Quantitative ultrasound to explore tactile perceptions of food elicited by tonguepalate friction: a biomimetic approach

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Unravelling the mechanisms of texture perception

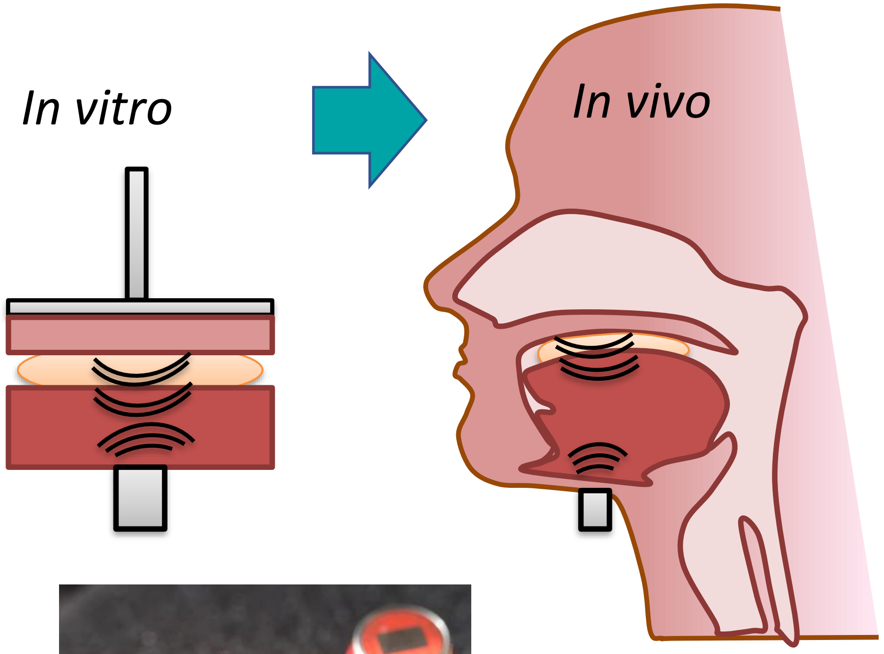
Towards the development of innovative methods in physiologically relevant environments

- Tongue has a central role in texture perception of food
- Mechanoreceptors with varied ranges of sensitivity (amplitude & frequency)

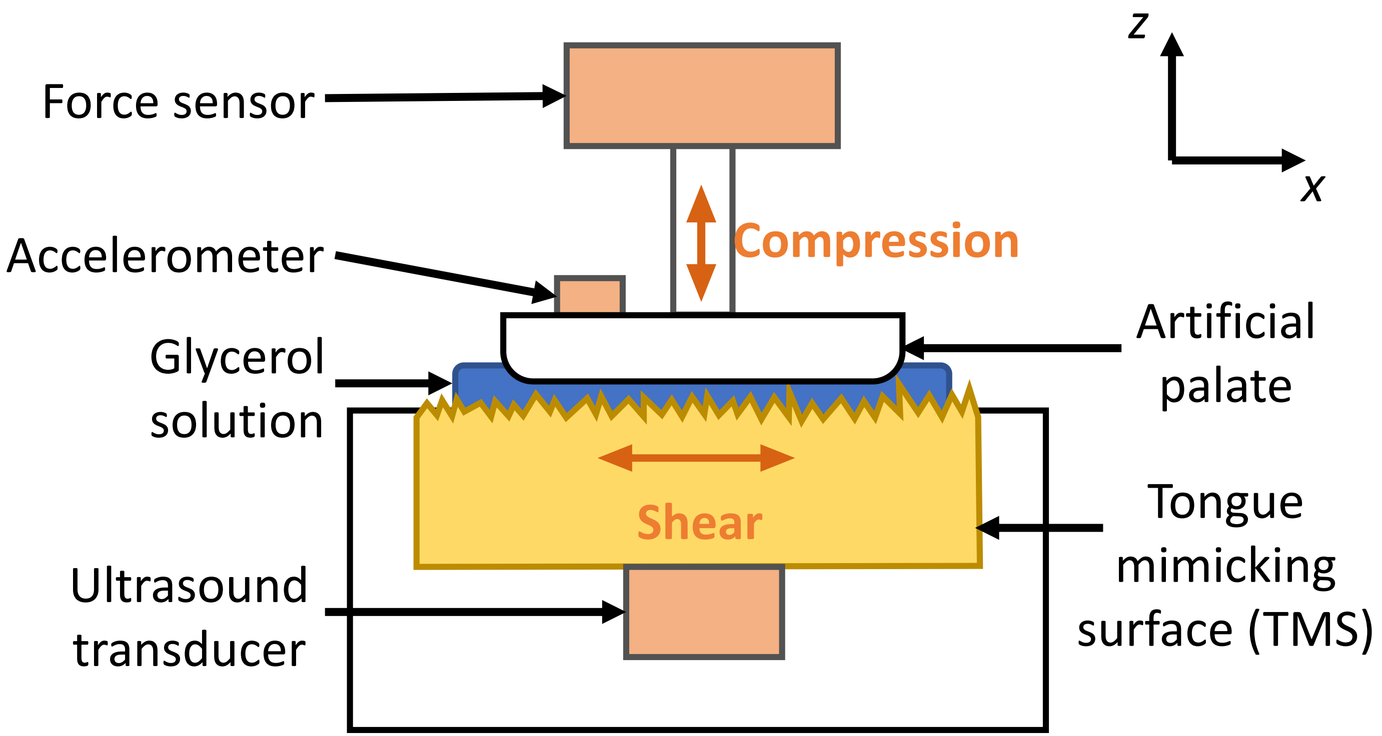
- Critical needs :
  - Physiologically relevant testing environments
  - Original techniques to monitor the mechanical interactions between the tongue, the food and the palate

- What about the potential of Ultrasound methods ?

