The TASTEMAP Project

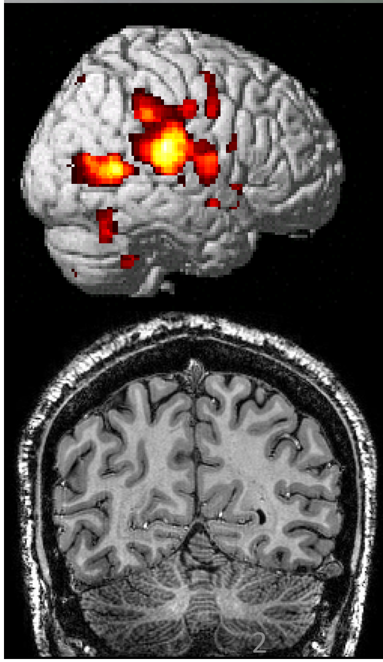
Sue Francis

Sir Peter Mansfield Imaging Centre,
University of Nottingham, Nottingham, UK

Overview

- Overview of Research at Nottingham
- Previous fMRI studies:
  - Taste, aroma, oral somatosensation
  - Subject Phenotype
  - Hunger/satiety/hormone influences

- The TASTEMAP Project
  - Variation in taste response
  - Gustotopic Mapping
  - Phantom Taste Mapping



Nottingham Research Focus

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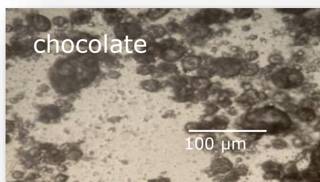
Understanding sensory perception requires a multidisciplinary approach including to understand both the stimuli and response, the former at receptor level and the latter in terms of consumer self report and at the cortical level. Such research involves the combination of sensory and instrumental techniques, and collaboration with experts in the fields of fMRI, psychology, and analytical flavour science – all available at University of Nottingham.

Understanding the Stimulus

Does aroma intensity follow volatile release in nose?



What is the in-mouth microstructure?
How does this impact on mouthfeel?

Understanding Individual and cultural variation

Understanding how individual differences impact on perception. E.g. Eating behaviour and Taster Status phenotypes.

What impact do genetic and cultural differences have on perception? Can understanding these differences inform design of better products for different population groups?

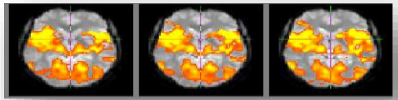
Multimodal Perception

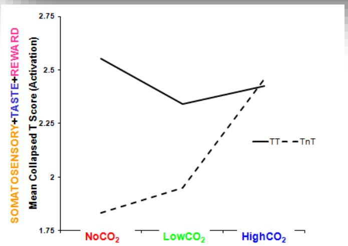
Investigating interactions between and within the different sensory modalities and across individuals.

Carbonation adds more than just bubbles to beverages! They influence taste and flavour as well and mouthfeel.

Understanding Cortical Response

Developing robust protocols to investigate sensory interactions, and the cortical response to fat





'Taster' and Thermal taster Phenotypes show increased cortical response

What can we learn by mapping the insular response to taste stimuli and does this differ across individuals/cultures?

Emotional Response

Does emotional response go beyond liking? How do sensory properties affect emotional response? Does emotional response vary across different cultures.

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Sir Peter Mansfield Imaging Centre (SPMIC)

MRC Medical Research Council

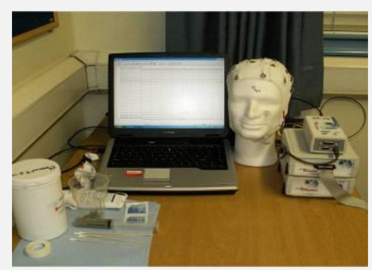
£7.7M MRC Clinical Research Infrastructure Initiative awarded to Nottingham for MRI


SPMIC/UP

1.5T MRI (Philips)
3T MRI (Philips)
3T Wide bore MRI
7T MRI with Multi-transmit
275 Channel Real-time MEG
Upgraded EEG facilities and screened room
NIRS
Sodium imaging - £1 million MRC Discovery grant

SPMIC/QMC

1.5T MRI(GE)
3T MRI (GE)
Vertical MRI
Clinical DNP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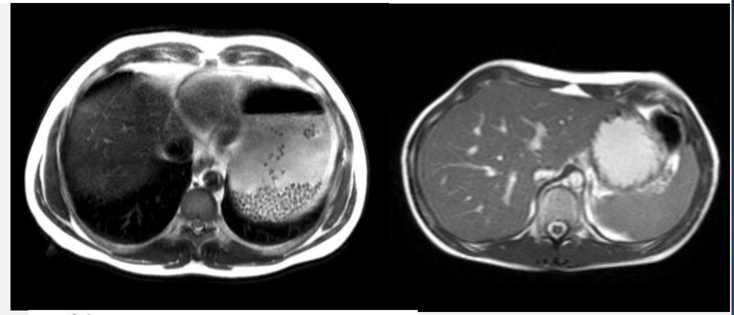
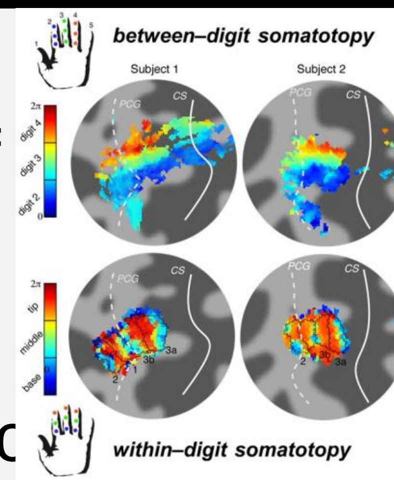
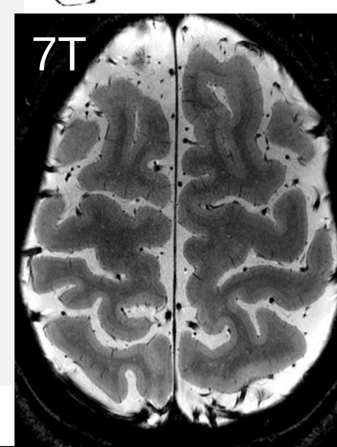
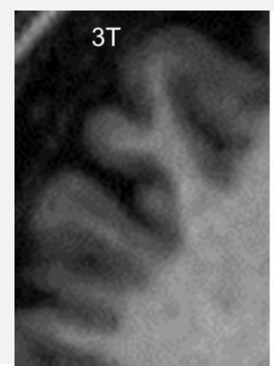
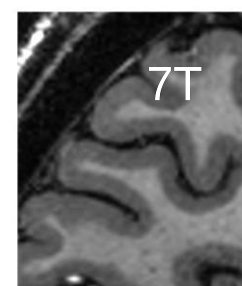
- fMRI of foods
- GI function
- Obesity
- Liver function
- Tactile properties – fMRI of touch and skin imaging
- Cognitive studies
- Ageing and Haemodynamic











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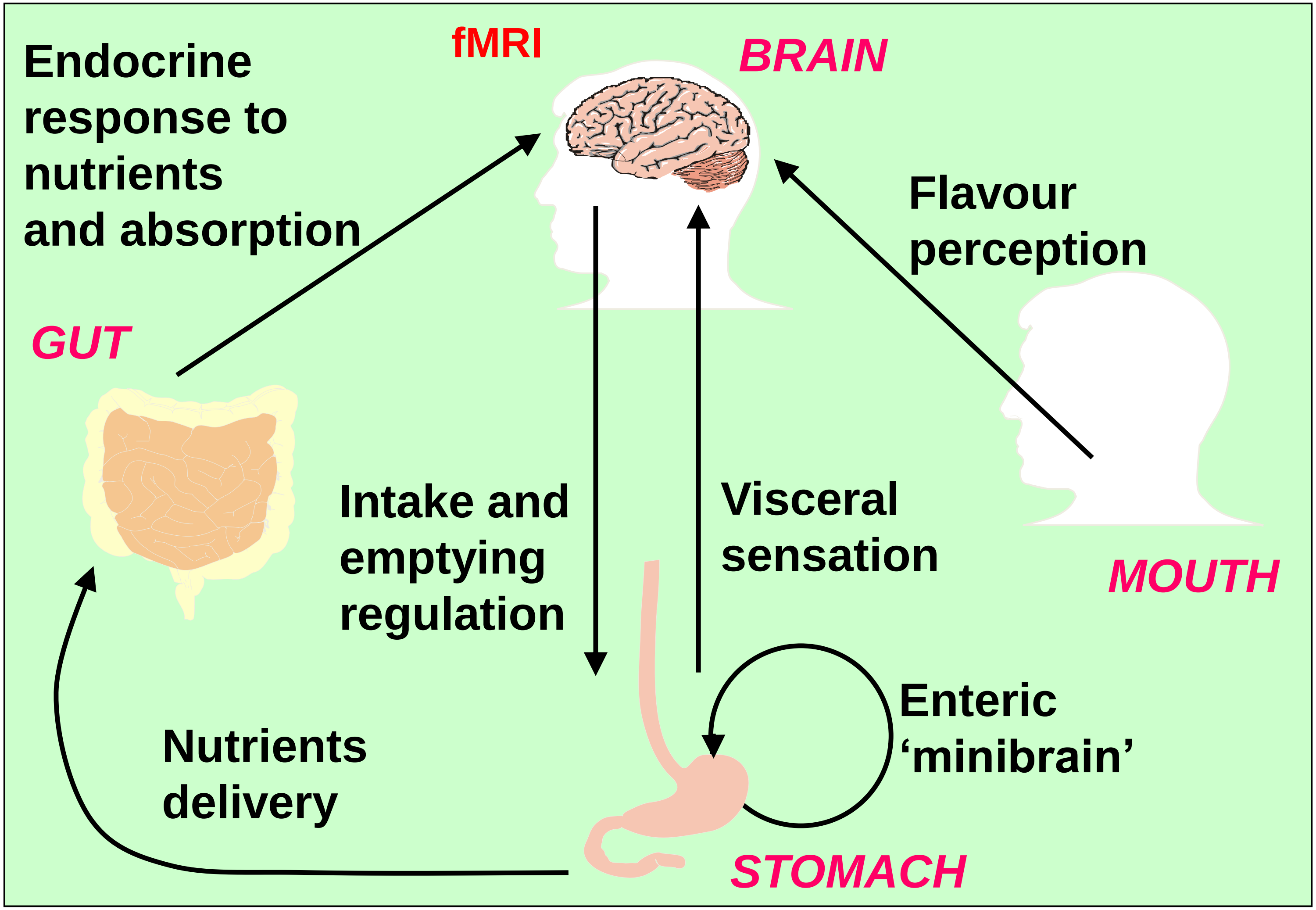
SSSC Sensory Science Centre

fMRI of gut-brain axis



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Combining sensory science and brain imaging

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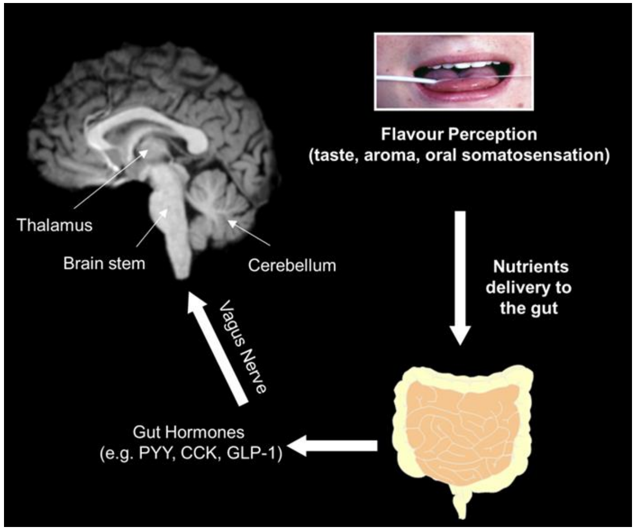
Understanding **sensory for fMRI**

- Hollowood, T., et al., ***Modelling sweetness and texture perception in model emulsion systems***. EUR FOOD RES TECHNO, 227(2): p. 537-545, **2008**.
- Yang, Q et al., ***Phenotypic variation in oronasal perception and the relative effects of PROP and Thermal Taster Status.*** Food Qual Pref, 38 , 83–91, **2014**.



