From food texture to global perception: respective impacts of food and human physiology

Elisabeth Guichard

From food texture to global perception: respective impacts of food and human physiology

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Food formulation

Excessive intake of salt/fat/sugar has undesirable effects on health

Consequently, health organisms recommended to modern countries to decrease salt/fat/sugar content in targeted foods

However, these ingredients have important functional properties

- antimicrobial properties of salt (fermented products)
- texturing agent
- sensory properties
- effect on biodisponibility of other nutriments and stimuli

Food reformulation with low salt/fat/sugar content modifies global sensory perception and consumer acceptability

Great inter-individual differences are observed

$\Rightarrow$ what is the impact of food oral processing?

Food breakdown in the mouth

Ingredients
Process

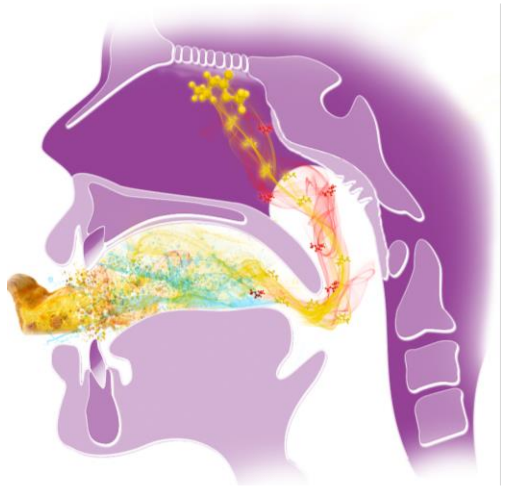
Food

Structural properties
Spacial distribution

Chewing
Saliva
Respiratory flow

In-mouth

Stimuli release
Tastants in saliva
Odorants in oral then nasal cavities

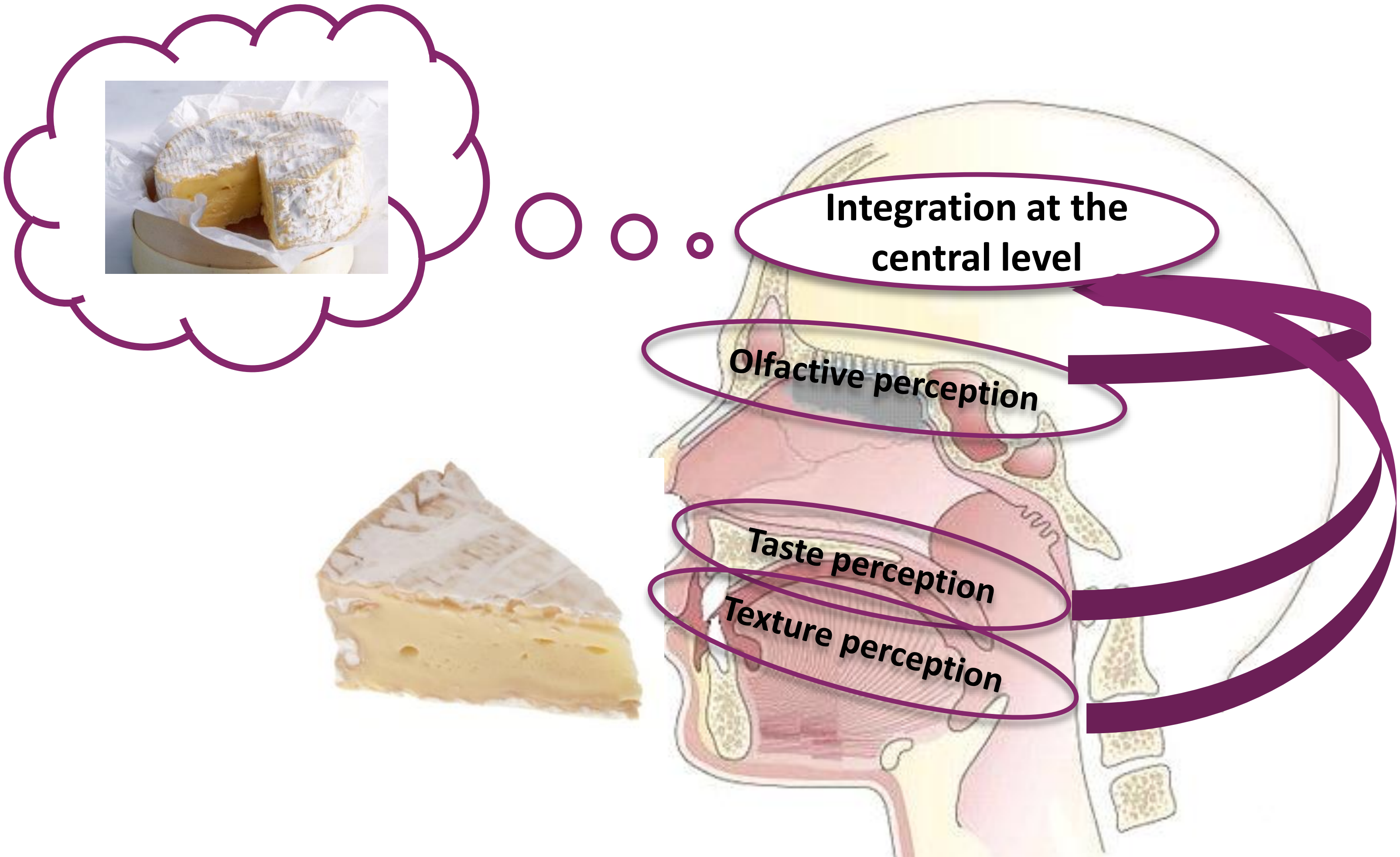


Mecanoreceptors
Taste receptors
Olfactory receptors

Perception

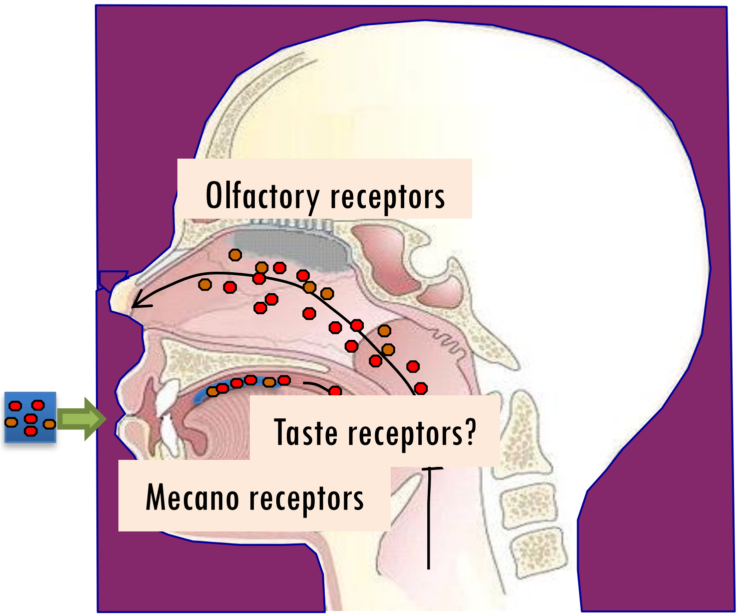
Texture
Taste
Aroma

Integration at the central level: sensory image

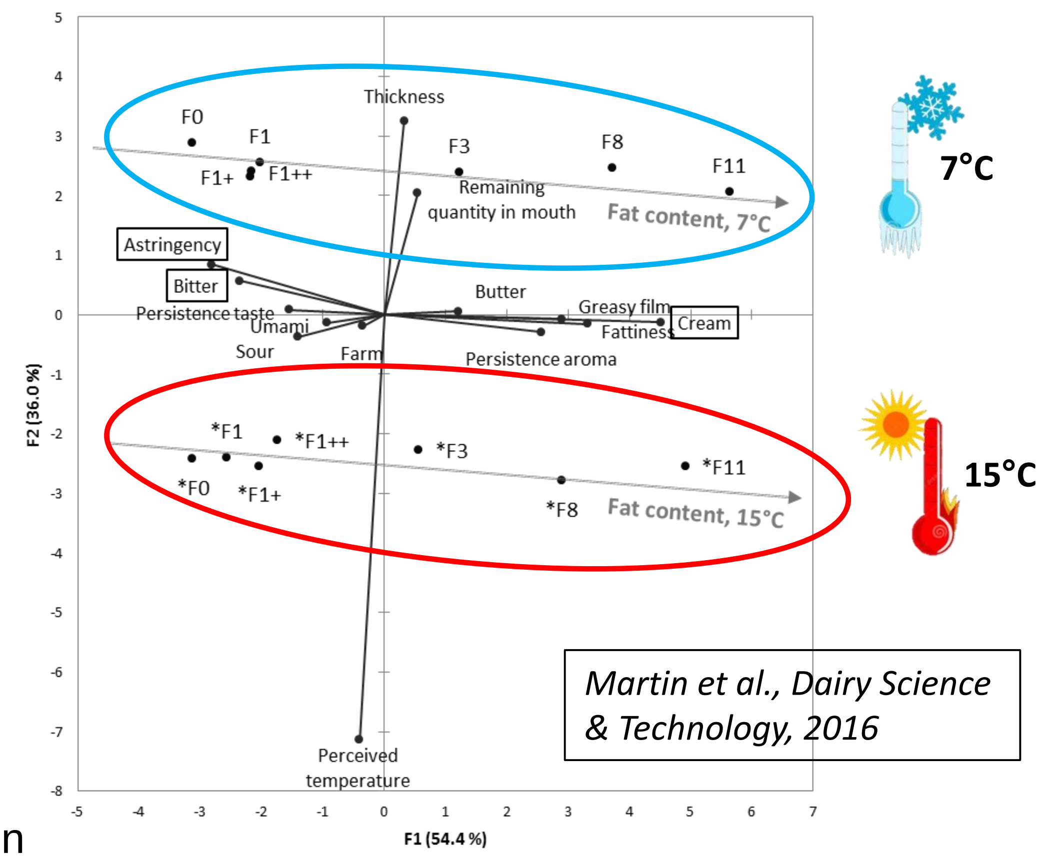


Small & Prescott (2005) ; Thomas-Danguin , 2009 ; Small D.M. (2010)