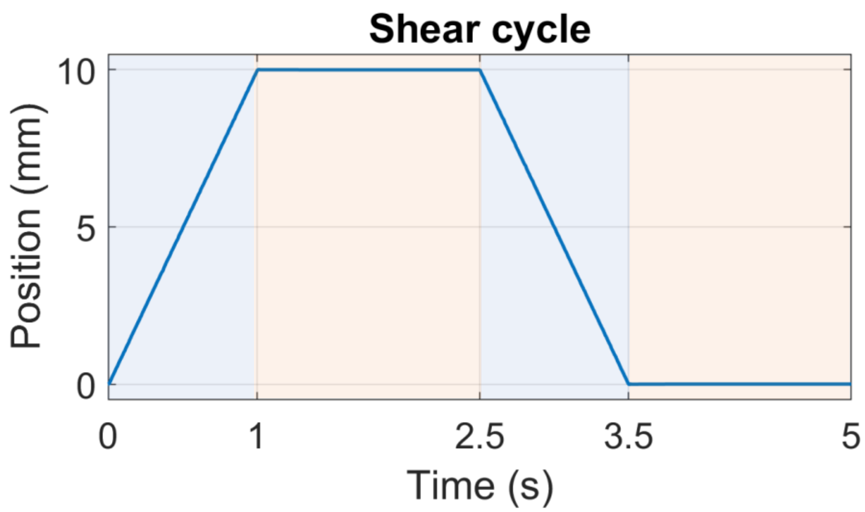
Let's see what we can get from them on a tongue-palate biomimicking testing bench…