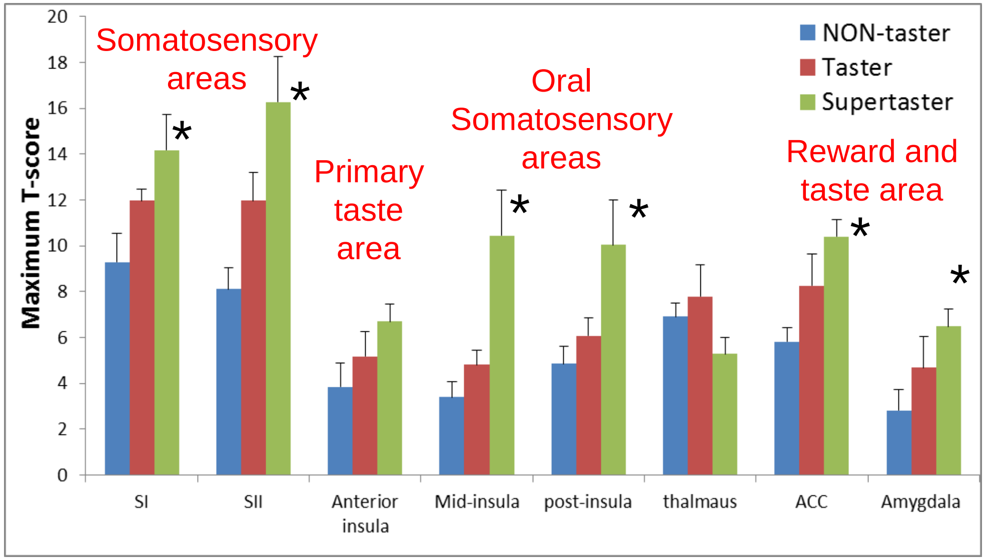
fMRI Methodology:

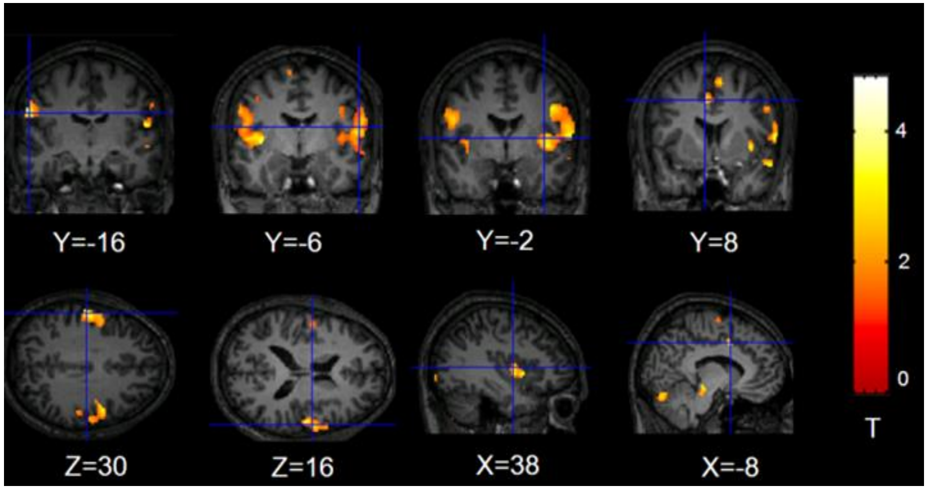
- Marciani, L., et al., ***Improved methods for fMRI studies of combined taste and aroma stimuli***. J Neurosci. Methods, 158(2): p. 186-194, **2006**.
- Hort, J., et al., ***The Effect of Body Position on Flavor Release and Perception: Implications for fMRI Studies***. C Chem. Percept., 1(4): p. 253-257, **2008**.
- Eldeghaidy S et al., **Use of an Immediate Swallow Protocol to Assess Taste and Aroma Integration in fMRI Studies**, Chem. Percept. , 4: 163–174 , **2011**.

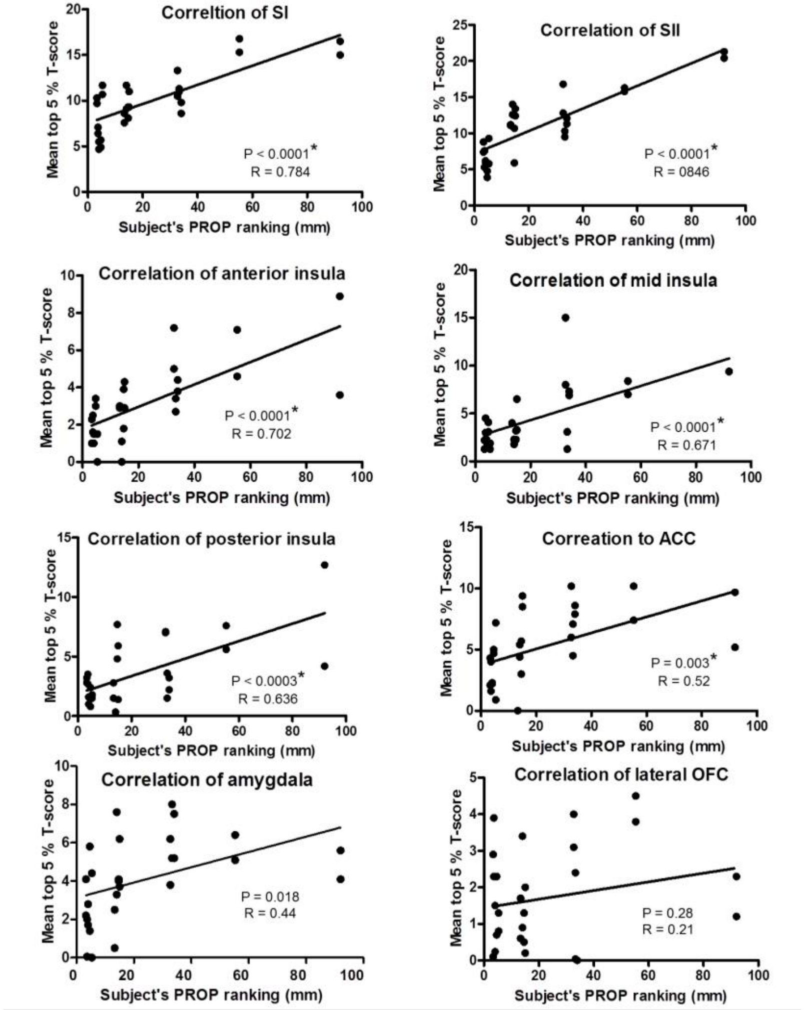
fMRI of Cortical Response to Taste, Viscosity, Fat

- Francis, S. et al., ***The Representation of pleasant touch in the brain and its relation to taste and olfactory areas,*** Neuroreport, 10, **1999**.
- O'Doherty et al., ***Sensory-specific satiety-related olfactory activation of the human orbitofrontal cortex,*** Neuroreport, 7, 11, 399-403, **2000**.
- O'Doherty et al., ***Representation of pleasant and aversive taste in the human brain***. J Neurophysiol.; 85(3):1315-21, **2001**.
- B. de Celis Alonso et al. ***Functional magnetic resonance imaging assessment of the cortical representation of oral viscosity***. J.Texture Stud., 38:725-737, **2007**.
- Eldeghaidy S et al., ***The Cortical Response to the Oral Perception of Fat Emulsions and the Effect of Taster Status***. *J Neurophysiol* 105: 2572–2581, **2011**.
- Eldeghaidy S et al., ***Does Fat Alter the Cortical Response to Flavor?*** Chem. Percept. 5:215–230, **2012**.
- Hort J et al., ***Thermal taster status: evidence of cross-modal integration.*** HBM, 37,6 , 2263–2275, **2016**.
- Eldeghaidy et al., ***Prior consumption of a fat meal by healthy adults modulates the brain's response to fat.,*** J Nutrition, under revision.

Effect of Taster Status on cortical response to fat







Eldeghaidy S et al. The cortical response to the oral perception of fat emulsions and the effect of taster status. J Neurophysiol. 2011 May;105(5):2572-81.

Effect of Thermal Taster status on response to carbonation

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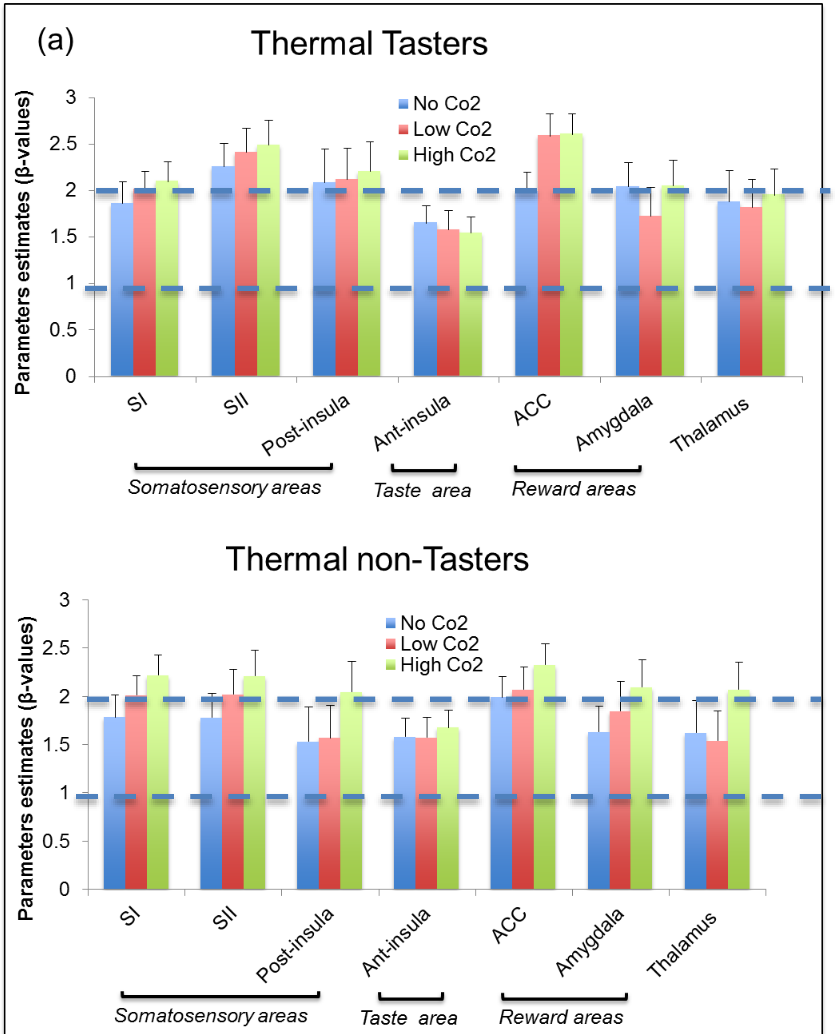
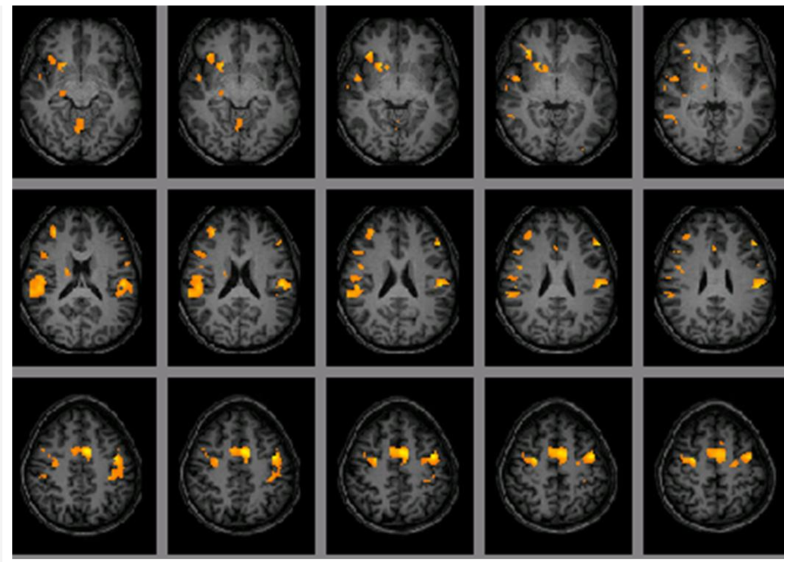


RFX group analysis map of (TTs> TnTs) for the no CO2 sample



In TnTs, a significant increase in in taste, somatosensory and reward areas with increasing CO_2.
In TTs, a significant increase in somatosensory areas (SI, SII) only.
Supports a cross-modal integration mechanism in thermal tasters, with both gustatory and trigeminal nerves highly stimulated to gustatory stimuli alone

Hort J et al., Thermal taster status: evidence of cross-modal integration. HBM, 37,6 , 2263–2275, 2016.

Hormonal interaction of gut and brain: effect of prior feeding of fat meal

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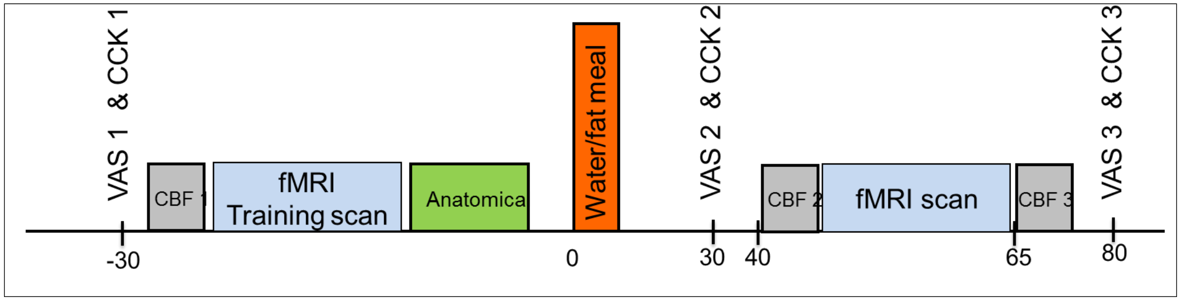
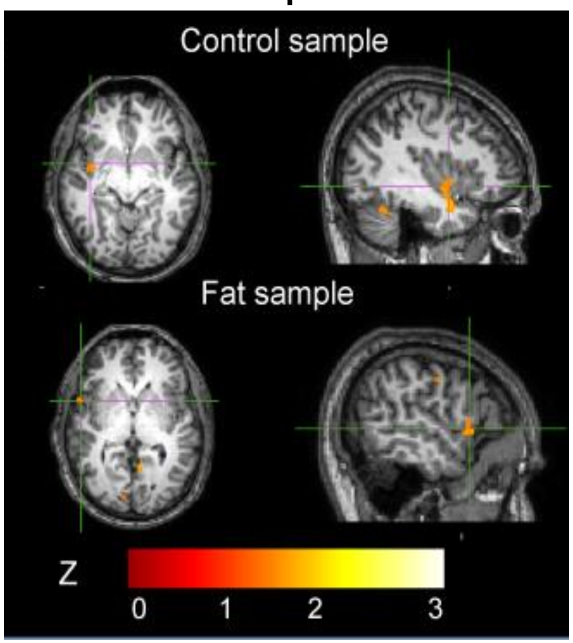
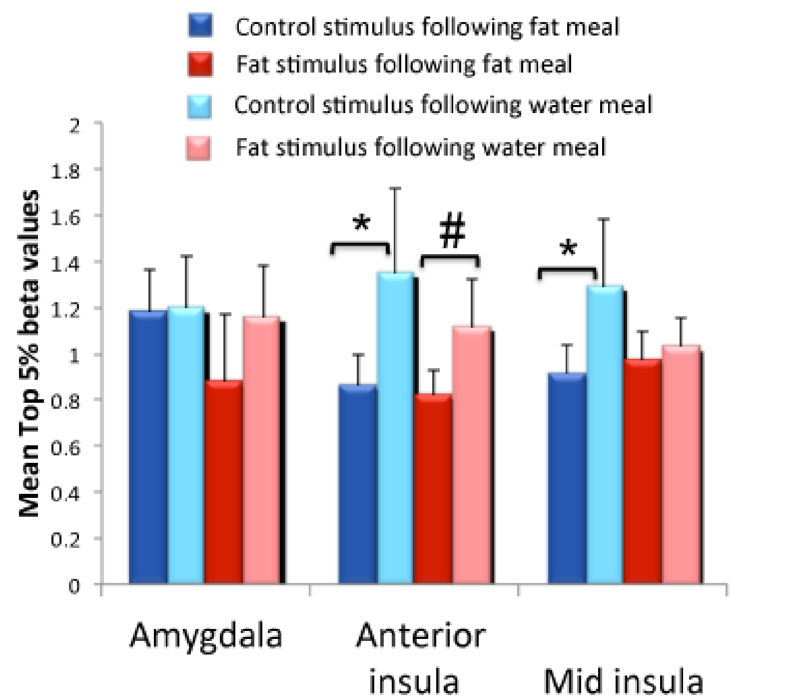


fMRI scan = control/fat sample

Response to water meal > fat meal for control sample and fat sample





Eldeghaidy et al., *Prior consumption of a fat meal by healthy adults modulates the brain's response to fat.*, J Nutrition, under revision.