Fattiness: example of a multimodal sensation



Sensory profile of cottage cheeses



Martin et al., Dairy Science & Technology, 2016

- ↗ fat content
- ↗ greasy film ⇒ tactile perception
- ↗ creamy aroma ⇒ aroma perception
- ↗ fattiness ⇒ tactile or taste perception?
- ↘ astringency, bitterness ⇒ taste perception (masking effect) or limited access to receptors

What are the respective impacts of
- food composition and texture
- oral physiology

on

- aroma and taste compounds release
- global sensory perception

Example of dairy products

Impact of food composition and structure on aroma release: general trends in dairy products

- **Fat** acts as a reservoir for hydophobic aroma compounds :
  - less fat $\Rightarrow$ higher release in the gas phase (*Guichard, 2002*)
- **Fat** acts as a barrier for sodium ions
  - slows down diffusion of ions in saliva (*Phan et al., 2008*)

- **Proteins** interact with aroma compound by hydrophobic effect
  - more protein induces a decrease in aroma release in the gas phase *(Tromelin et al., 2006)*
- **Proteins** play a role in food microstructure
  - denser network limits sodium ions mobility *(Gobet, 2008)* and salt diffusion *(Guinee et al., 2004; Floury et al., 2009)*

- **Salt** contributes to food structure *(Geurts et al., 1980, Guinee and Fox, 1986)* by interactions with other ingredients (proteins) and thus impacts aroma and taste compounds release
- **Salt** increases aroma release in the gas phase: salting out effect *(Lauverjat et al., 2009)*

- Effect of **carbohydrates** highly depends on the nature of the carbohydrate, the nature of the aroma compound and the type of food matrix *(Paravisini and Guichard, 2017)*

Impact of food composition and structure on perception

(model cheeses varying in lipid/protein and salt content)

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FOOD CHEMISTRY

The salt and lipid composition of model cheeses modifies in-mouth flavour release and perception related to the free sodium ion content

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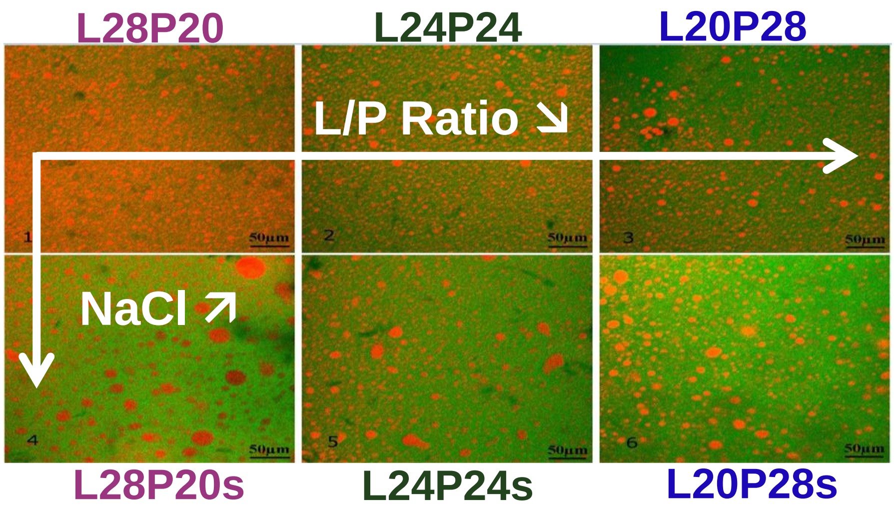
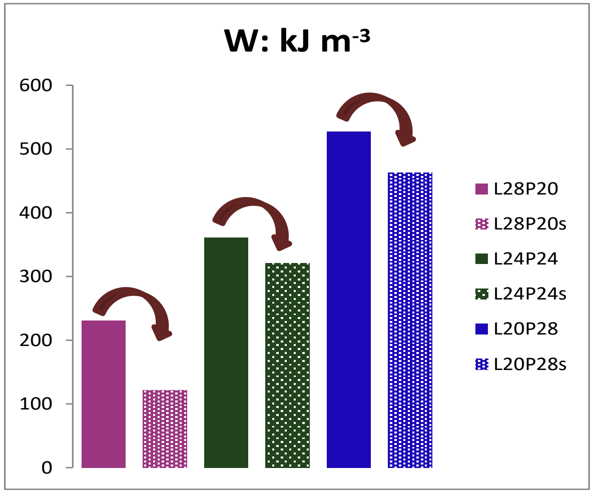
Model cheeses varying in fat/protein ratio and salt content

Microstructure (confocal laser scaning miroscopy)