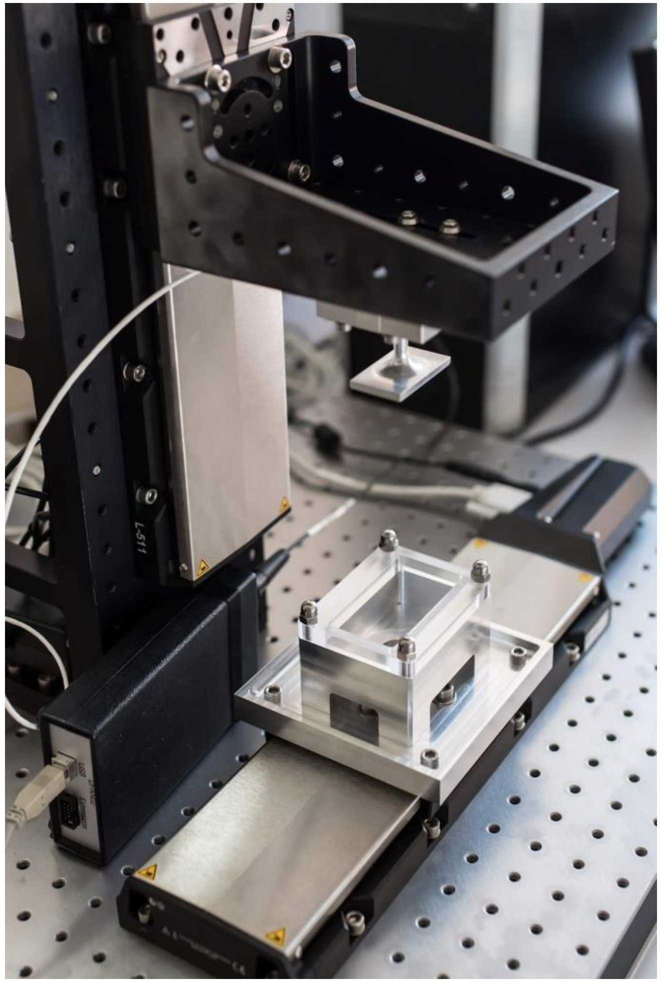
Tongue palate biomimicking system

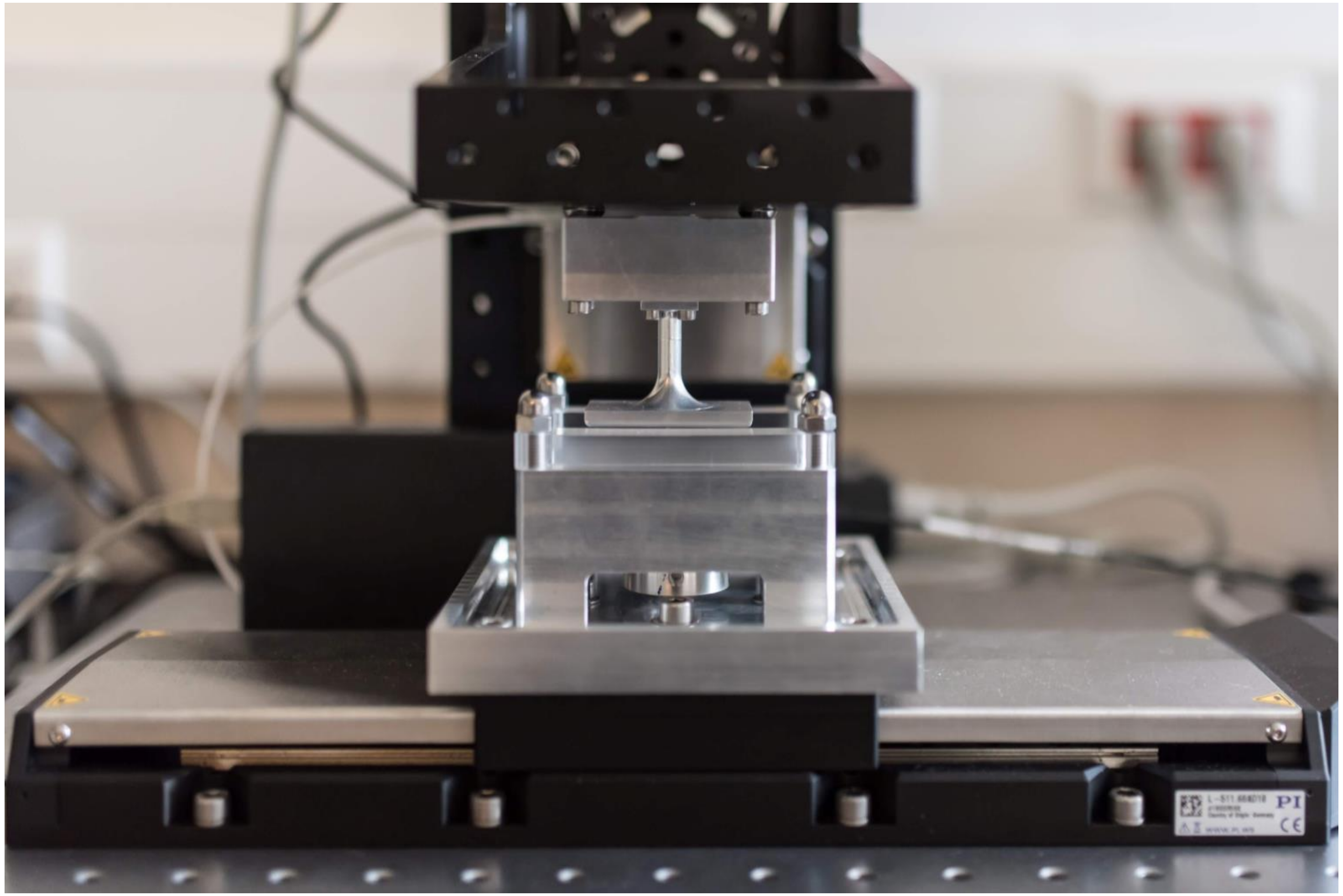


- Contact area : 45 x 25 mm²
- Imposed initial normal load : 10 N (around 9kPa)
- 5 cycles of shearing motions : Amplitude 10 mm; Velocity 10 $mm.s^{-1}$



Tongue palate biomimicking system

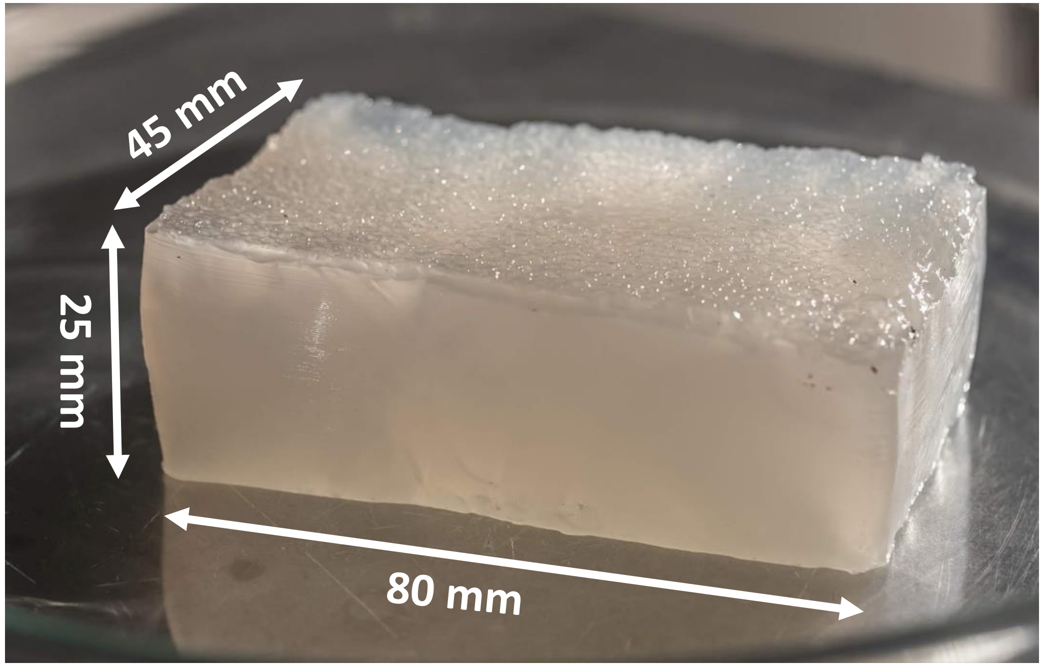


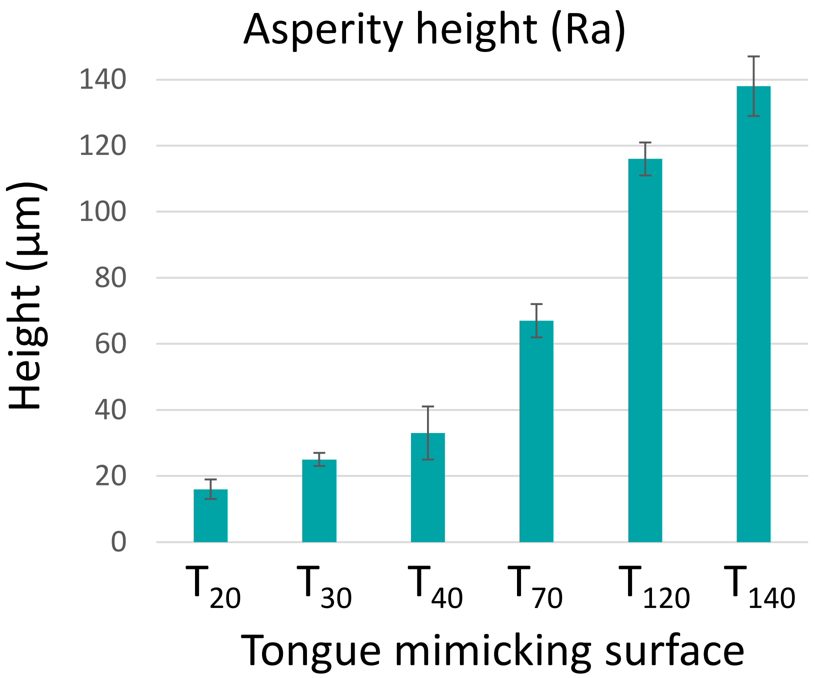


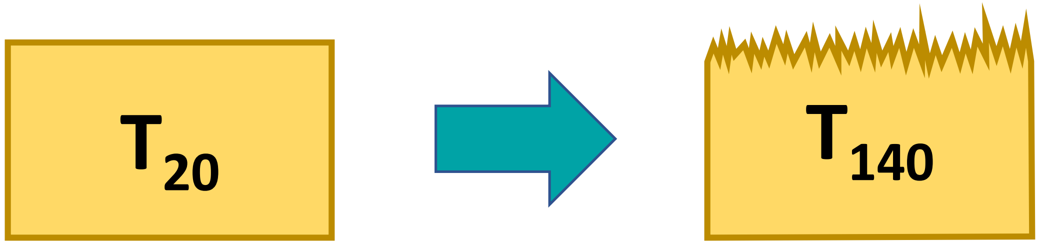
Tongue mimicking surfaces

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 m.s^{-1}
- Varied roughness