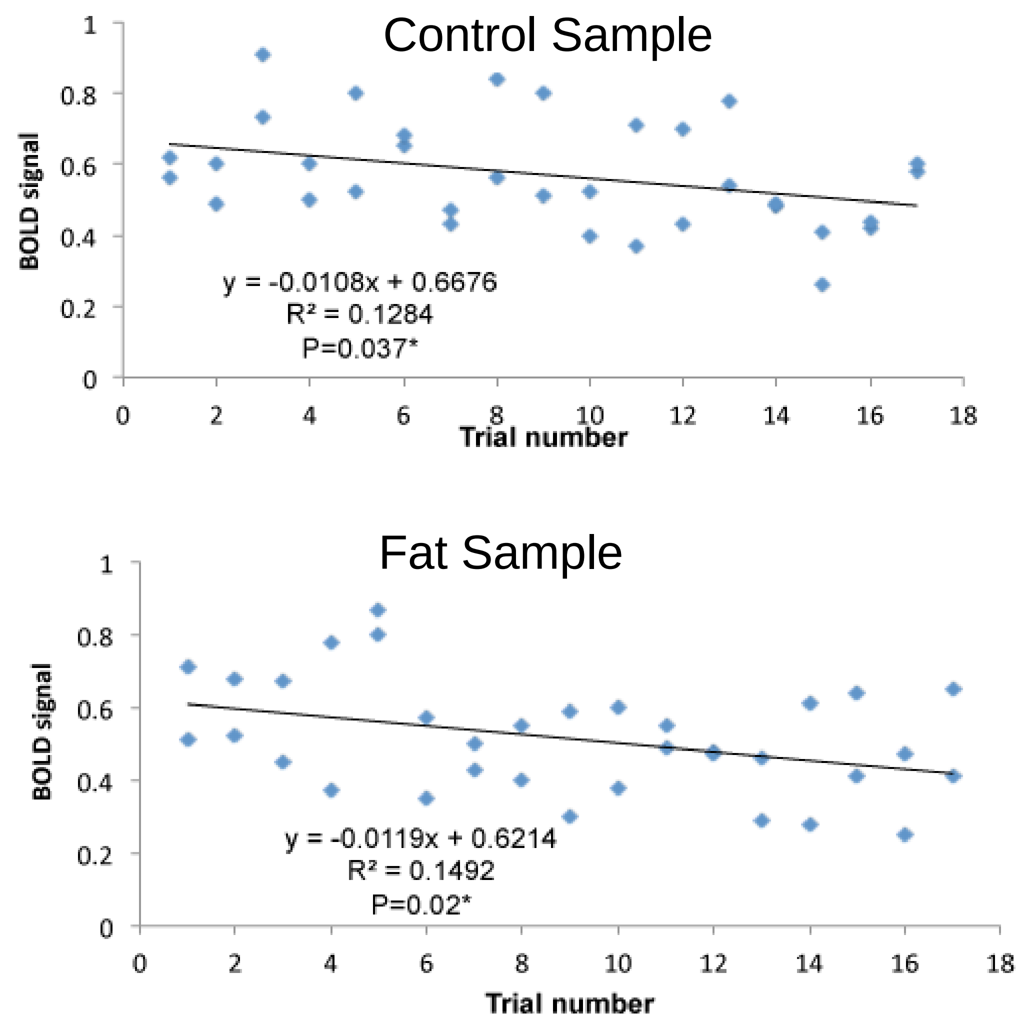
BOLD Habituation following fat meal

Reward areas (amygdala)

Primary taste areas (AI)

Oral somatosensory areas (MI and PI)

Thalamus



CCK correlation with BOLD response

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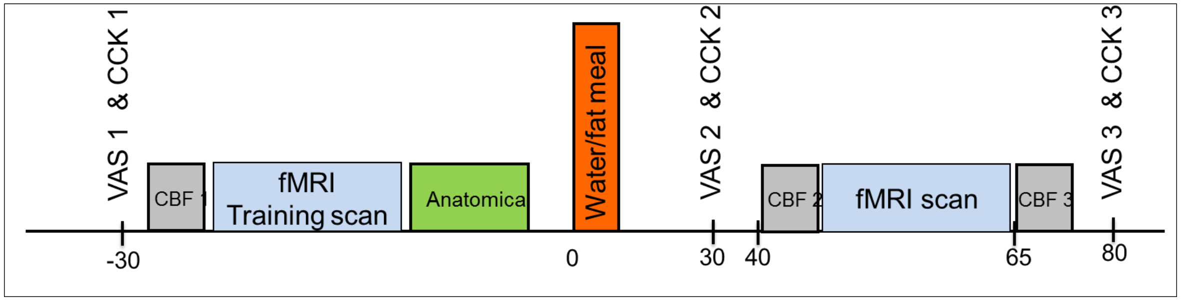

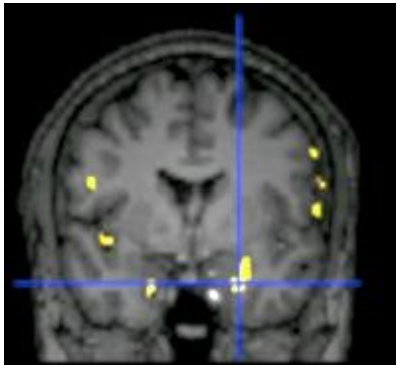

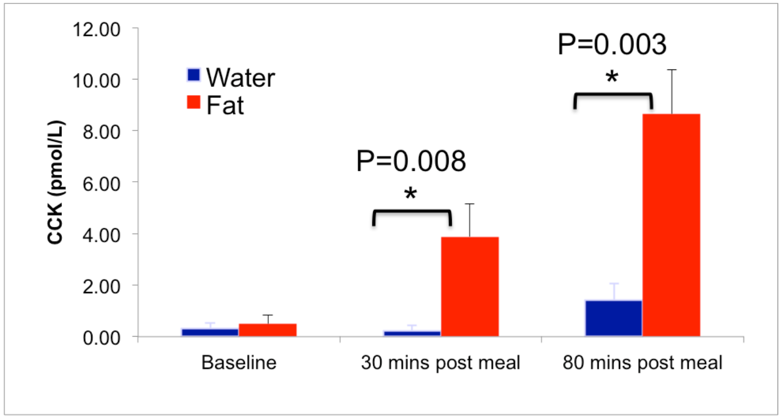

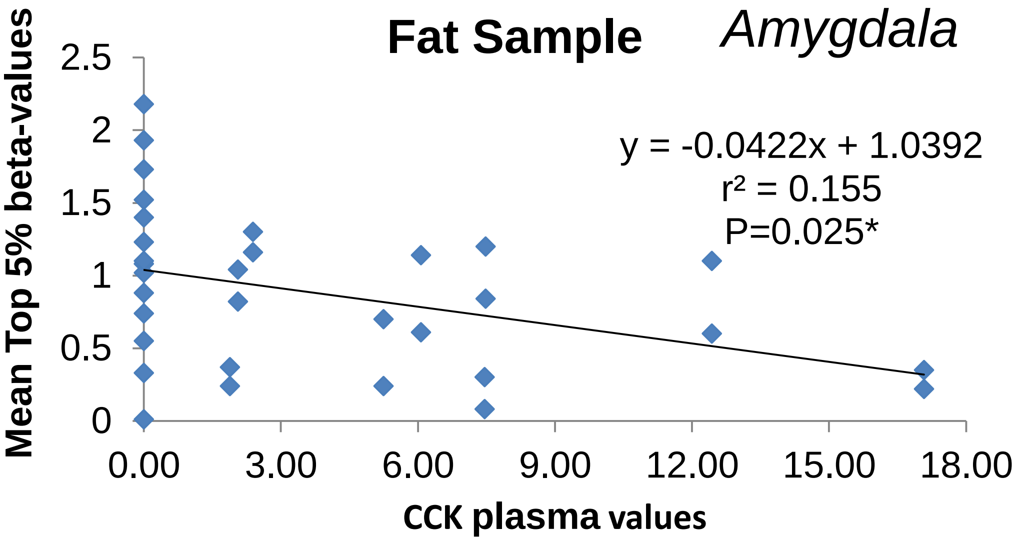

Negative BOLD correlation with CCK following the fat meal in amygdala, anterior, mid- and posterior insula, SI.

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TASTEMAP PROJECT

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Gustotopic mapping in humans: a high resolution fMRI study to assess detailed topography and modulations (TASTEMAP)

BBSRC IPA grant £661,453

10/02/2014-09/02/2017

bbsrc
biotechnology and biological sciences research council

AIM: To understand taste processing using sensory science and functional MRI (fMRI)

SPMIC Sir Peter Mansfield Imaging Centre Nottingham

Sensory Science Centre

Unilever

Prof Sue Francis
Professor of Physics
Prof Joanne Hort
SABMiller Chair of Sensory Science & Head of Brewing Science

Unilever: Anna Thomas, Marco Hoeskma, Timo Giesbrecht
PDRAs: Sally Eldeghaidy, Becki Ford; BBSRC CASE studentship: Martha Skinner

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Objectives

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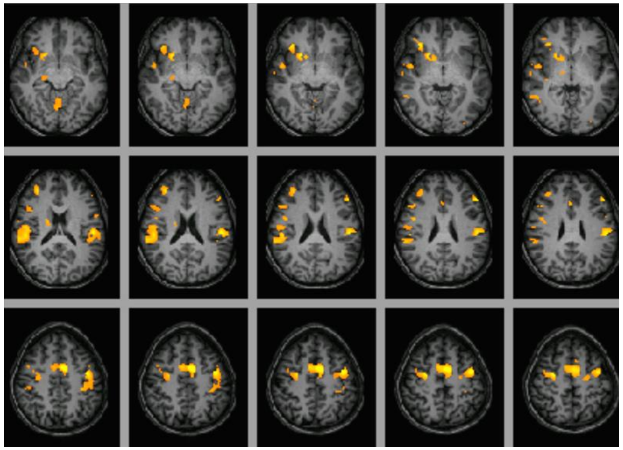
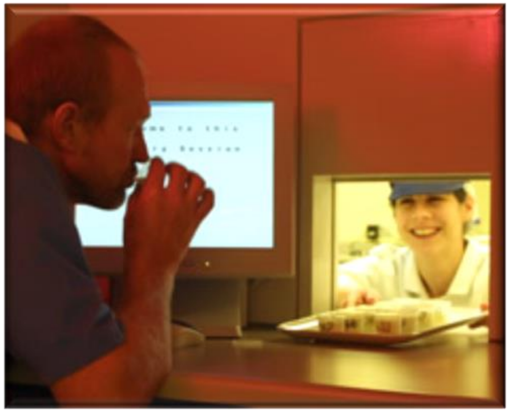
To combine sensory science and brain imaging



1. To form a gustotopic map of tastants in humans.



2. To study how ‘phantom’ taste is mapped in the brain.

TASTEMAP Project

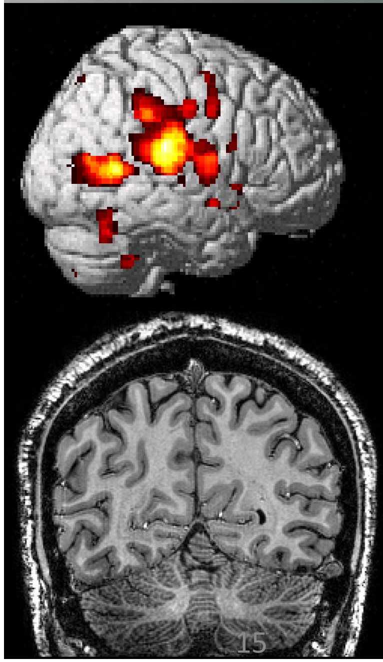
- **Variation in taste response**

- Gustotopic Mapping

- Development of taste samples for fMRI
- fMRI measures

- Phantom Taste Mapping

- Sensory measures
- fMRI measures



Variation In Taste Perception

Gender

Age

Culture

Food availability

Societal factors

Economic factors

Health/disease

Taste/aroma disorders

PROP taster status

Thermal taster status

Nutritional status

Why is Taster Status Important?