Rheology: uniaxial compression test
Work at maximal deformation



L/P ↘ ⇨ few fat droplets, protein network denser, W ↗ **,** harder model cheeses

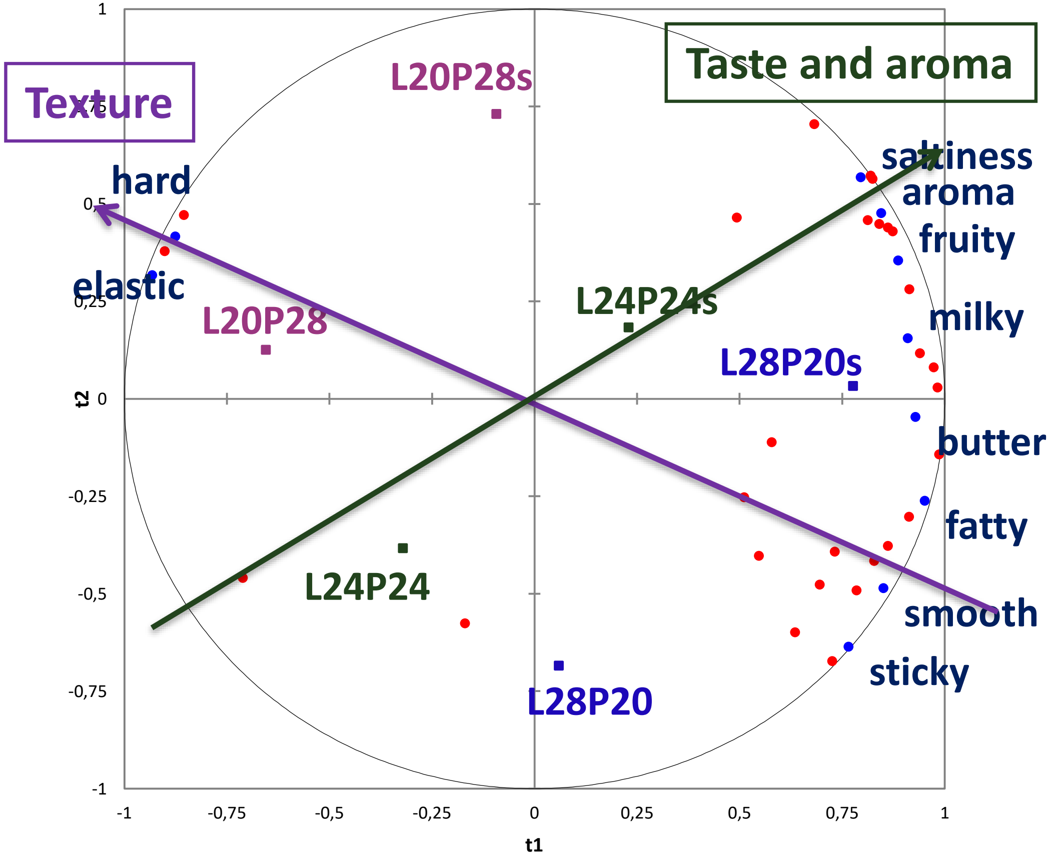
NaCl added ⇨ Large fat droplets due to more hydrated protein network , **W ↘**
Greater binding of Na^+ ions by caseins ⇨ better hydration of proteins (Floury *et al.,* 2009)

Chewing behaviour:
L/P ↘ ⇨ number of cycles, chewing duration, total chewing work ↗
NaCl added ⇨ number of cycles, chewing duration, total chewing work ↘

} In line with rheology

Model cheeses varying in fat/protein ratio and salt content

PLS: representation of sensory descriptors



Texture:
more protein (L20P28)
⇨ Hard, elastic ↗
more lipids (L28/P 20)
⇨ Fatty, smooth sticky ↗
more salt
⇨ Hard, elastic ↘, Fatty, smooth ↗
In agreement with structure

Taste and aroma:
more protein (L20P28)
⇨ total aroma ↘ (molecular interactions)
more lipid (L28P20)
⇨ fatty, butter aroma ↗
Dumping effect of fat on butter aroma?
more salt
⇨ saltiness ↗,
⇨ total aroma ↗ (salting out: higher rate of aroma release)
⇨ fatty ↗ (increase droplet size)

Inter-individual differences exist between subjects
Impact of physiological parameters on food breakdown and sensory perception?

Physiological parameters involved in bolus formation and sensory perception

General trends:

For solid and semi-hard foods, mechanical destruction is the most important mechanism *(Chen, Trends in Food Sci & Technol., 2015)*

⇨ mastication leads to a swallable food bolus *(Woda et al., J. Oral Rehabilitation, 2006)*

Mastication process adjusts to different textural properties, following a sensory feedback *(Plesh et al. Exp Neurol, 1986)*

Different chewing strategies (more or less adaptation to food product)

- impact on bolus rheology (particle size, bolus spreadability):
  ⇨ bolus consistency not influenced by chewing strategy *(Yven et al. J. Texture Studies, 2012)* : better indicator of safe swallow than particle size *(Prinz and Lucas, 1997)*

- impact *in vivo* aroma and taste compounds release:
  ⇨ high number of cycles and high amplitude increase aroma release due to increase exchange area from sample breakdown *(Hansson et al., JAFC, 2003; Tarrega et al., IDJ, 2007)*

Physiological parameters involved in bolus formation and sensory perception

For semi-solid foods, use of teeth not always required

⇨ tongue muscle strength and tongue pressure contribute to bolus formation *(Alsanei et al., Food Res. Int., 2015, van Aken et al., 2007)*

For all types of foods, saliva contributes to bolus formation and flavour release *(Mosca & Chen, Trends in Food Sci & Technol., 2017)*

⇨ saliva is essential for lubrification of oral tissus, bolus moistening and oral clearance *(Guichard et al., Trends in Food Sci & Technol., 2018)*