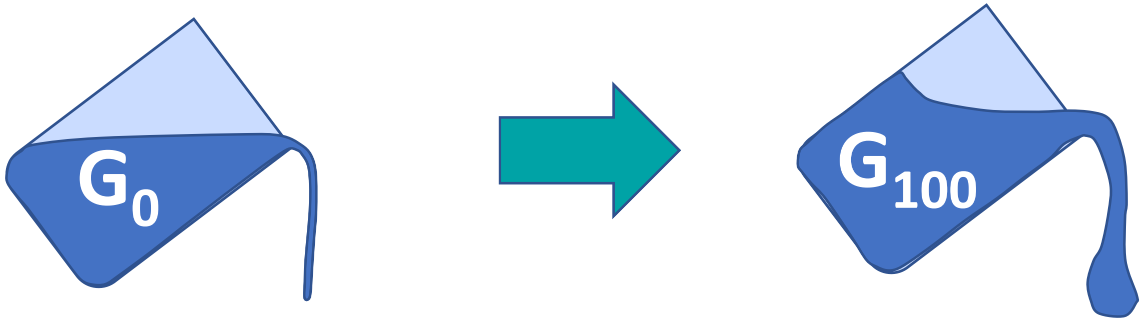


Lubricants

Preparation of 6 mixtures of water and glycerol

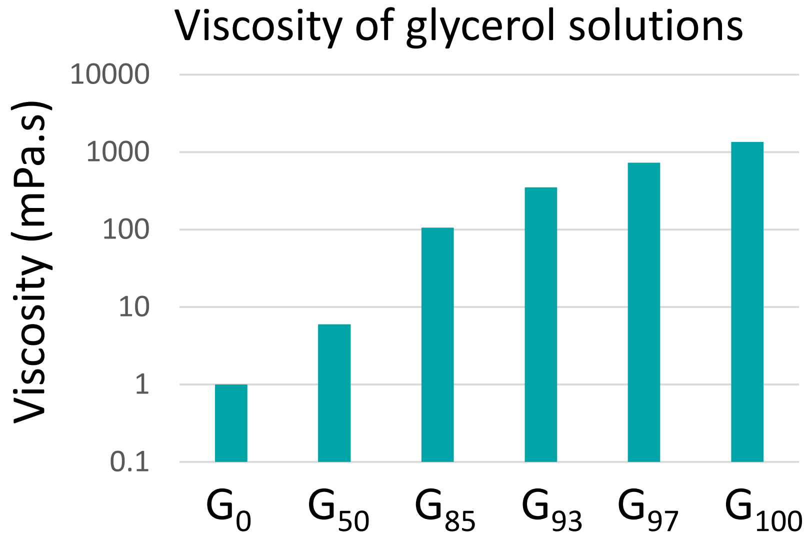
- Newtonian fluids
- Covering a wide range of viscosity

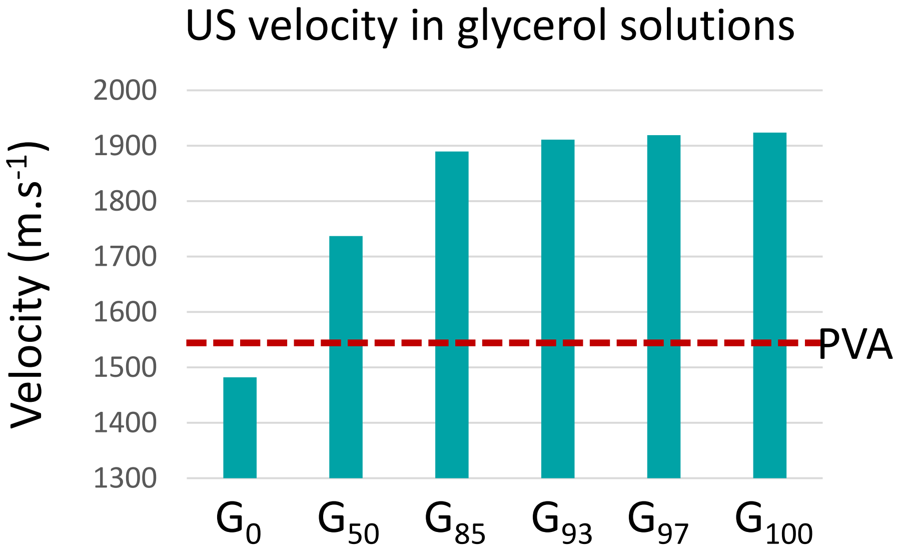
Solutions labels	G_0	G_{50}	G_{85}	G_{93}	G_{97}	G_{100}
Concentration (% w/w)	0	50	85	93	97	100