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Sweet

Bitter

Sour

Salt

Umami

(Chang *et al*, 2006: Pickering *et al*, 2010)

FOOD CHOICE

(Keller *et al*, 2002)

(Tepper *et al*, 1998)

(Lanier *et al*, 2005: Bajeck & Pickering, 2010)

Taster status

PROP Taster Status

- **PROP Tasters:**
  More sensitive to other oral stimuli such as tastes and tactile sensations, probably due to having more receptors

Thermal Taster Status

- **Thermal tasters (TTs) :**
  Individuals reporting taste sensations during both the warming and cooling trials

  Thermal Tasters are more sensitive to other oral stimuli such as tastes, tactile sensations and temperature differences.

PROP Taste Phenotype

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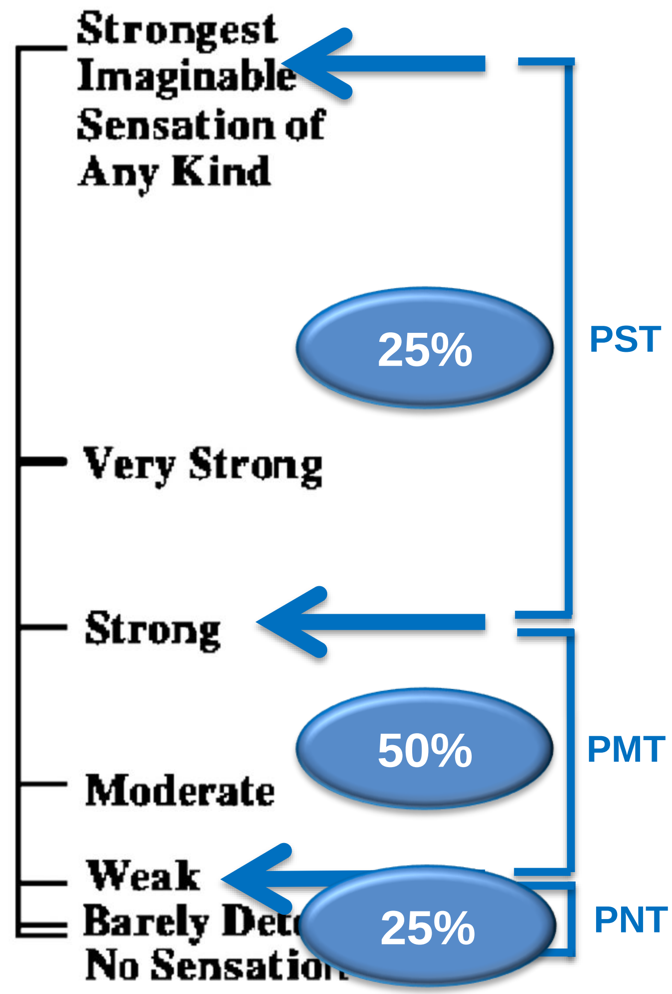
6-n-propylthiouracil (PROP)

- PROP non taster (PnT)
- PROP taster (PT)
  - -Medium taster
  - -Supertaster

(Bartoshuk & Duffy, 1994)



(Bartoshuk, 2004)

Papillae Density and TAS2R38 Genotype

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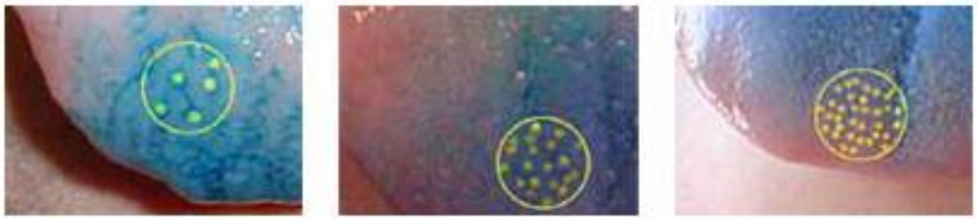
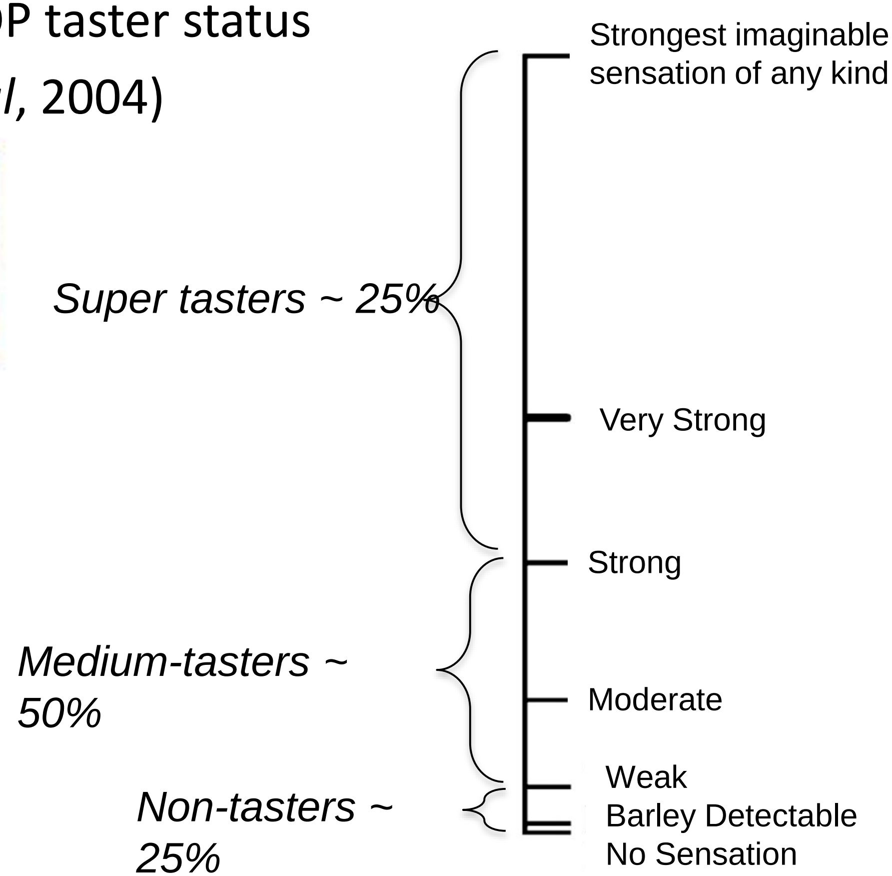
- gLMS scale – Rate basic tastes and PROP taster status
- **Genotype TAS2R38** PAV/AVI (Duffy *et al*, 2004)



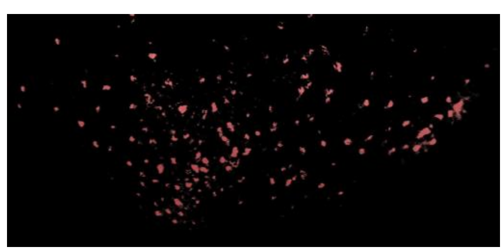
PROP sensitivity →



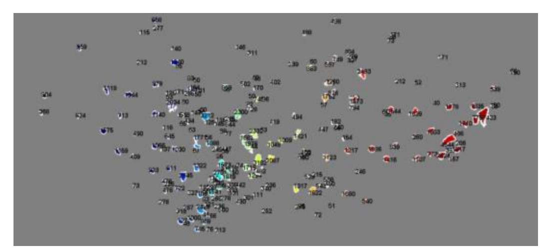
Limited assessment

Automated papillae assessment

High resolution image



Papillae segmented



Area of each papillae

Thermal Tasters

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WARMING TRIAL

Sweet

Bitter

COOLING TRIAL

Sour

Salty

Metallic

Menthol/Mint

Umami

Spicy

Thermal taster (TT)

Thermal non taster (TnT)

TASTEMAP Project

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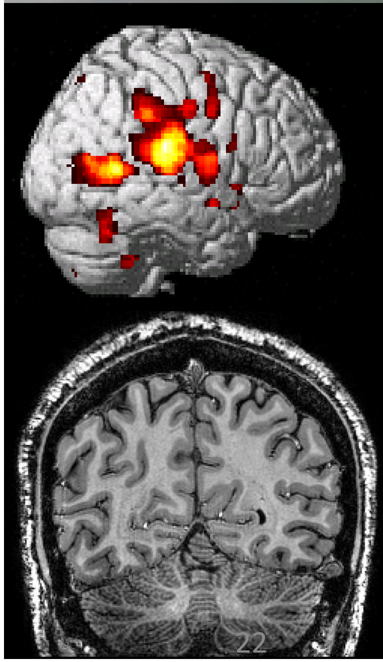
- Variation in taste response

- **Gustotopic Mapping**

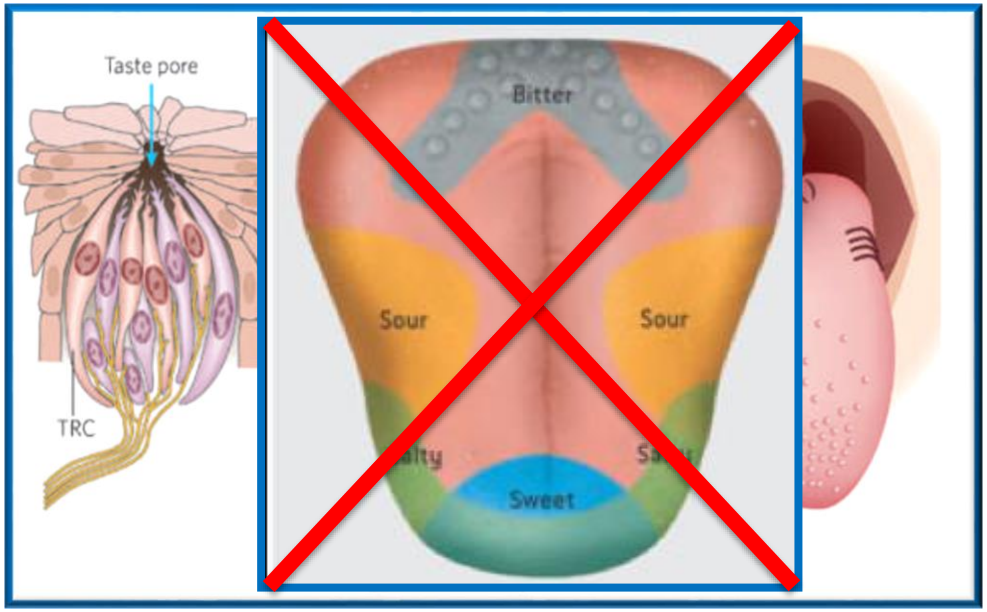
- Development of taste samples for fMRI
- fMRI measures

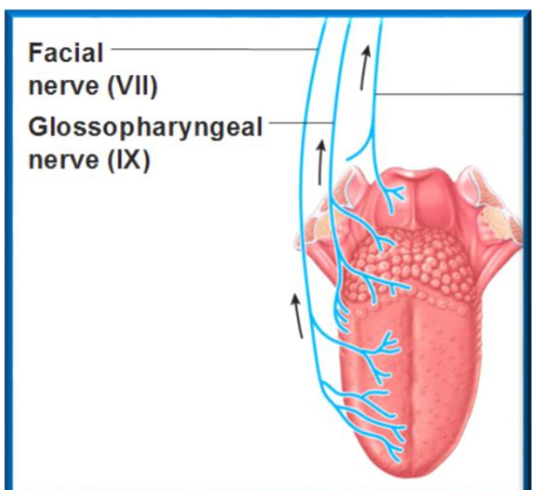
- Phantom Taste Mapping

- Sensory measures
- fMRI measures



Taste Processing





Tastant dissolved in saliva

↓

Papillae

↓

Taste bud

↓

Taste receptor cell

↓

Cell depolarises & action potential

↓

Peripheral nervous system

↓

Central nervous system

Taste Processing

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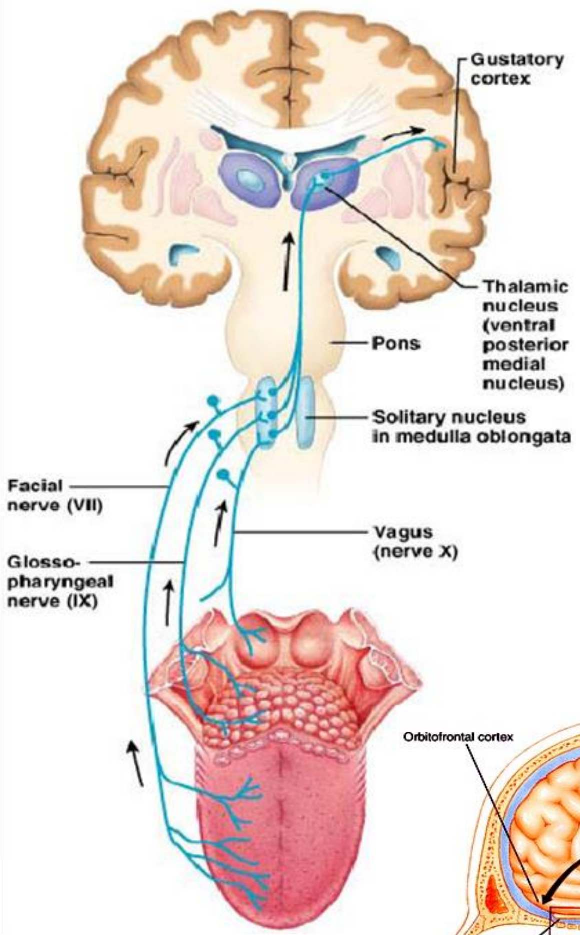
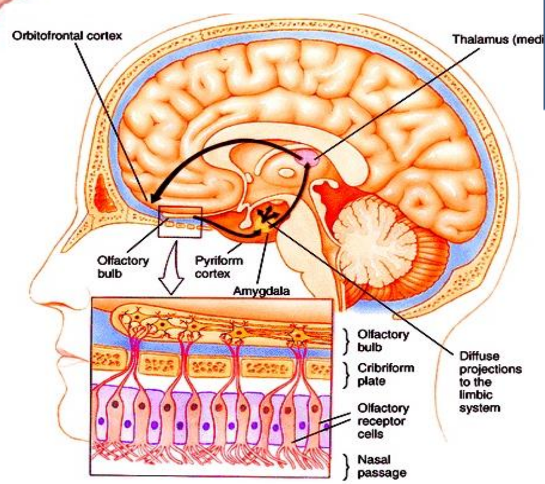




