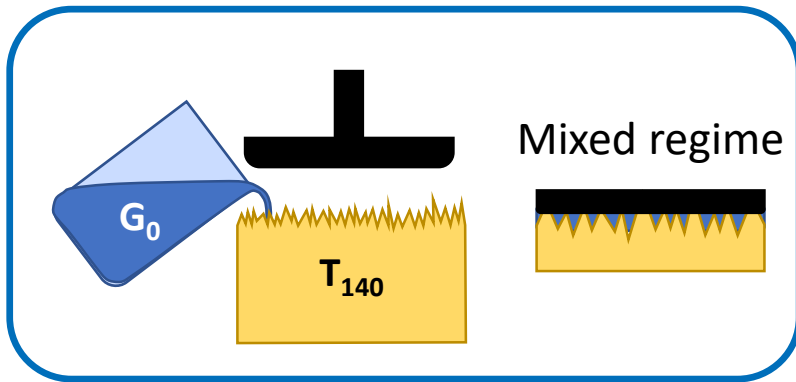
Two contrasting cases



- Mixed regime :
 - longer static friction phase
 - higher friction amplitude
 - higher variations in normal force

➤ US time-of-flight as a marker of lubrication regime

Two contrasting cases

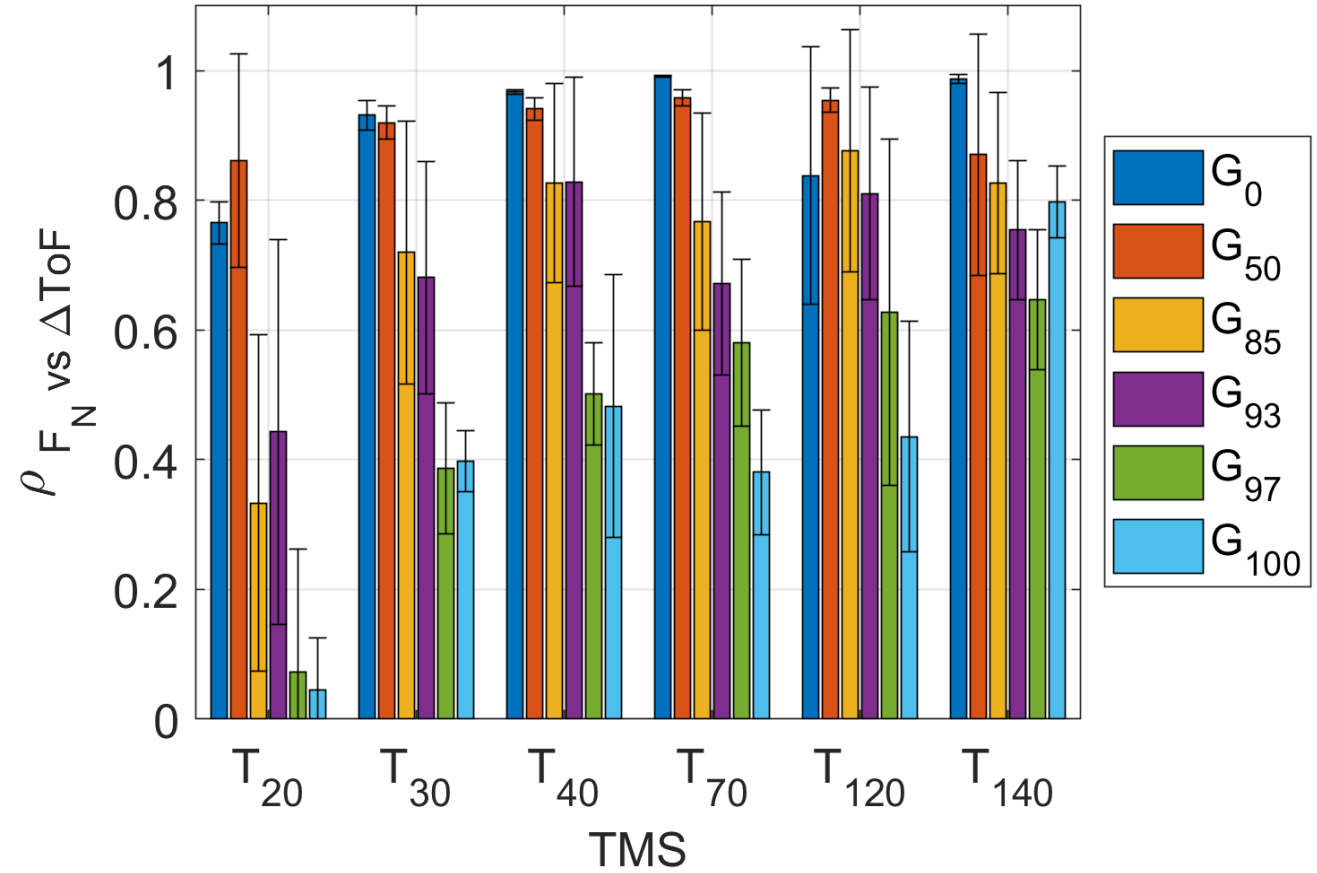


- Mixed regime :
 - longer static friction phase
 - higher friction amplitude