Pure water

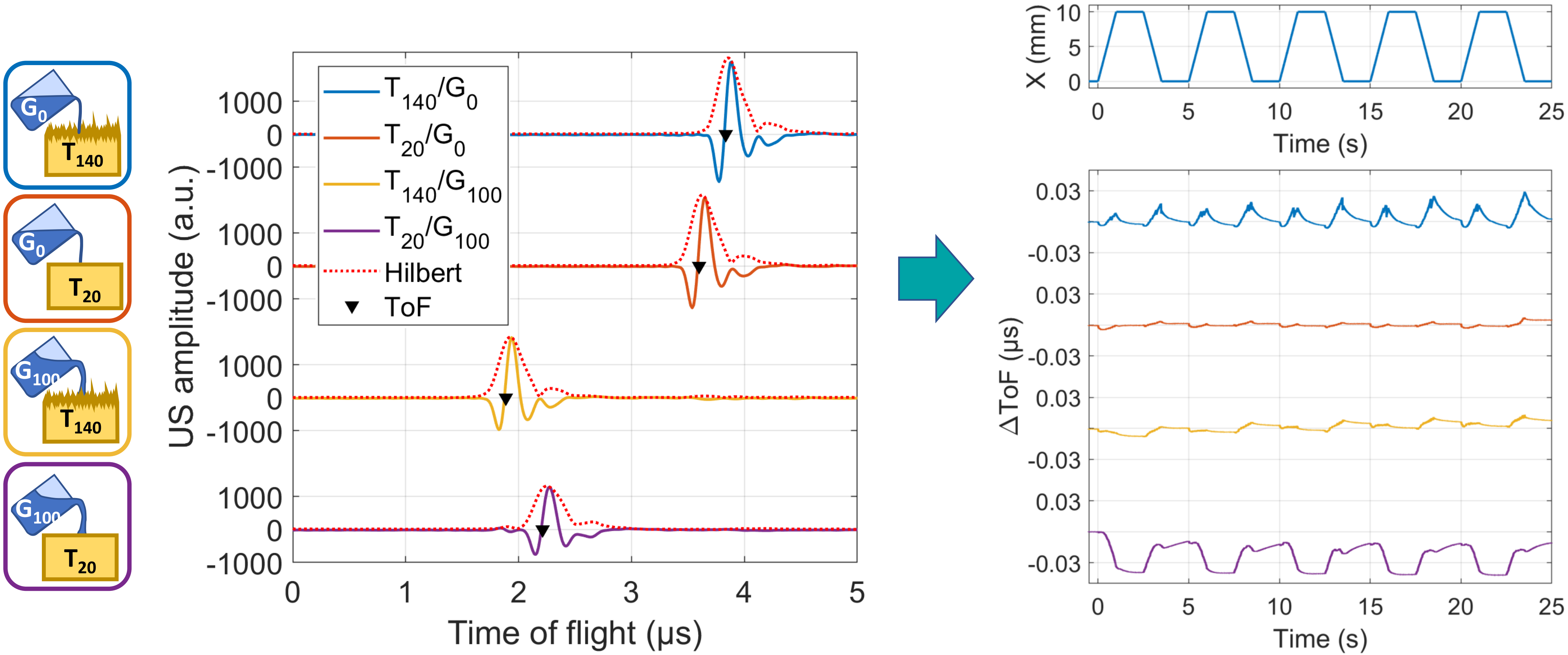
Pure glycerol





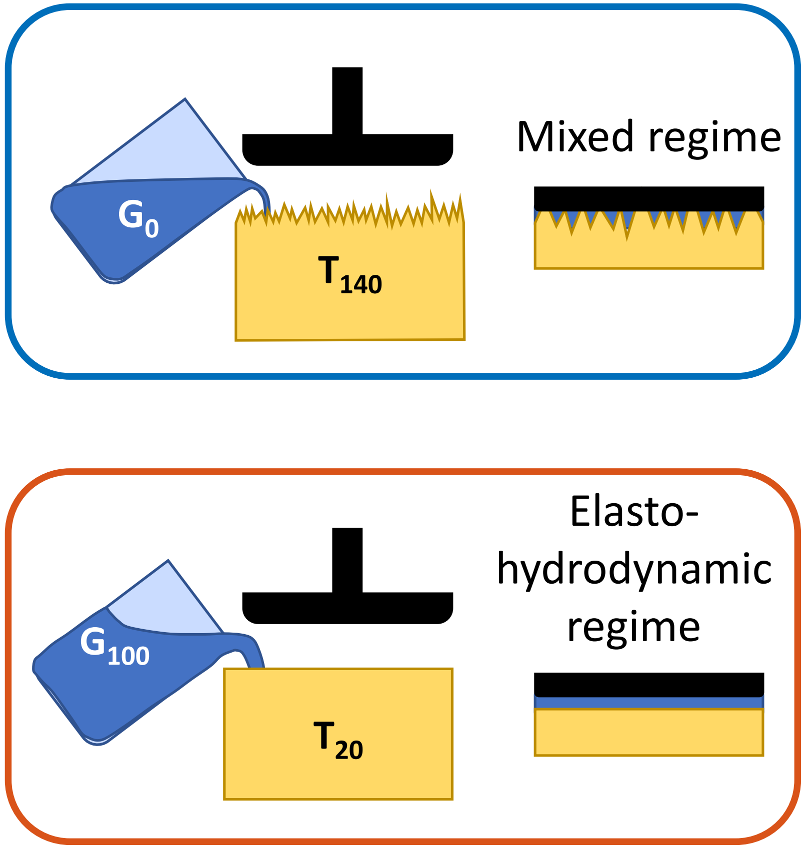
Signal processing of ultrasound signals

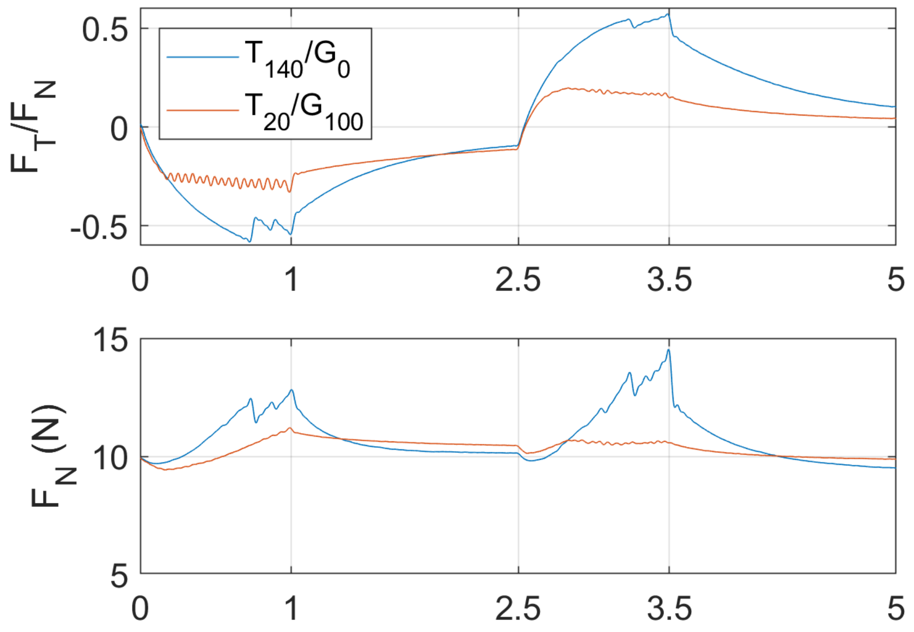
Detecting & monitoring the time-of-flight of tongue-palate interface.