⇨ saliva affects aroma and taste compounds release by dilution and through interactions between salivary proteins and flavour compounds *(Salles et al., Crit. Rev Food Sci. Percep., 2011)*

Other physiological parameters impact *in vivo* aroma release, such as oral volume and respiratory flow *(Mishellany-Dutour et al., PlosOne, 2012)*

Impact of human physiology on food oral processing and perception
(model cheeses varying in fat content and firmness)

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Model cheese aroma perception is explained not only by *in vivo* aroma release but also by salivary composition and oral processing parameters†

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Model cheeses

Cheese	Description	Fat content per dry matter (%)	Breakdown stress (Pa)	Critical strain at breakdown (rad)
lfS	low fat, soft	25 ± 0.9	8129 ± 469	0.804 ± 0.056
lfF	low fat, firm	25 ± 0.9	15253 ± 1231	0.836 ± 0.048
hfS	high fat, soft,	50 ± 0.5	8022 ± 1309	0.273 ± 0.022
hfF	high fat, firm	50 ± 1.4	15556 ± 2307	0.348 ± 0.061

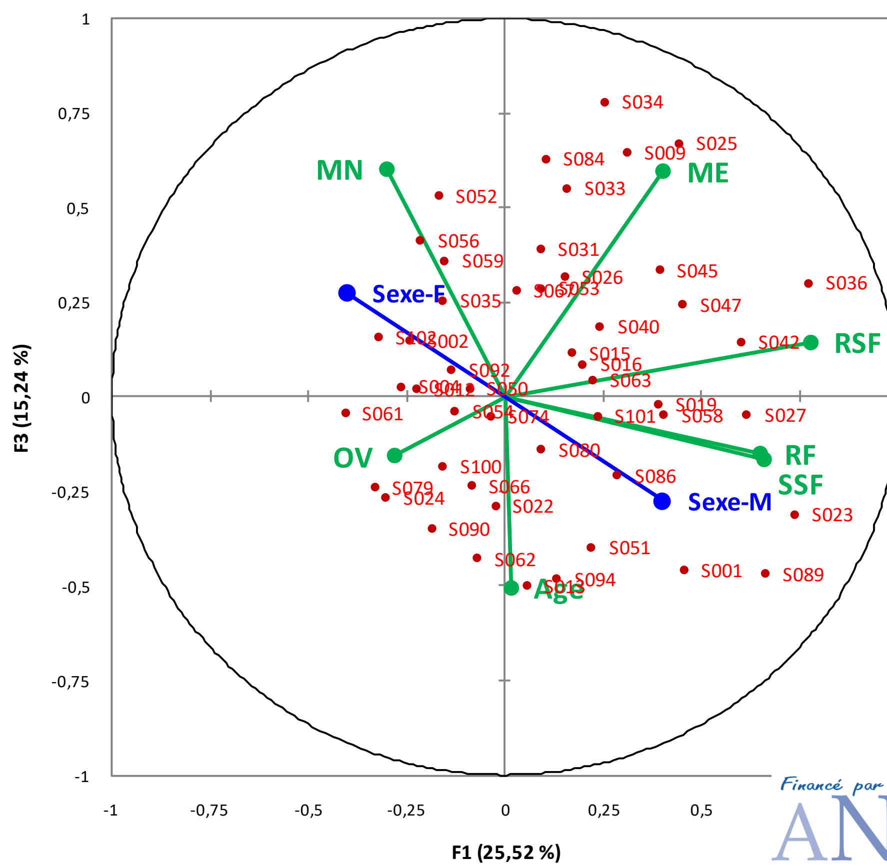
Flavoured with 2 aroma compounds :
blue cheese aroma: nonan-2-one (NO), more hydrophobic
fruity aroma: ethyl propanoate (EP)

48 subjects

Oral physiology
- Oral volume (OV)
- Masticatory efficiency (ME)
- Mastication normality (MN)

Salivary flows
- At rest (RSF)
- Stimulated (SSF)

Respiratory Flow (RF)



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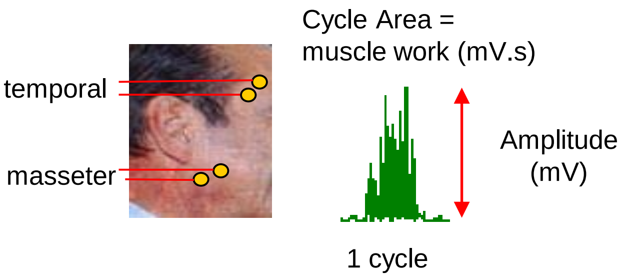
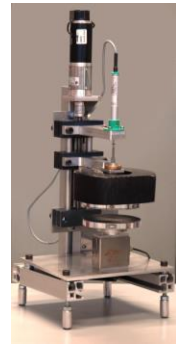
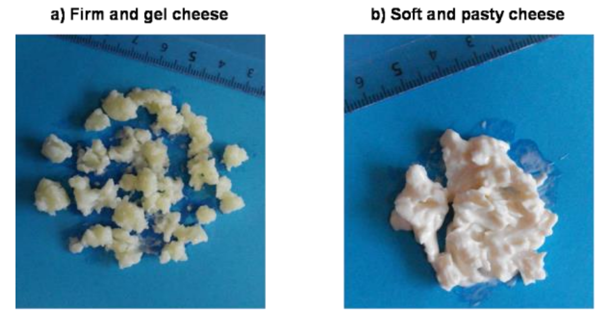
Measured variables