 - higher variations in normal force
- US ToF in mixed regime reflects deformations induced by bulk deformations of the TMS
- US ToF in hydrodynamic regime reflects the evolution of fluid film thickness

➤ US time-of-flight as a marker of lubrication regime

Overall analysis

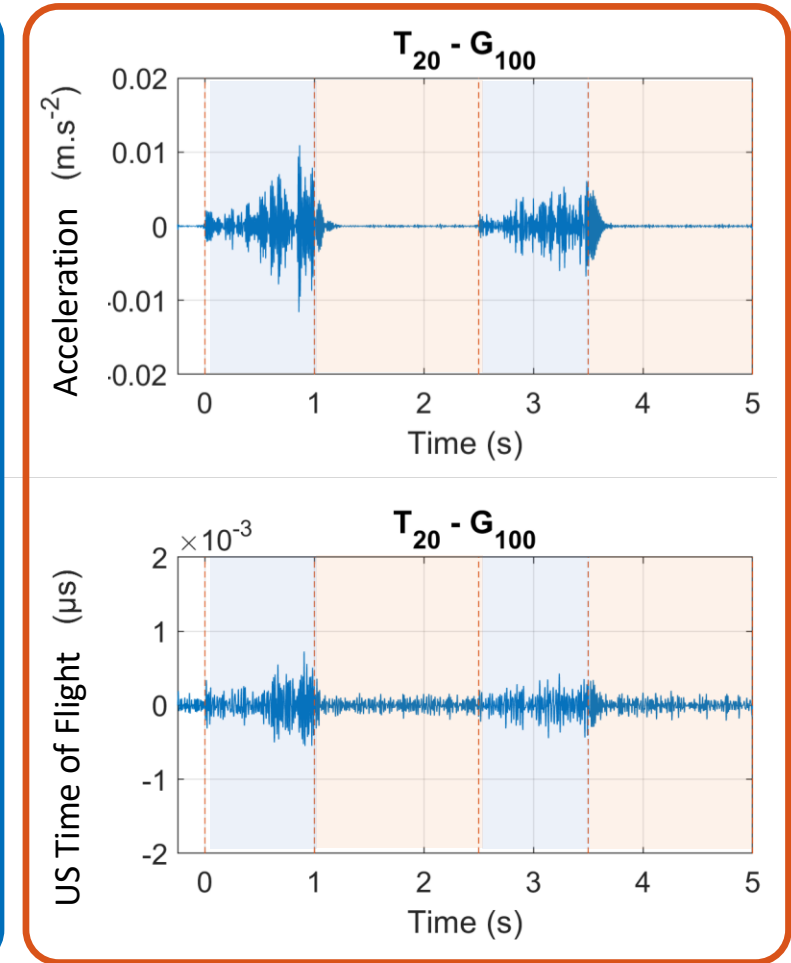
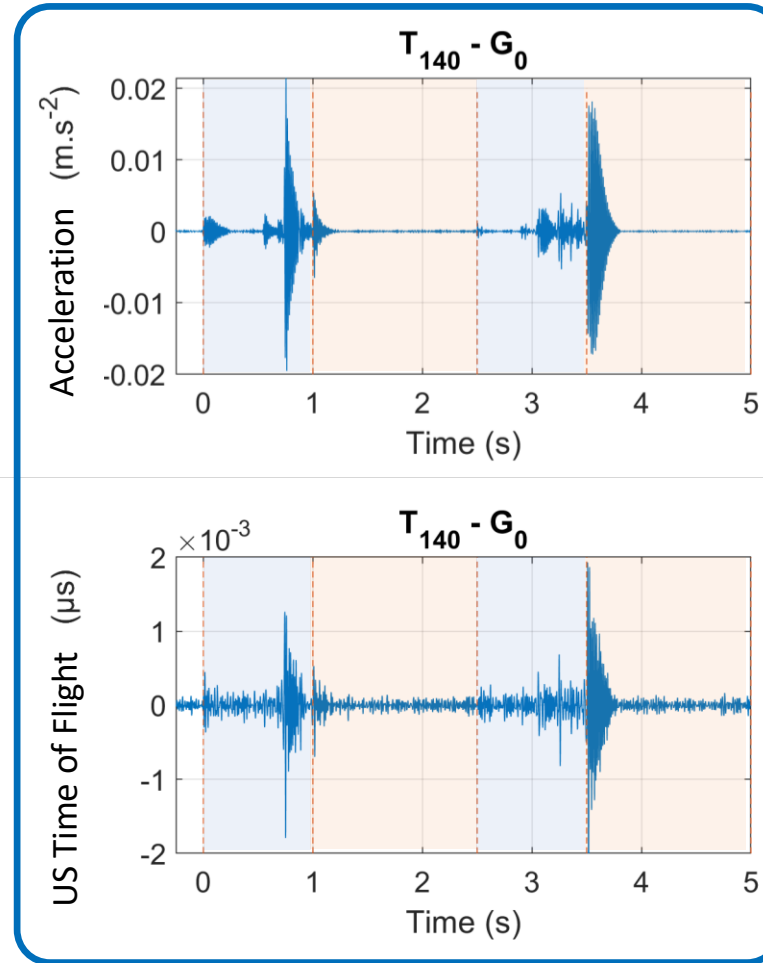
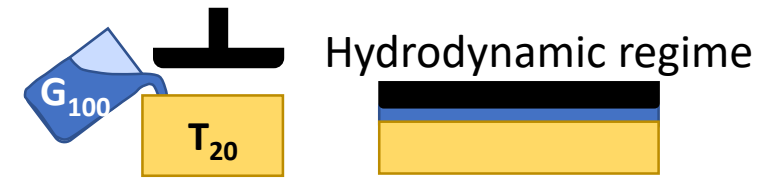
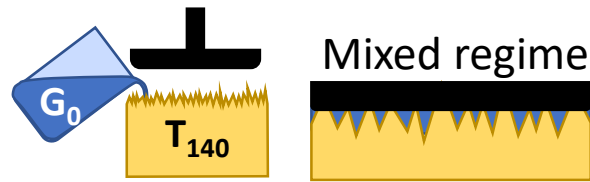
- Pearson's linear correlation tests performed between normal force and time-of-flight signals
- G_0 and G_{50} in mixed regime : strong correlations reflecting the deformations induced by TMS bulk deformations
- G_{85} , G_{93} , G_{97} , G_{100} getting closer to hydrodynamic regime : loss of correlation due to fluid film thickness at the interface.