Nucleus of solitary tract

↓

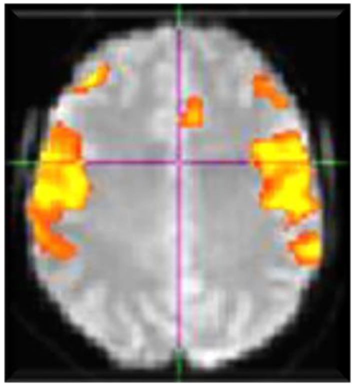
VPM Thalamus

↓

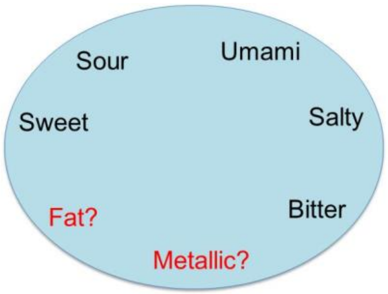
Primary gustatory cortex

↓

Secondary gustatory cortex



Gustotopic map



Development of Taste Stimuli

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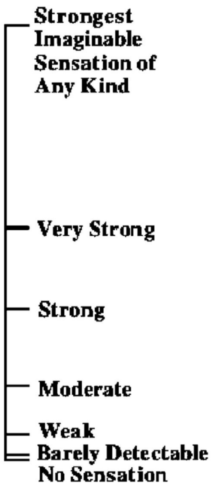
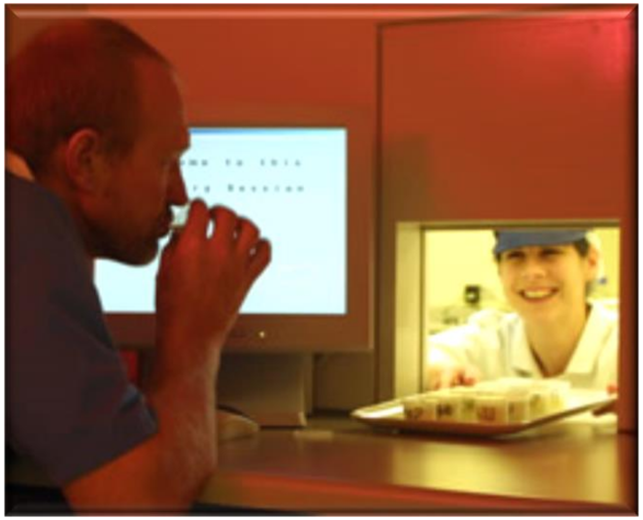
Aim
Equi-intense between moderate/strong on gLMS



- Sweet (glucose)
- Sour (citric acid)
- Salty (sodium chloride)
- Bitter (quinine sulphate)
- Umami (monosodium glutamate)
- Metallic (iron sulphate)

(Lawless *et al*, 2004)



Sensory Analysis of Samples

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10 sensory panellists

Training

- Use of scale
- Discrimination between samples
- Reproducibility

Sensory Analysis

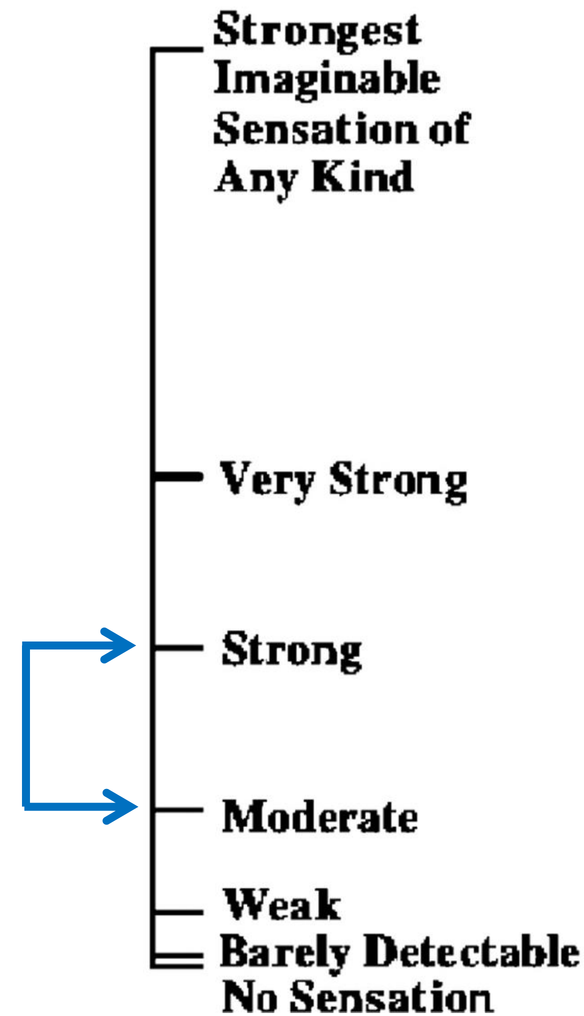
- Rate intensity of 5ml samples

Statistical Analysis

- ANOVA
- Post Hoc Testing (Tukey)

Sensory Analysis

- Adapt sample concentration
- Re-rate intensity



Stimuli Developed

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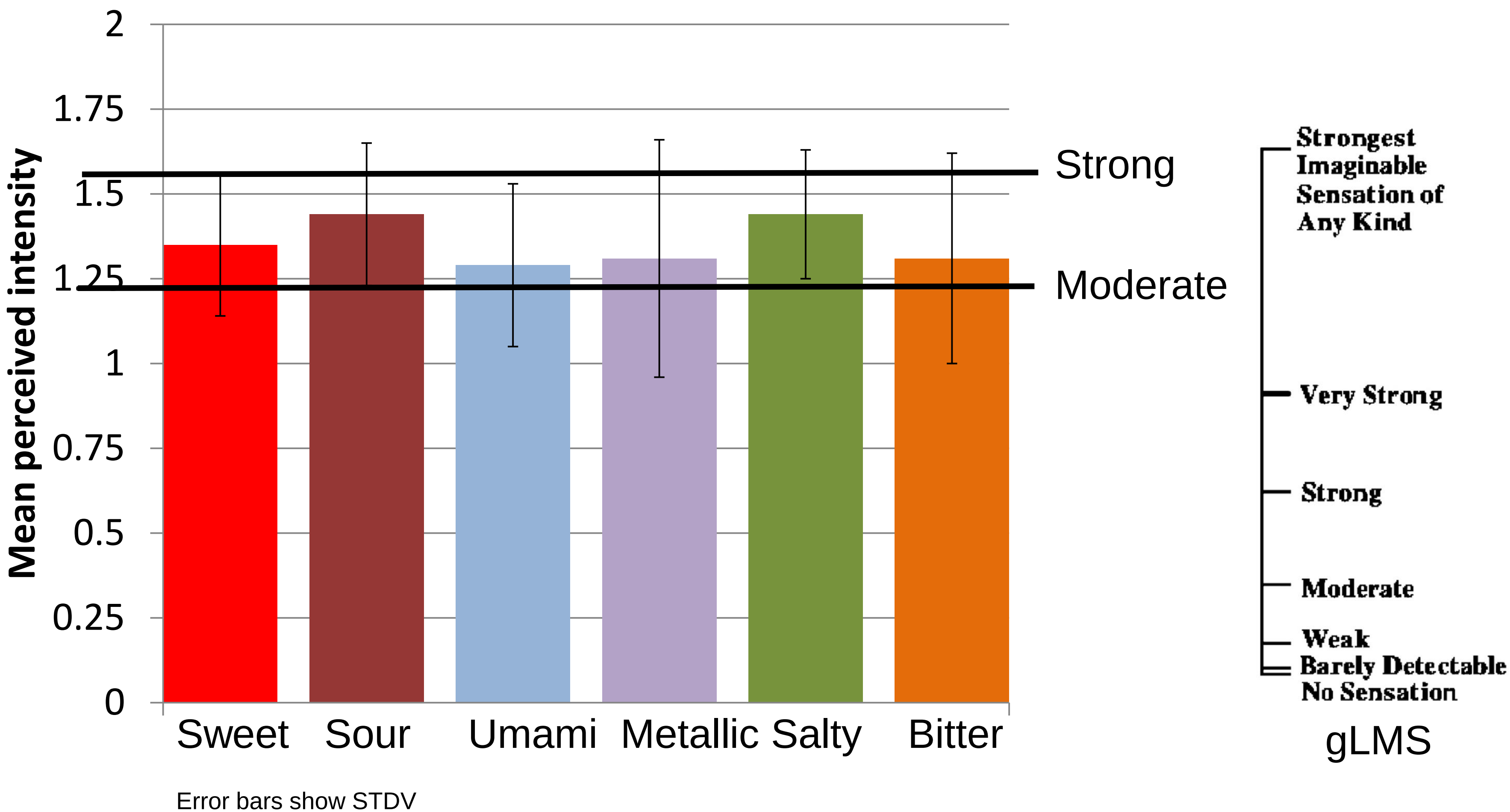

Outcome: Equi-intense between moderate/strong on gLMS

Sensory Screening

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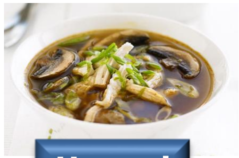
Taste sensitivity test