Masticatory behaviour

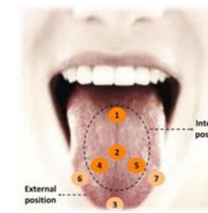


Bolus rheology

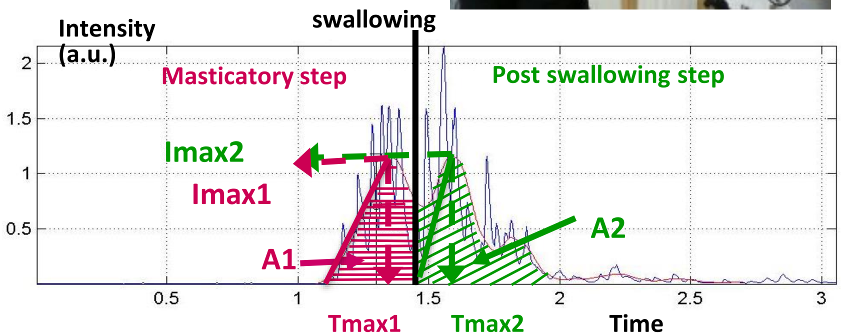
Mouth coating

Amount of product remaining in the mouth after swallowing

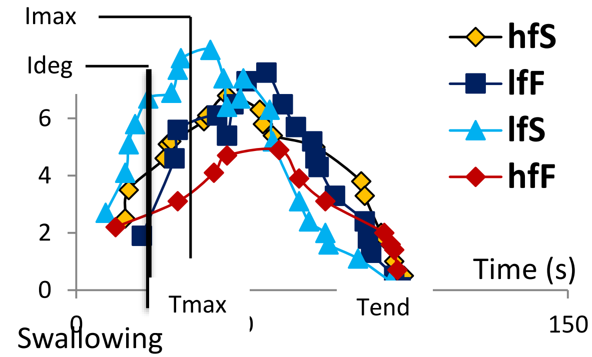


In-vivo aroma release

APCI-MS (atmospheric pressure chemical ionisation mass spectrometry)



Aroma perception



Combined effects of product and oral physiology on aroma release and perception

High impact of chewing behaviour on both aroma release and perception

Subjects with a **high chewing activity**

⇨ **high amount of aroma release** (mainly before swallowing), whatever aroma compound and cheese (increase in surface area due to sample breakdown)

⇨ **high sensory perception**

Stimulated saliva impacts more than resting saliva

Subjects with a **high salivary flow**

⇨ **high bolus moistening** then **high bolus speadability**

⇨ **low rate of aroma release** (dilution effect)

⇨ **low rate of perception**

For **high fat cheeses** and subjects with **high mouth coating**

⇨ **high amount of aroma release after swallowing** (hydrophobic compounds retained in the fat layer)

⇨ **longer sensory persistence**

For **low fat firm cheeses** and subjects which produce **boluses with a low spreadability**

⇨ **high rate of aroma release** (more exchange area)

⇨ **high rate of perception**

Combined effects of product and oral physiology on aroma release and perception

Sensory perception not fully explained by in-vivo aroma release, why?

Physiological variables explaining aroma perception but not aroma release

Subjects with a low amount of Na^+ in saliva
Perceive more the **blue cheese aroma of nonan-2-one**
Explanation by sensory cross-modal interactions:
low **Na^+ in saliva** ⇨ high saltiness perception (differential threshold)
blue cheese aroma congruent with saltiness
⇨ high saltiness can induce high blue cheese aroma

Subjects with a high lipolytic activity
Perceive more the **blue cheese aroma of nonan-2-one**
Salivary lipolysis is correlated to fat sensitivity *(Feron & Poette, Oilseeds Fats, Crops Lipids, 2013)*
blue cheese aroma congruent with fat perception
⇨ high lipolysis can induce high fat perception and thus high blue cheese aroma

Impact of human physiology on food oral processing and perception of soft dairy products (example of spreads)

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Review

Physiological mechanisms explaining human differences in fat perception and liking in food spreads-a review

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The main steps during food oral processing of food spreads are:

- Melting
- Phase inversion
- Bolus formation

Heat transfer and melting

Melting occurs immediatly after ingestion

= rapid transfer of heat from mouth oral cavity to the product

⇨ perception of coolness (tactile modality) *(Galindo-Cuspinera et al., J. Texture Studies, 2017)*

Melting depends on emulsion composition and structure

⇨ more crystal fat : slow melting *(Bot et al., Texture in food, 2003)*

⇨ more low chain fatty acids: high melting *(Keogh, Advance dairy chemistry, 2006)*

⇨ free milk instead of bound milk fat : quick melting, low viscocity, low hardness in mouth *(Bolenz et al., Eur Food Res & Technol, 2003)*