➤ US time-of-flight as a marker of stick-slip

Two contrasting cases

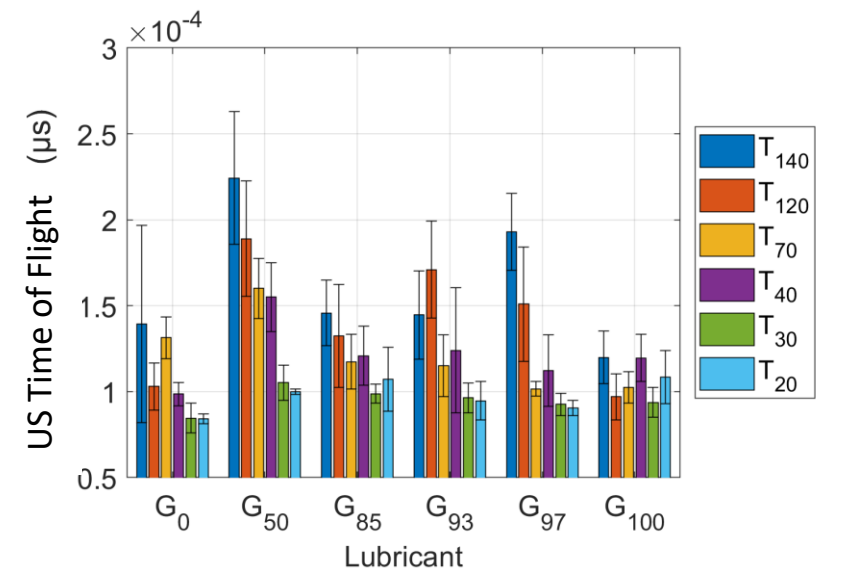
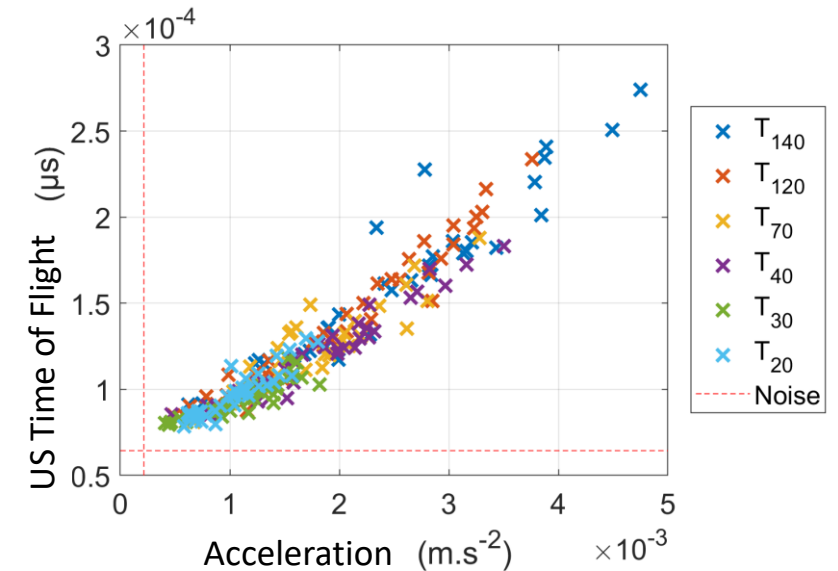
- Fast Fourier Transform analysis performed on all acceleration and ultrasound ToF signals
- Passband filters (40-120Hz)
- Observation of synchronized events between both signals
- Filtered US ToF as a marker of vertical induced by vibrations at the micrometer scale.



➤ US time-of-flight as a marker of stick-slip

Overall analysis

- Calculation of root-mean-square on acceleration and US time-of-flight signals
- Consistent trends of variations through TMS roughness and lubricant
- Smoothest TMSs (from T_{20} and T_{40}) : low levels of vibrations and low variations across lubrication conditions
- Roughest TMSs (from T_{70} to T_{140}) : high fluctuations across lubrication conditions, complementary with friction coefficients



➤ Conclusions

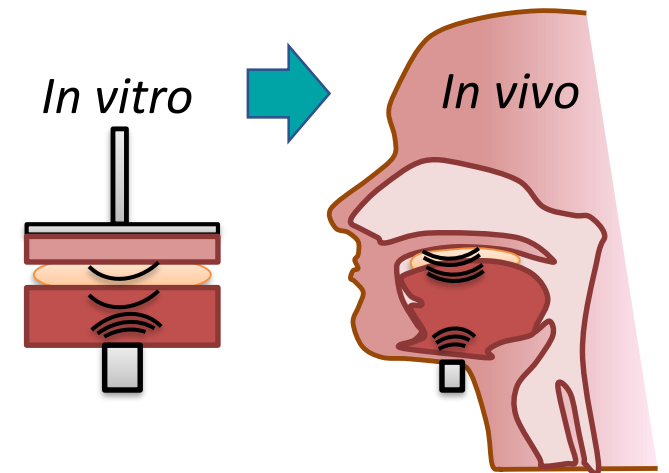
- Signal processing of US time-of-flight proved to be efficient to capture :
 - Fluid film thickness evolution in the case of contrasting speeds of sound
 - Palate displacements induced by tongue deformation (static friction) and palate vibrations (stick-slip)
- Both the roughness of the artificial tongues and the viscosity of the lubricant were shown to influence friction mechanisms
- The work opens perspectives for the development of food for people with specific physiology (tongue roughness, rigidity, lubrication)
- Potential applications a little further during digestion

Thank you for your attention !

Thanks to my colleagues :



Thanks for funding :



Want to know more about *in vivo* US imaging ?
Come to see Poster #8 😊