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

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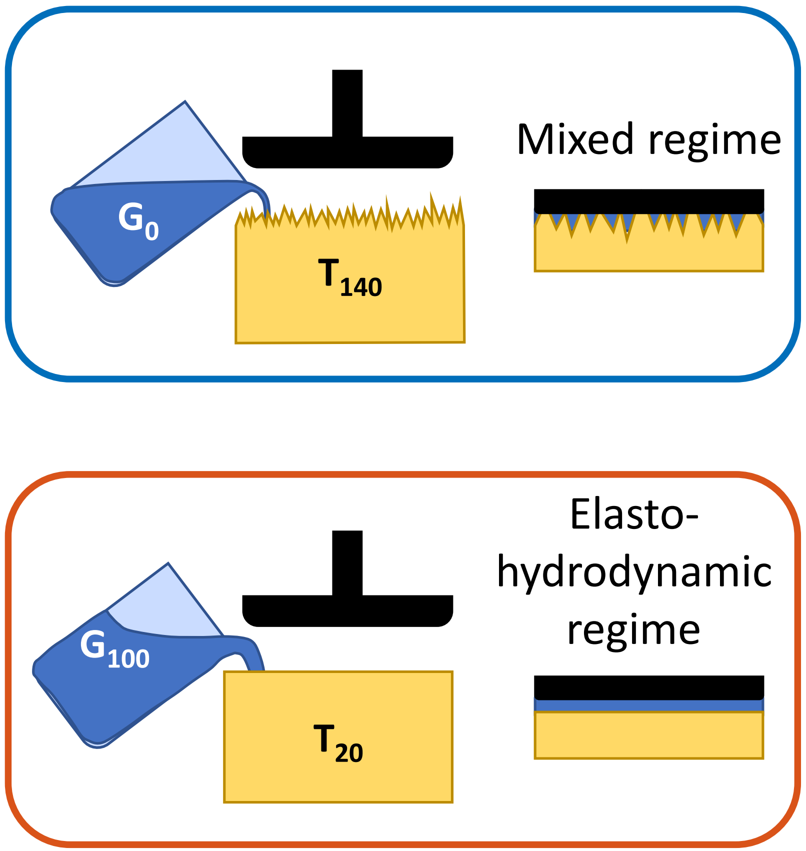
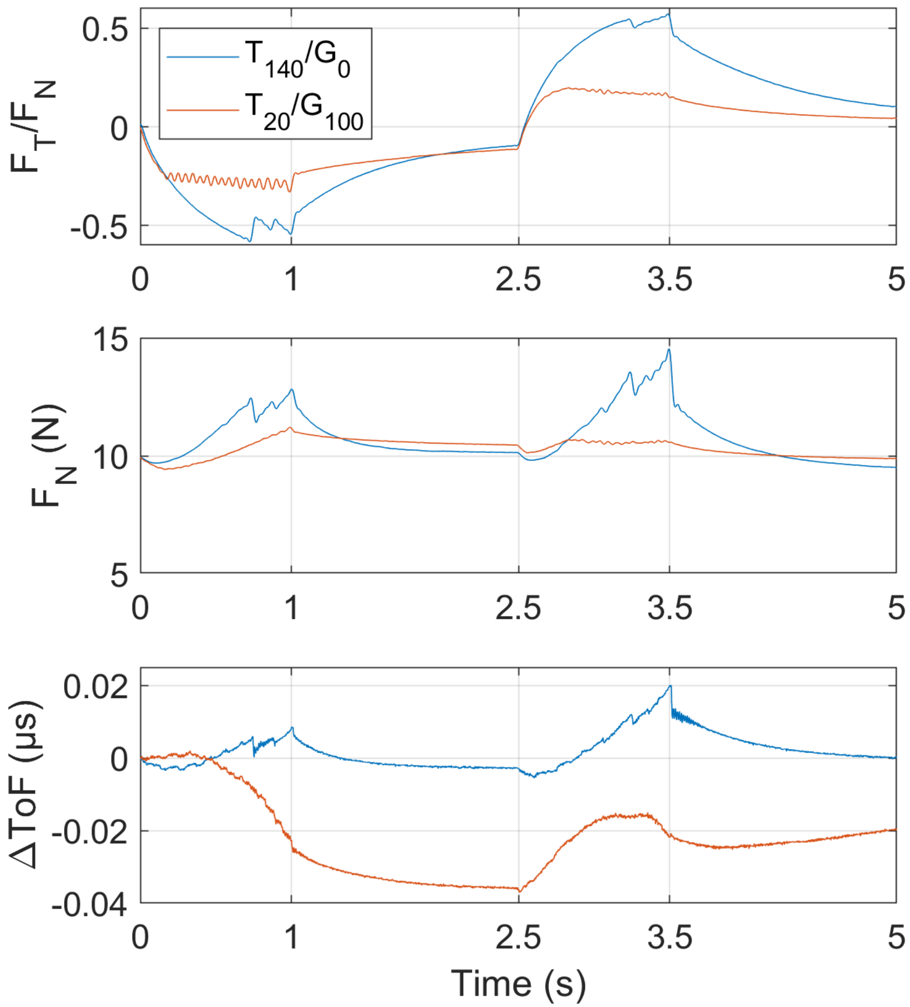