Oral volume: ⇨ large oral volume increases heat transfer and coolness

Tongue palate compression

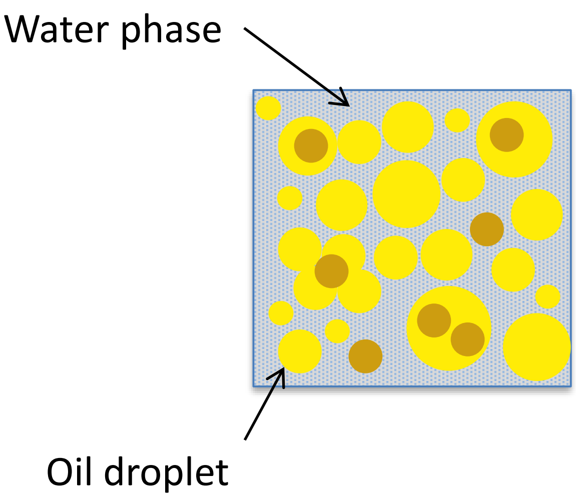
⇨ high compression increases heat transfer and coolness

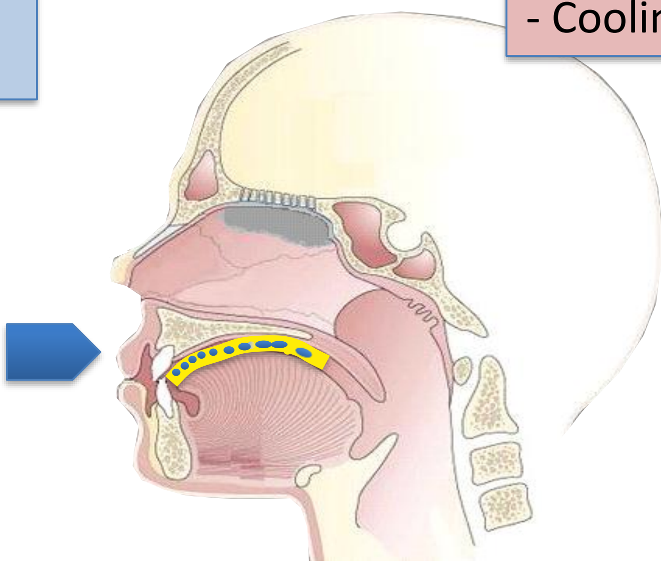
shear forces depend on emulsion composition *(Malone et al., Food hydrocolloids, 2003)*

⇨ less fat: high frictional forces

Melting phase

Product effect
- Fat level ↗: melting ↗
- SFC ↗: melting ↘





Sensory perception
- Cooling/fresh effect

Human physiology
- Oral volume ↗: melting ↗
- Tongue-palate compression ↗: melting ↗

Specific case of Water-in-Oil (W/O) emulsions

Phase inversion occurs simultaneously with melting (in case of W/O emulsion): dilution with saliva,depending on food composition and structure

⇨ too small water droplets, phase inversion will be delayed
no cooling effect and more unpleasant afterfeel *(Keogh, 2006)*
⇨ less emulsifiers : larger coalescence and thus higher perception of fat

Tongue palate compression

⇨ high compression : increases instability and thus inversion *(Dresselhuis et al., Food hydrocolloids, 2008)*

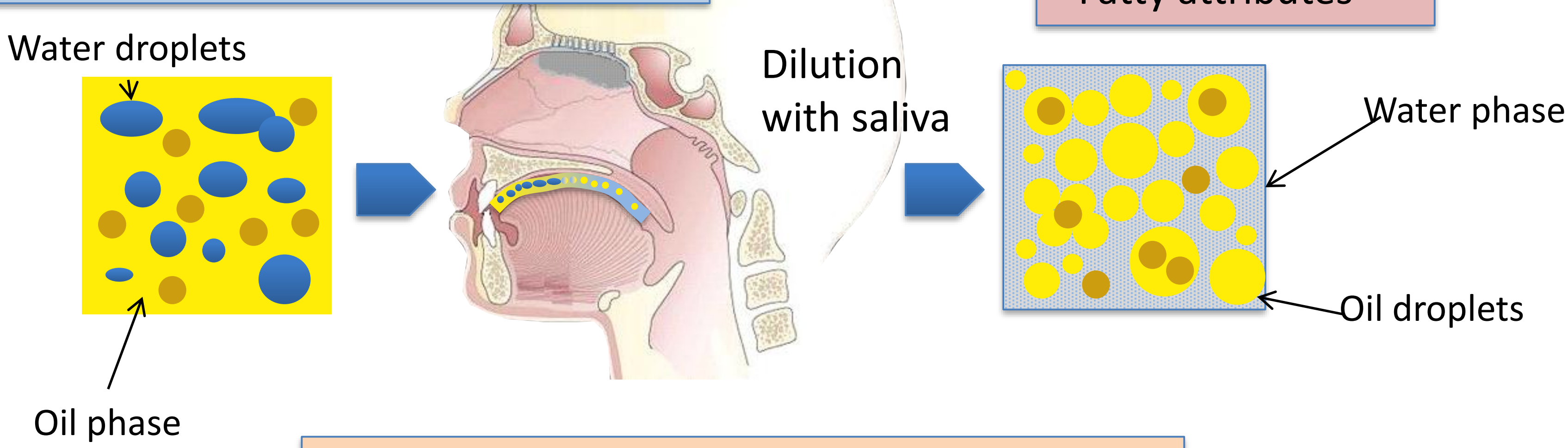
Saliva composition

⇨ mucins and enzymes (alpha-amylase) provoke floculation and coalescence *(Vingerhoeds et al., Food Hydrocolloids, 2005)* by a depletion mechanism
⇨ saliva effect depends on the type of emulsifier at the oil/water interface *(Vingerhoeds et al., Food Hydrocolloids, 2009)*