Sweet

Bitter

Sour

Salt

Umami

Metallic

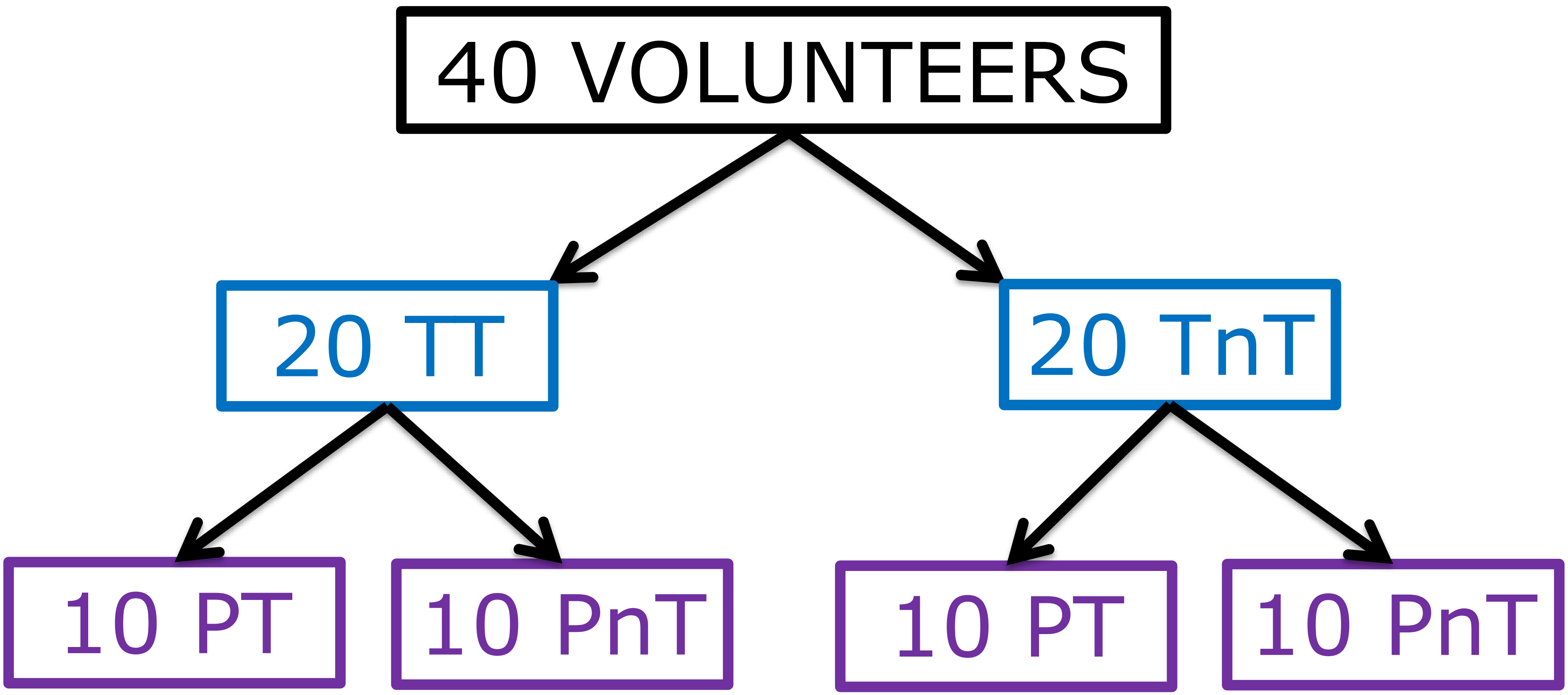
PROP

Collect saliva swab

Gene	# SNP's
CD36	5
CA6	4
TAS2R38	3
TRPM5	9
TOTAL SNP's	**21**

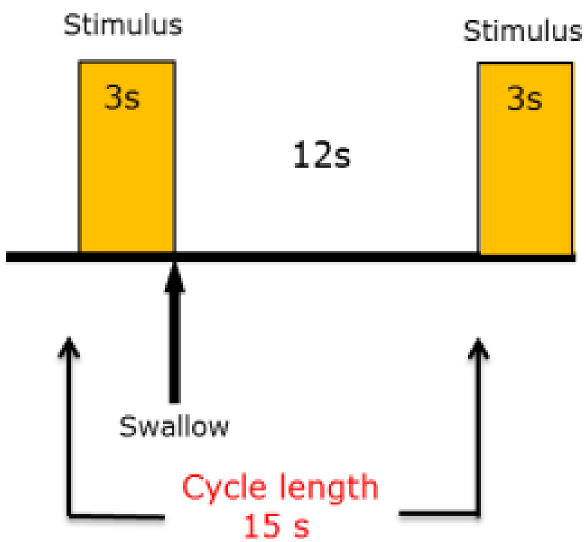
Collect tongue images

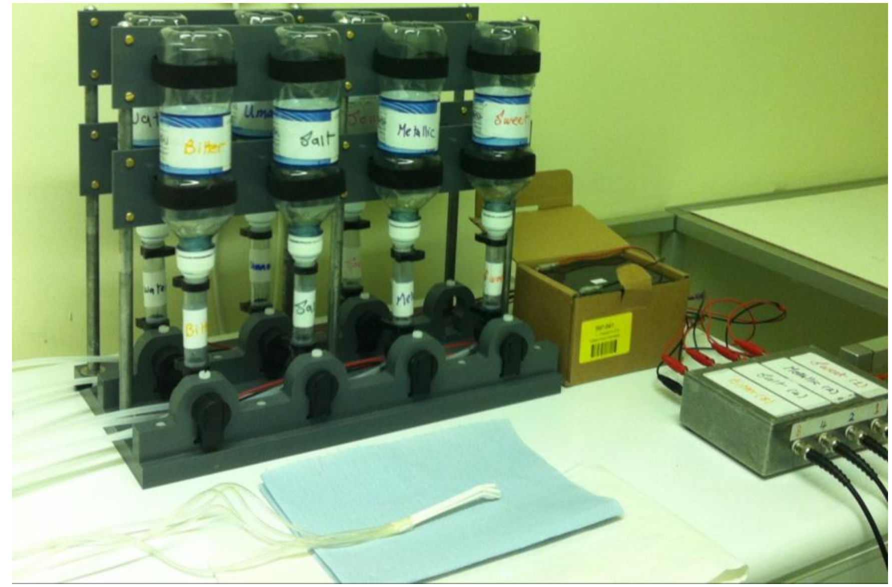
Volunteers



Gustotopic mapping

- Sweet
- Sour
- Salty
- Bitter
- Umami
- Metallic
- Deionised water (control)



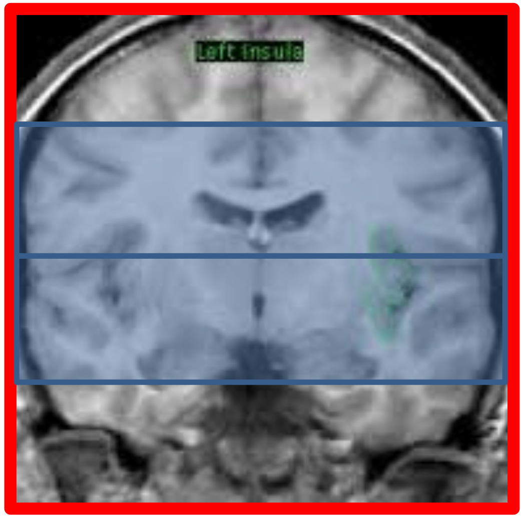


Marciani L. et al. J. *of Neuroscience Methods.* 2006; 158:186-194.

10 cycles of each taste

Image acquisition

- 26 Subjects
- 7T Philips Achieva scanner
- 40 axial slices using multiband 2, TR= 2 s; TE=30 ms; voxel size 1.5mm^3 isotropic, SENSE=2.5



- T_2*-weighted (0.5x0.5x1.5mm^3),
- High resolution PSIR (1x1x1mm^3)

7 Tesla: Gustotopic mapping

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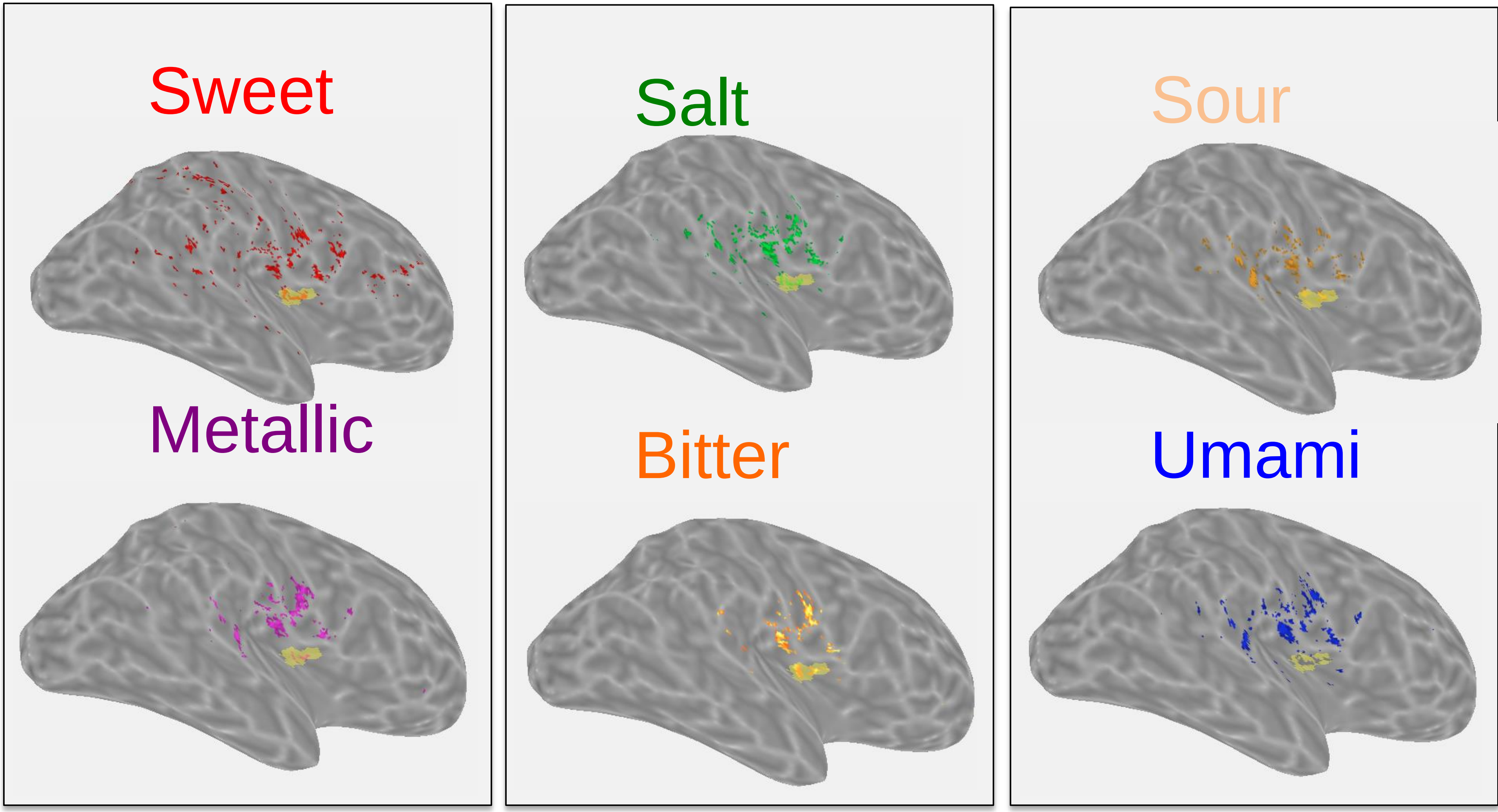

TASTEMAP Project

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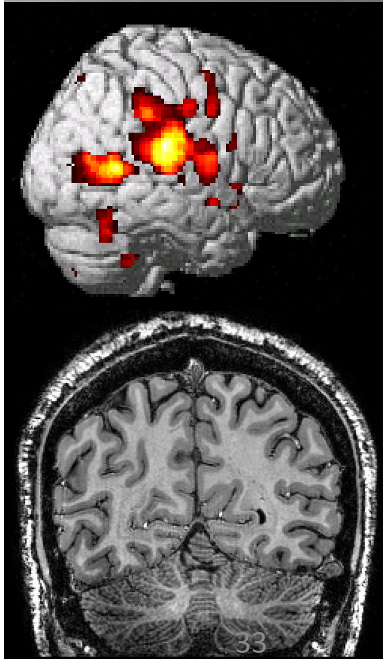
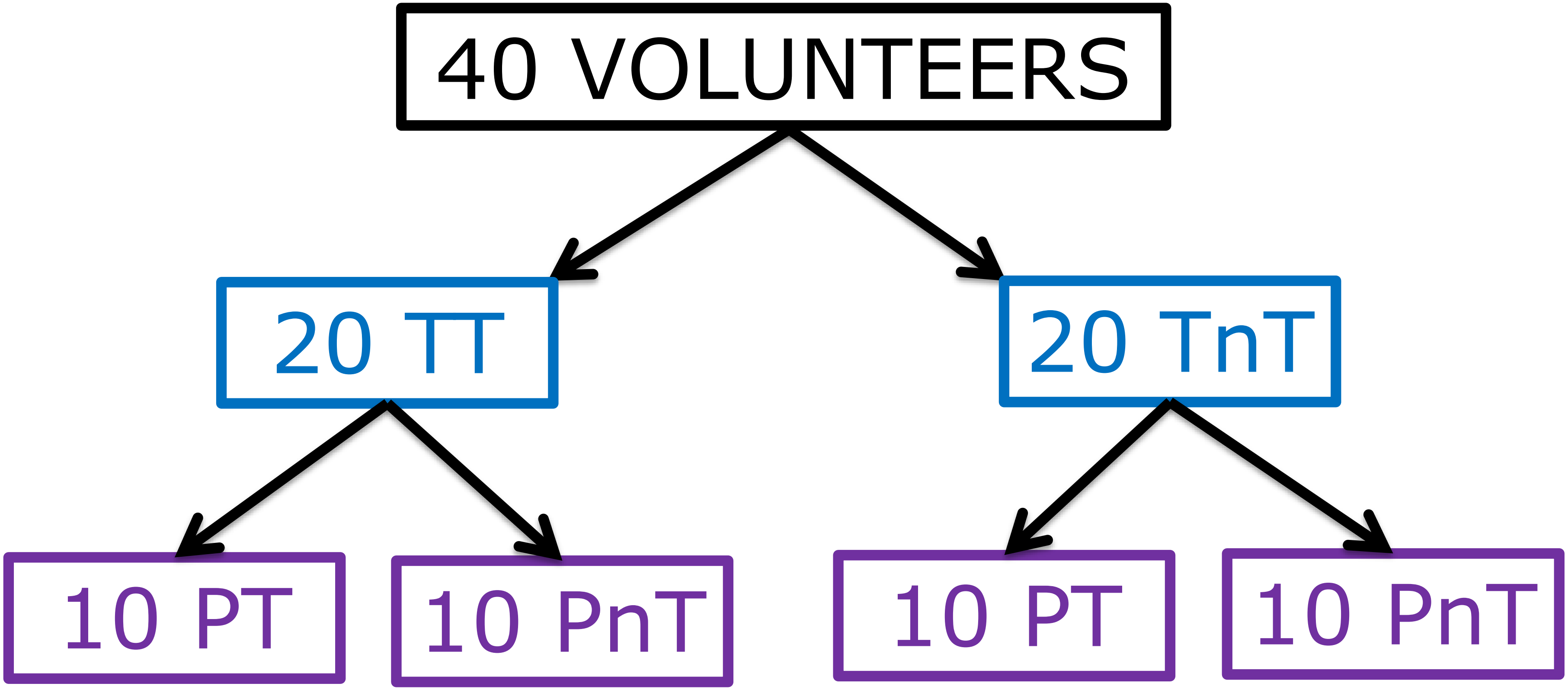
- Variation in taste response

- Gustotopic Mapping
  - Development of taste samples for fMRI
  - fMRI measures

- **Phantom Taste Mapping**
  - Sensory measures
  - fMRI measures



Volunteers



Same volunteers as for gustotopic mapping

Thermal Taster (TT) Status

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Relatively new taste phenotype

'Thermal Taste'

(Cruz & Green, 2000)

TT Test Protocol

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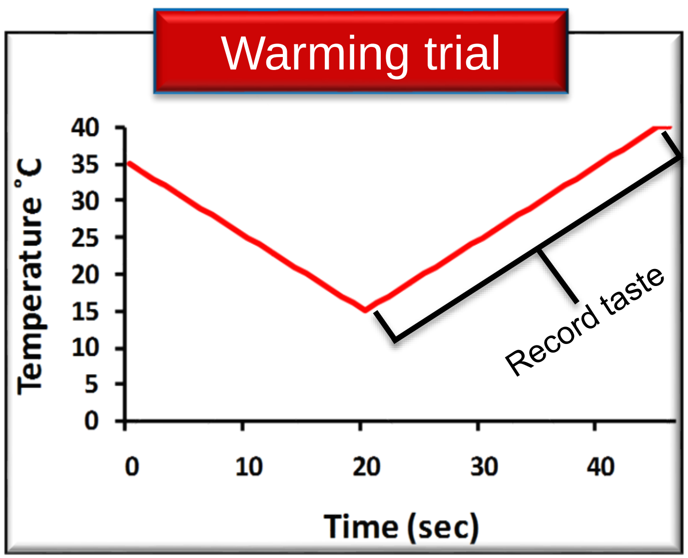