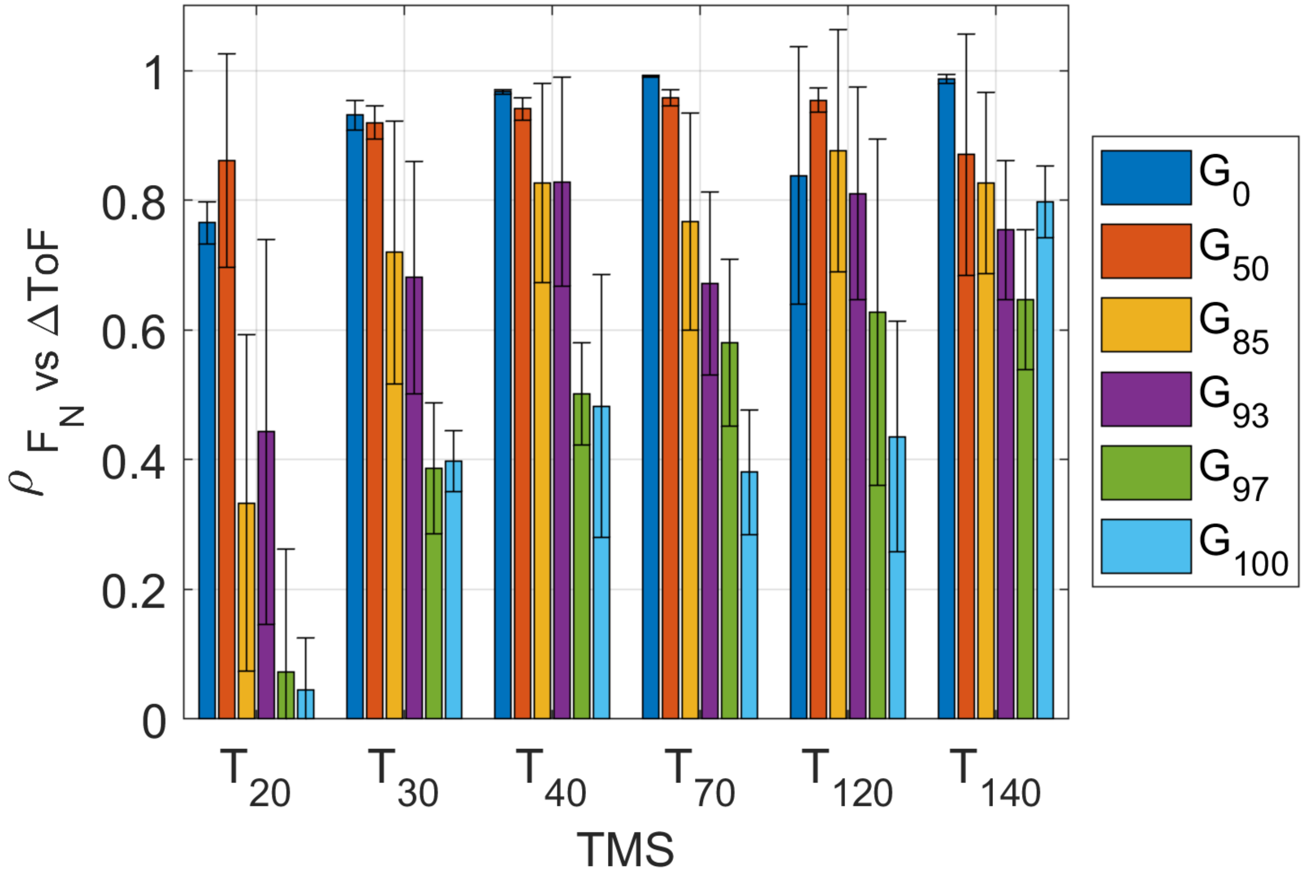


- Mixed regime :
  - longer static friction phase
  - higher friction amplitude
  - higher variations in normal force
- US ToF in mixed regime reflects deformations induced by bulk deformations of the TMS
- US ToF in hydrodynamic regime reflects the evolution of fluid film thickness

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

Overall analysis

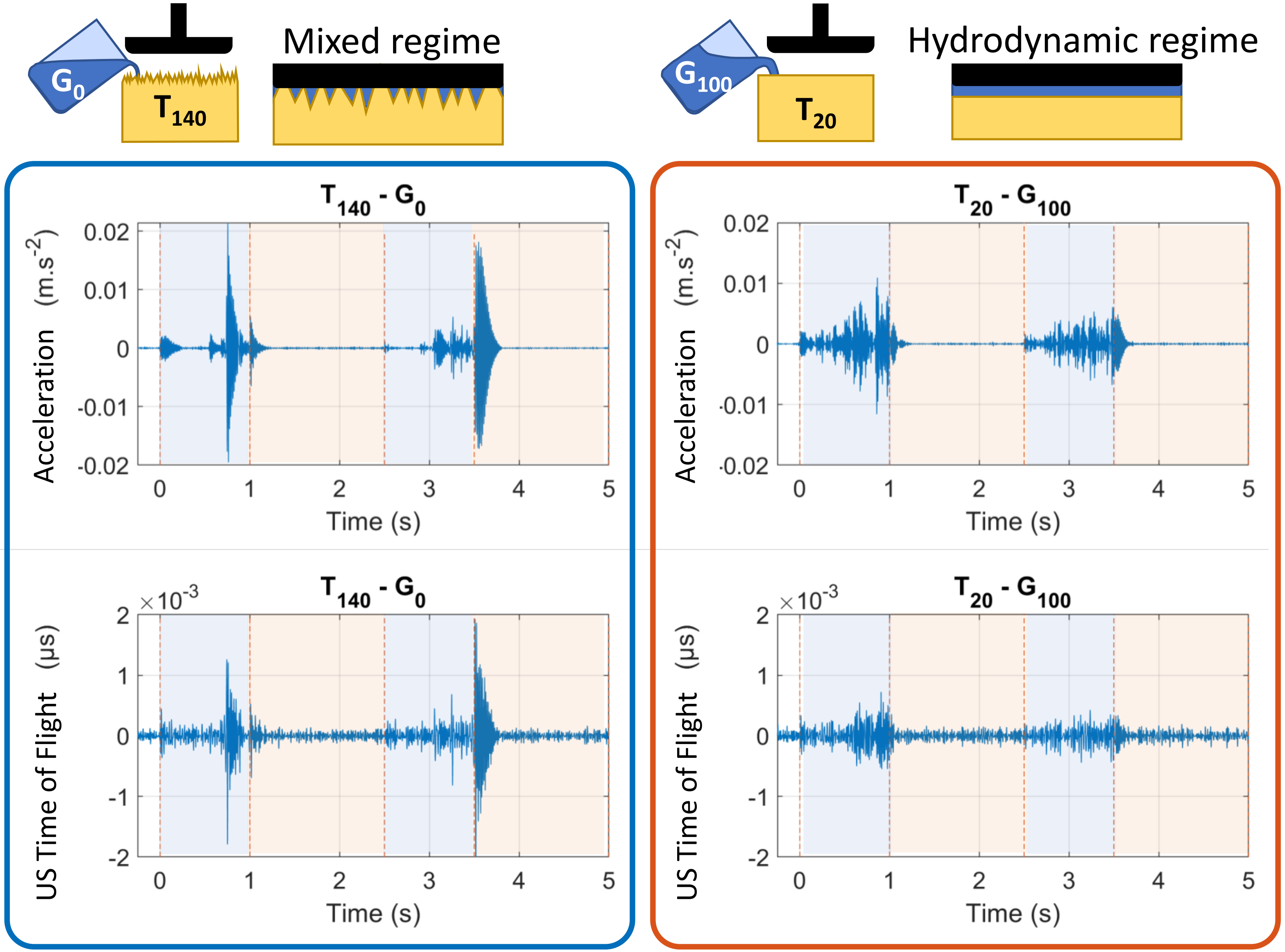
- Pearson's linear correlation tests performed between normal force and time-of-flight signals
- G_0 and G_{50} in mixed regime : strong correlations reflecting the deformations induced by TMS bulk deformations
- G_{85}, G_{93}, G_{97}, G_{100} getting closer to hydrodynamic regime : loss of correlation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