Inversion phase (W/O emulsions)

Product effect
- Water droplet size ↗: instability ↗
- Stabilizer & emulsifier

Sensory perception
- Fatty attributes



Human physiology
- Tongue-palate compression ↗: instability ↗
- Saliva composition

Physiological parameters involved in food bolus formation

Many sensory descriptors are perceived during bolus formation

Tongue pressure and frictional effects important for texture perception *(Kokini et al., J. Texture Studies, 1977)*

⇨ thickness explained by viscous force between tongue and roof of the mouth

⇨ smouthness explained by 1/frictional force

Mouth coating and oral clearance depend on emulsion structure

⇨ thickeners create a lubricating layer on the tongue

↘ friction and ↗ fatty after feel *(Camacho et al., J. Texture Studies, 2015)*

⇨ high fat spreads ↗ mouth coating mainly on the back of the tongue (Poette et al., 2014)

Role of saliva in food bolus formation

Saliva flow

High saliva flow : high bolus moistening *(Guichard et al., Food & Function 2017)*

product effect: less saliva incorporated in low fat products

High saliva flow: high oral clearance *(Carpenter, Food Oral Prcessing, 2012)* and low afterfeel

Saliva viscosity : no evidence on the effect of inter-individual variability on food bolus properties and perception

Saliva composition

⇨ alpha-amylase contributes to starch breakdown ⇨ decrease in bolus viscosity *(de Vijk et al., Physiology & Bihaviour, 2004)* ⇨ higher lubrication, higher release of fat and higher creaminess perception

⇨ mucins contribute to droplet aggregation and bolus viscosity and increase perception of heterogeneity

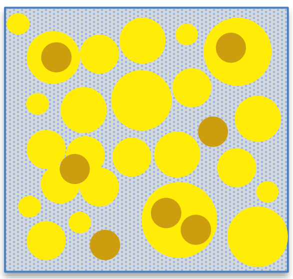
⇨ proline-rich-proteins (PRP) contribute to droplet aggregation/repulsion as a function of their charge (+ or -)

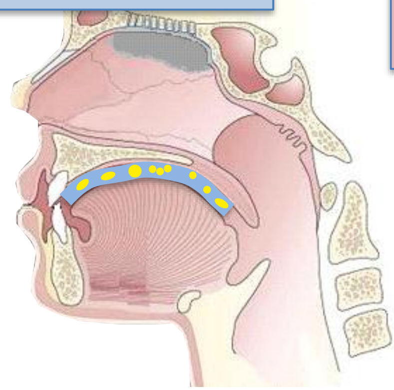
⇨ ions (+ or -) modulate droplet aggregation as a function of emulsifier

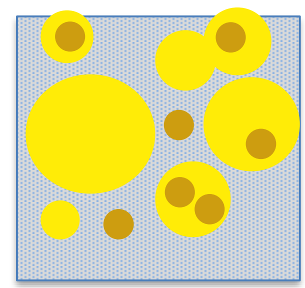
Bolus formation

Product effect
- Fat level ↗: coating ↗, fattiness ↗
- Fat quality, melting point ↗: no cooling effect
- Particle size ↗: roughness ↗: liking ↘
- Salt level: effect on protein network

Sensory perception
- Creaminess
- Roughness
- Granny
- Fattiness
- Aftertaste







Human physiology
- Tongue movements
- Saliva flux
- Saliva composition (mucins, ions, α-amylase, PRP)

Conclusion

Food composition and structure impact bolus formation and sensory perception
Great inter-individual differences exist in oral physiology and masticatory behaviour

- what are the consequences on the digestibility?
- few studies combine nutritional and sensory properties

Further developments are needed to better understand
during food breakdown:

- mechanisms involved in bolus formation as a function of food product
- mouth coating and oral clearance contributing to mouthfeel
- relative impact of salivary proteins, mucosal pellicle, fungiform papillae

at the brain level:

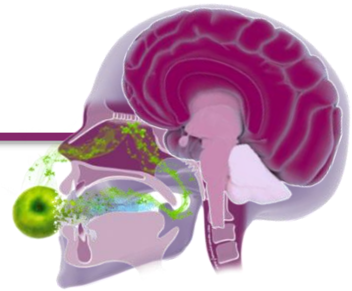
- multimodal perception : relative contributions of texture, taste and aroma to the global sensory perception and their sensory interactions taking into account the socio-economical context

Need of pluridisciplinary research:

- to formulate food products for specific populations, with high nutritional properties, good sensory acceptability while using eco-friendly transformation process

Group leaders
Elisabeth GUICHARD
Christian SALLES

Research group FFOPP: Flavour, Food Oral Processing and Perception



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