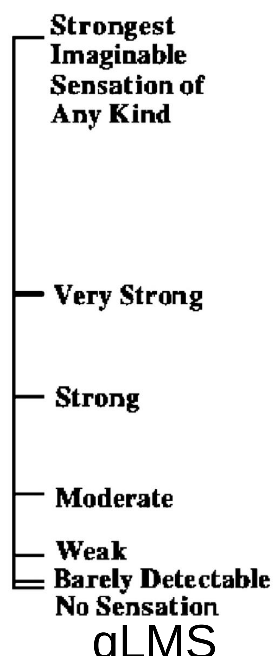

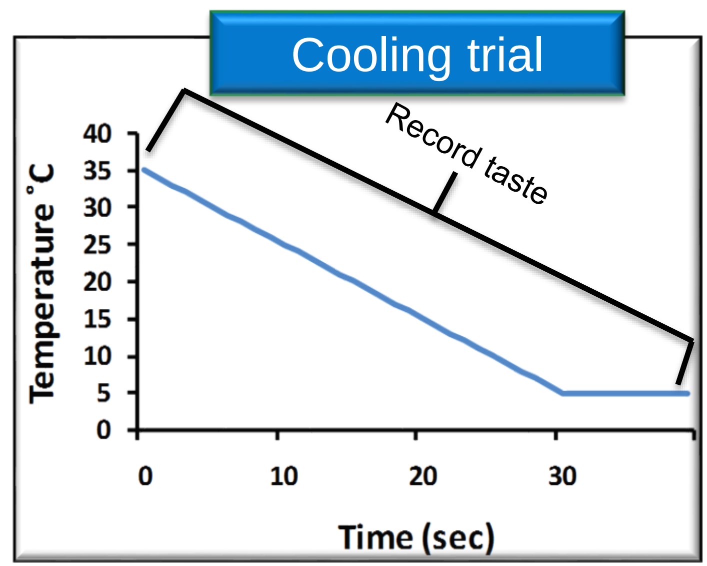

What do TT's Report?

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WARMING TRIAL

Sweet

Bitter

COOLING TRIAL

Sour

Salty **Metallic** **Menthol/Mint**

Umami **Spicy**

Thermal taster (TT)

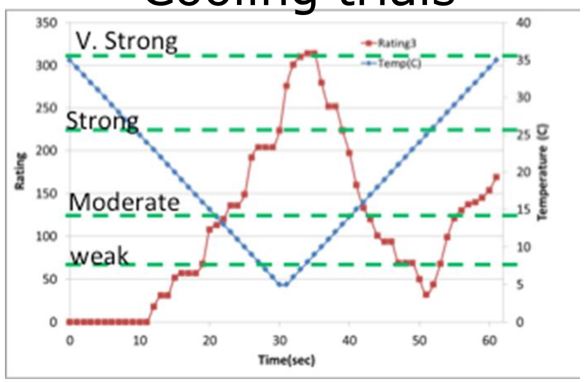
Thermal non taster (TnT)

Understanding thermal taster status

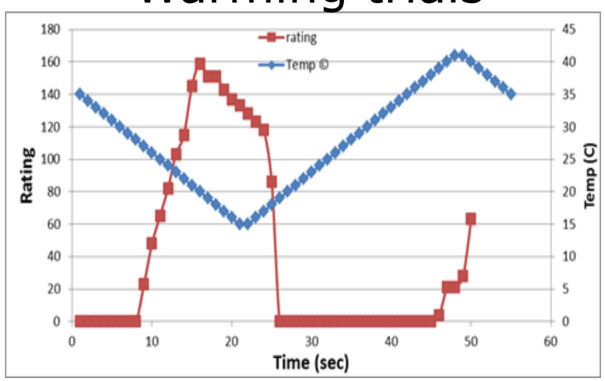
1. Identify TT status (TT/TnT)

2. Temporal data for phantom taste

Cooling trials

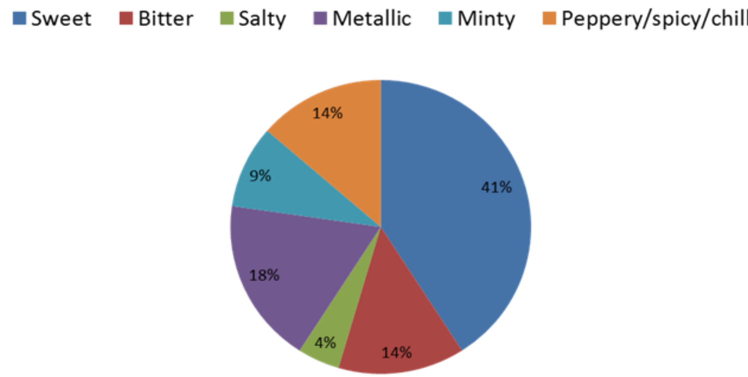


Warming trials

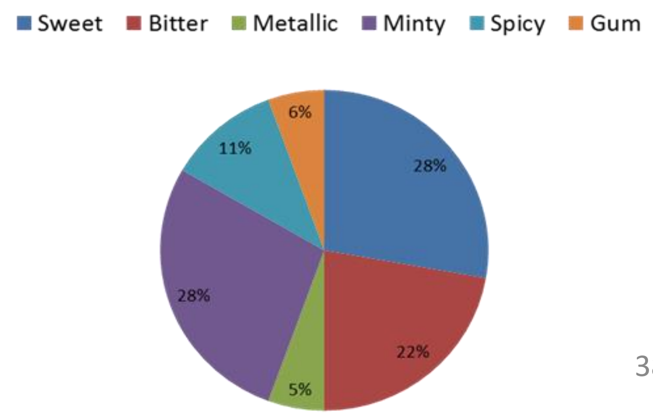


Behavioural Results

A) Tastes perceived during warming trials



B) Tastes perceived during cooling trials



Reproducibility of phantom taste

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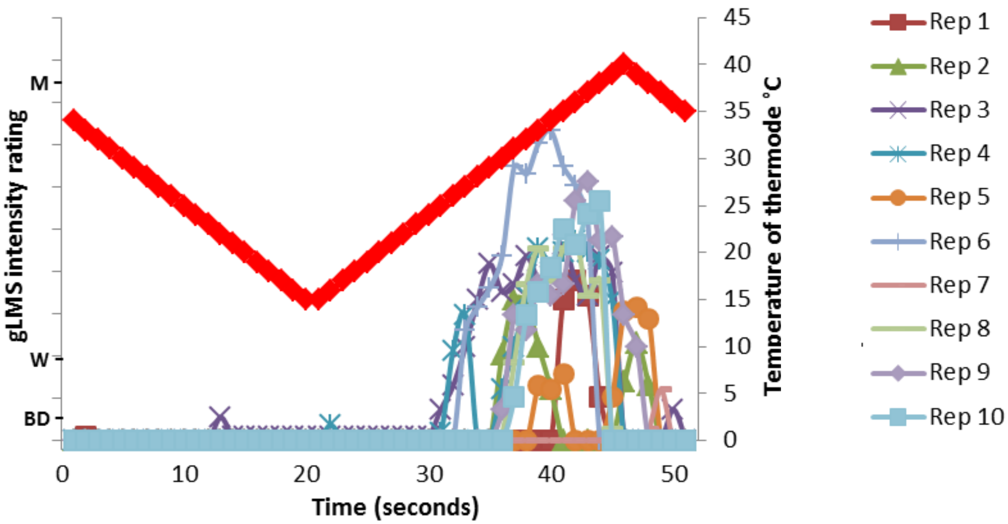
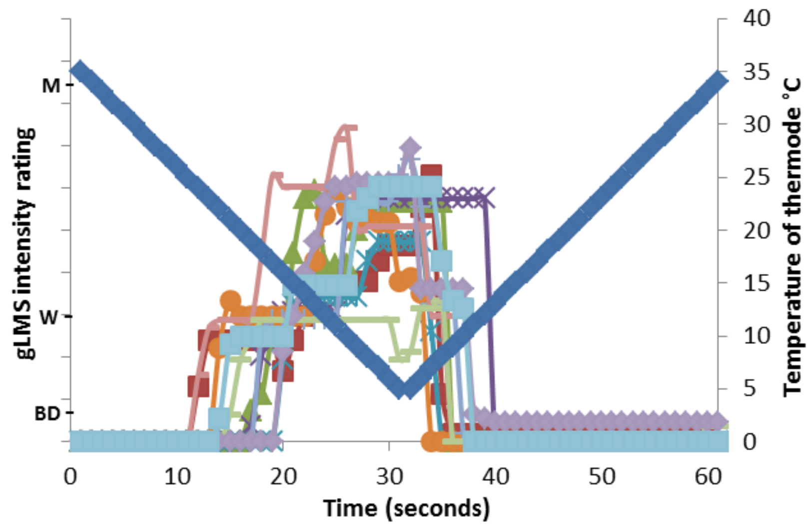
WARMING



COOLING



Reproducible responses across repeat trials

Temperature versus taste response

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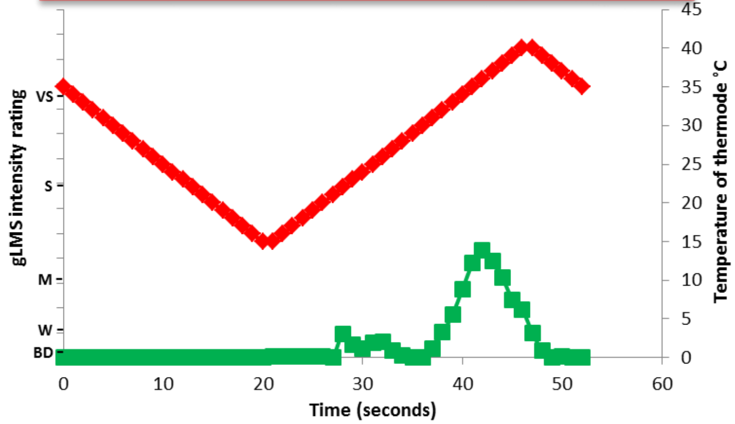
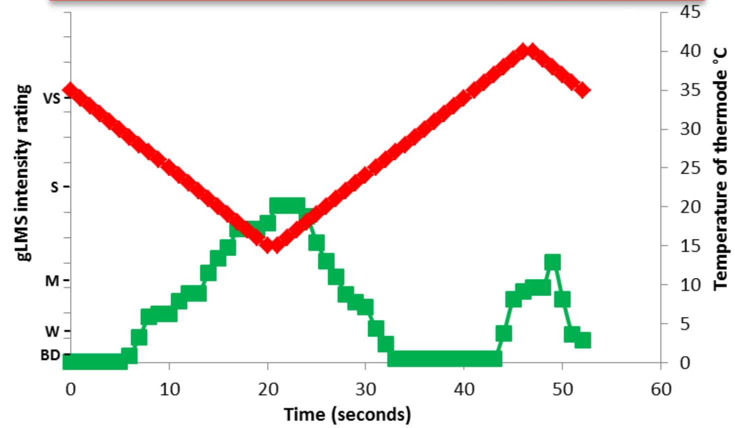
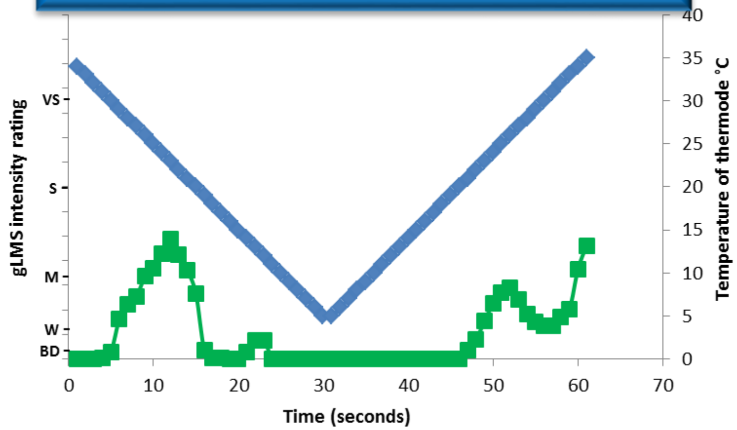
TASTE RESPONSE