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

Two contrasting cases

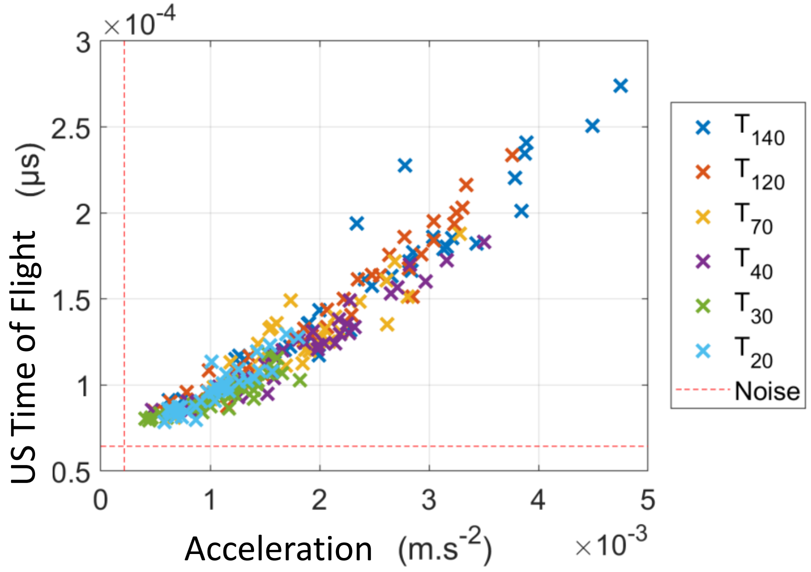
- Fast Fourier Transform analysis performed on all acceleration and ultrasound ToF signals
- Passband filters (40-120Hz)
- Observation of synchronized events between both signals
- Filtered US ToF as a marker of vertical induced by vibrations at the micrometer scale.

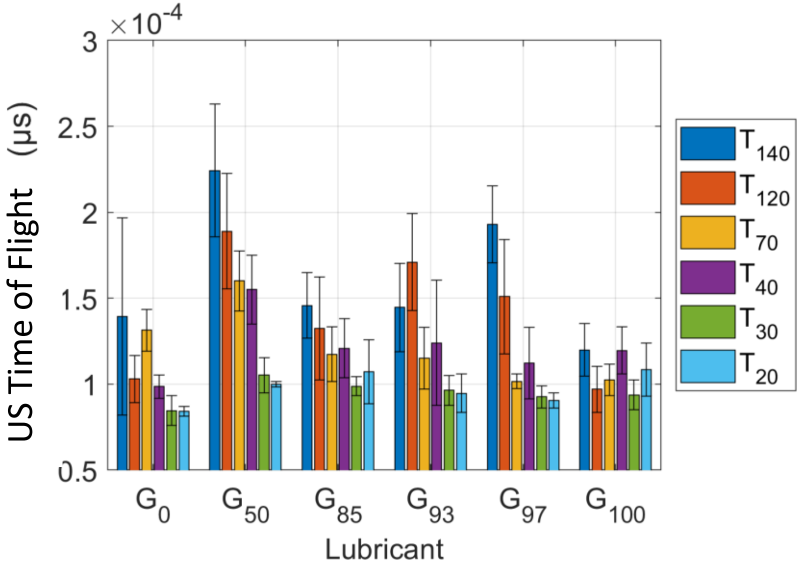


US time-of-flight as a marker of stick-slip

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 (form 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 to 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

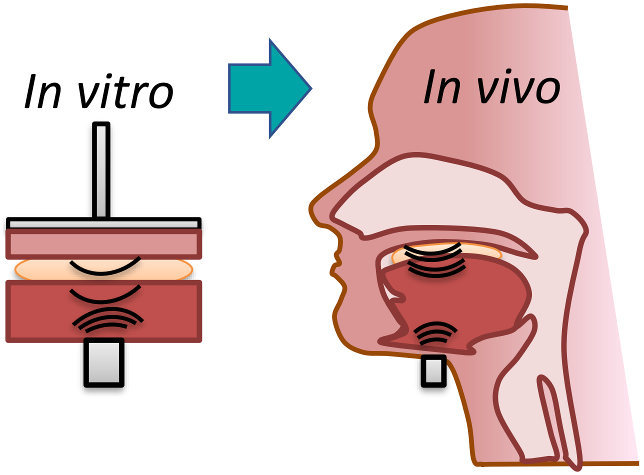
Thank you for your attention !

Thanks to my colleagues :

SayFood Food & Bioproduct Engineering LPS STLO

Thanks for funding :

anr



Want to know more about *in vivo* US imaging ?
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