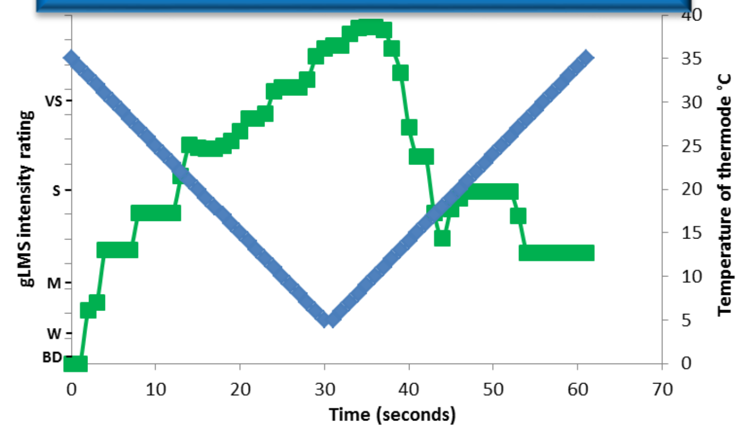
TEMPERATURE RESPONSE



TASTE RESPONSE



TEMPERATURE RESPONSE



Different temporal response for taste and temperature

Warming trial

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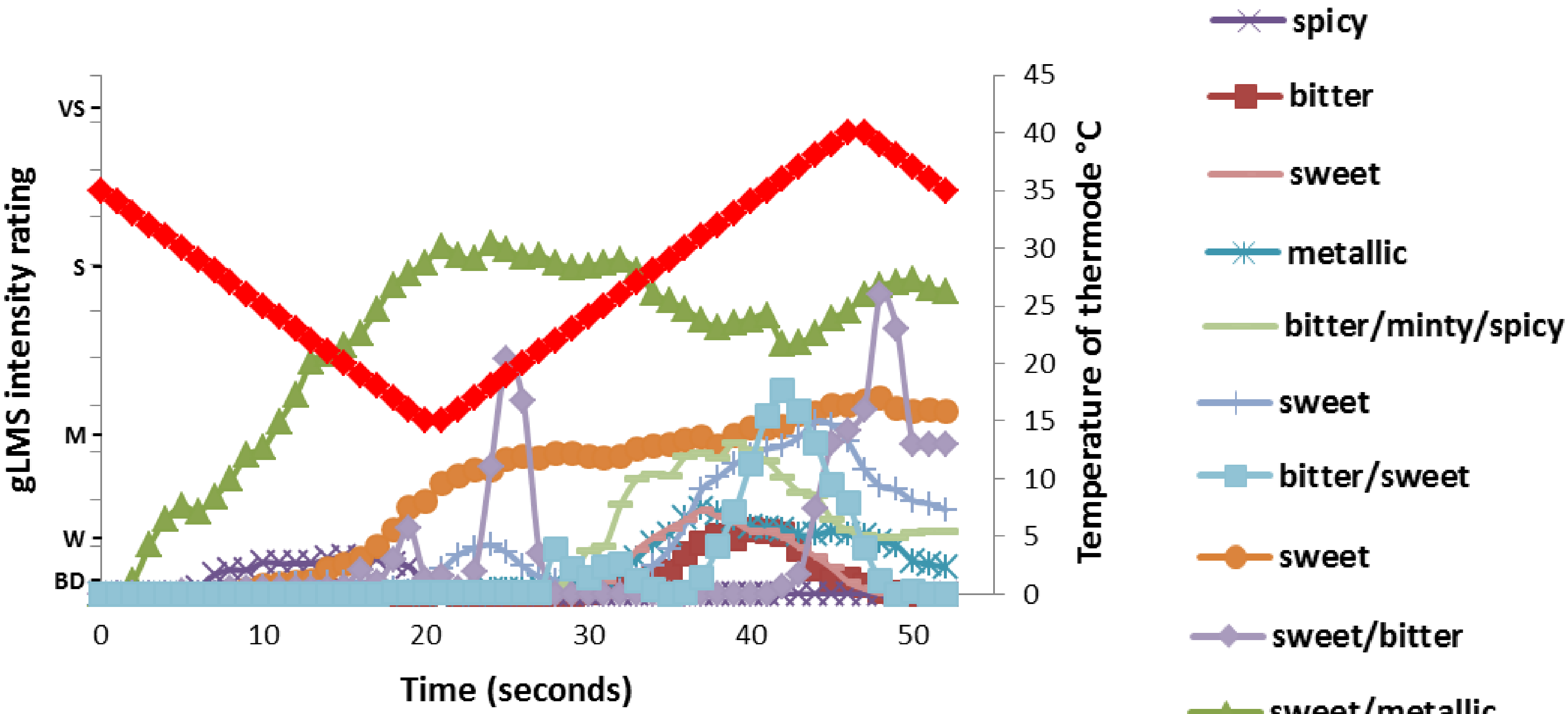

Different temporal response for taste across subjects

Cooling trial

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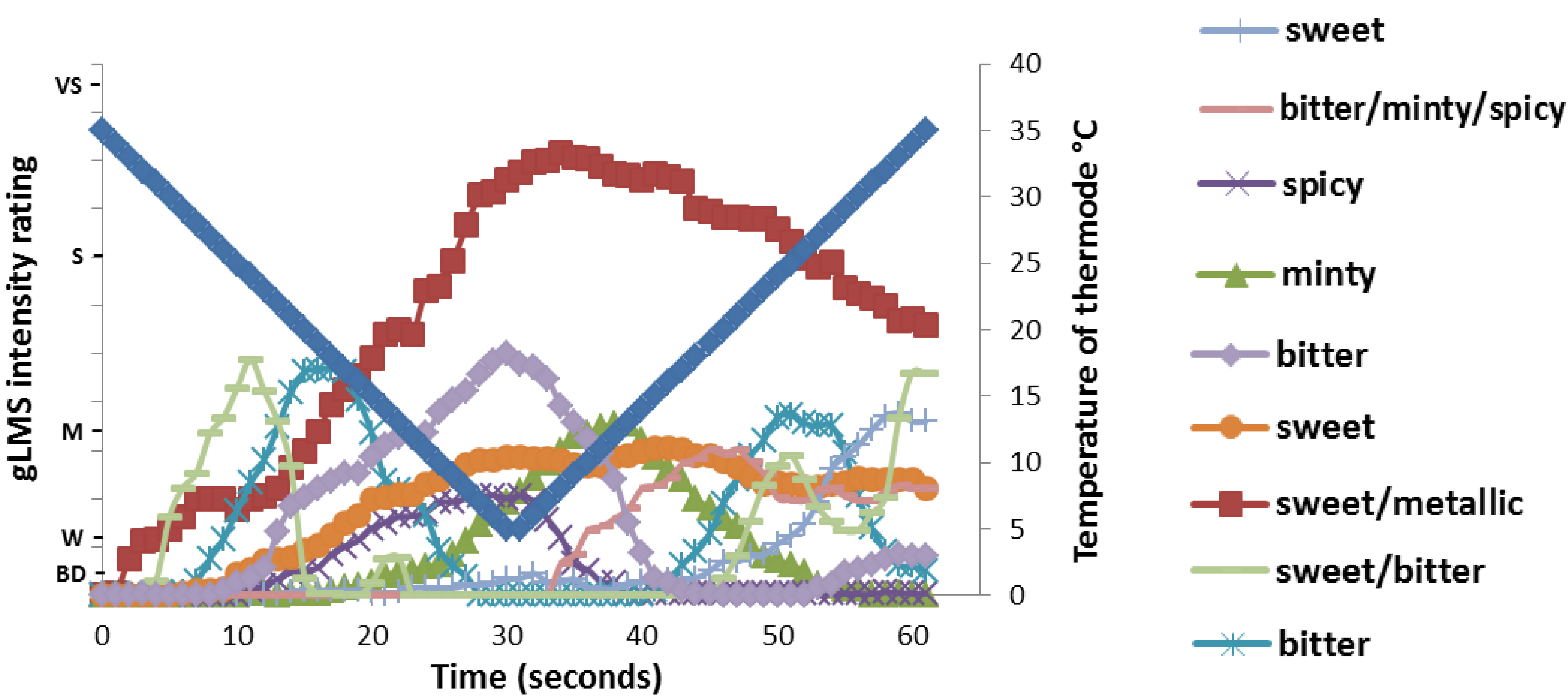
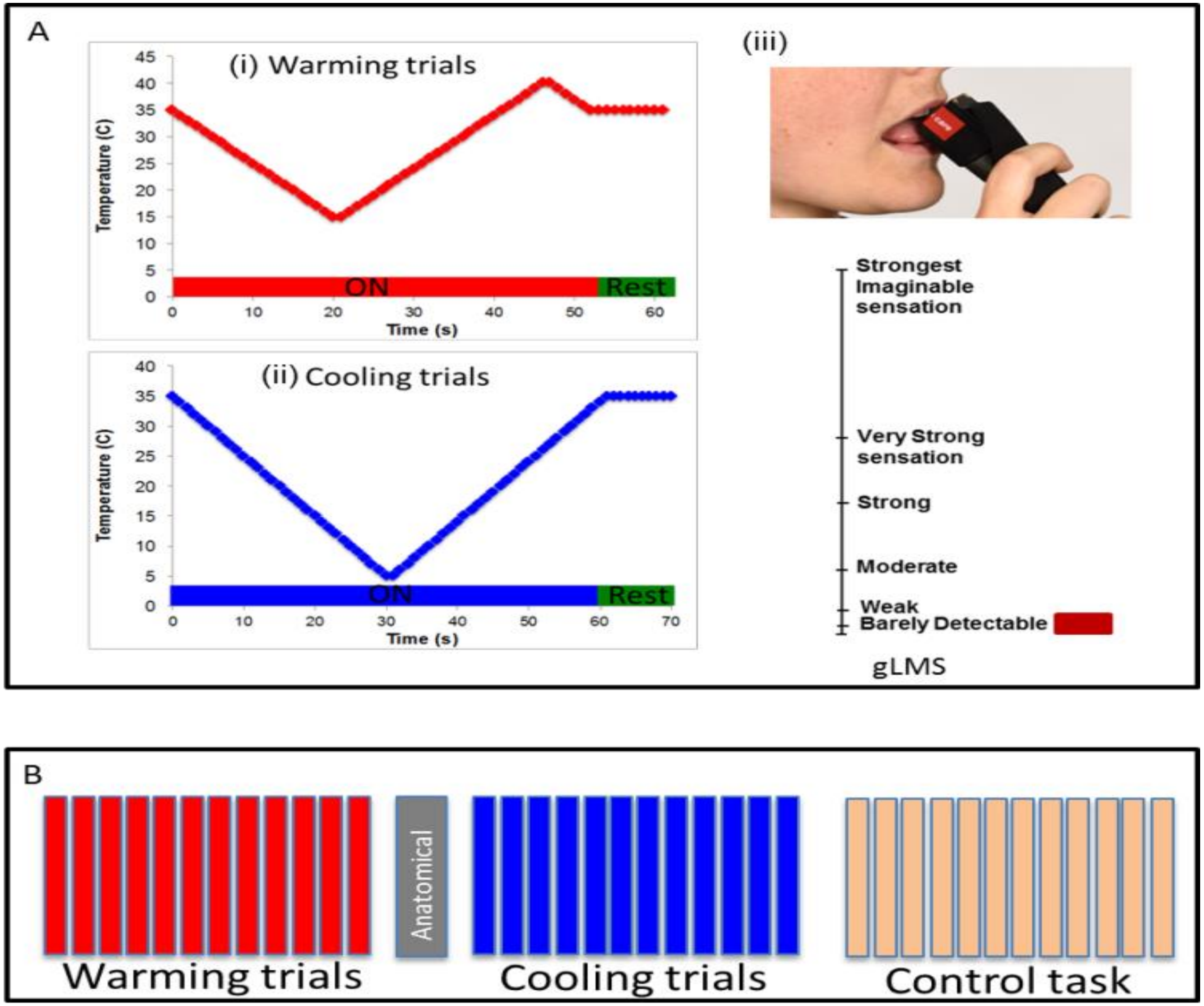


Different temporal response for taste across subjects

Understanding thermal taster status

fMRI Paradigm



Phantom taste mapping

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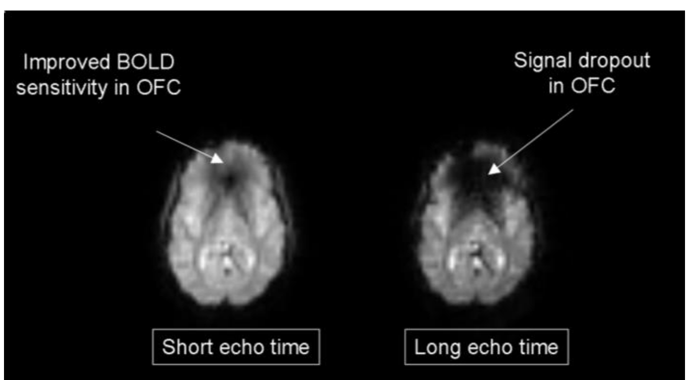
- 3 T Philips Achieva scanner, 32-element SENSE head coil.
- fMRI data acquired with double-echo gradient EPI (TE: 20 ms, 45 ms). 64 x 64 matrix size, $3x3x3mm^3$ voxel size, 36 transverse slices, TR = 2.5 s.
- T_1 weighted 1 x 1 x 1 mm^3 MPRAGE image.



Global
Top 100
University

Understanding thermal taster status

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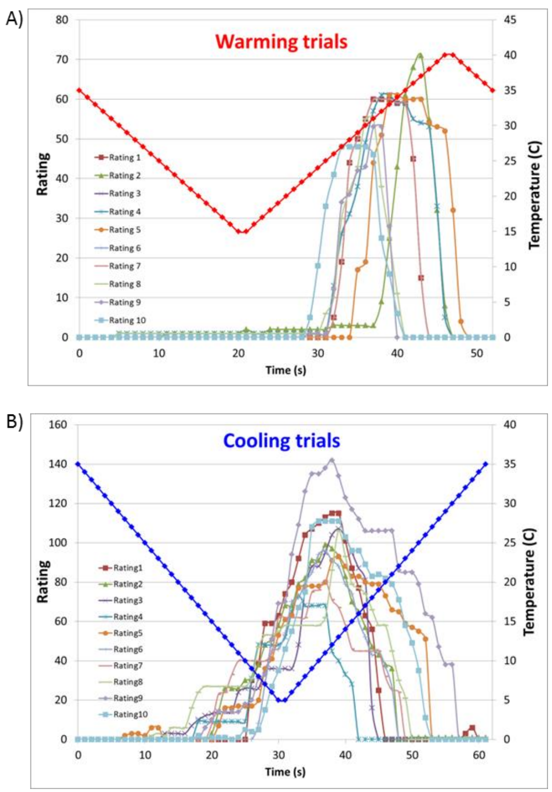
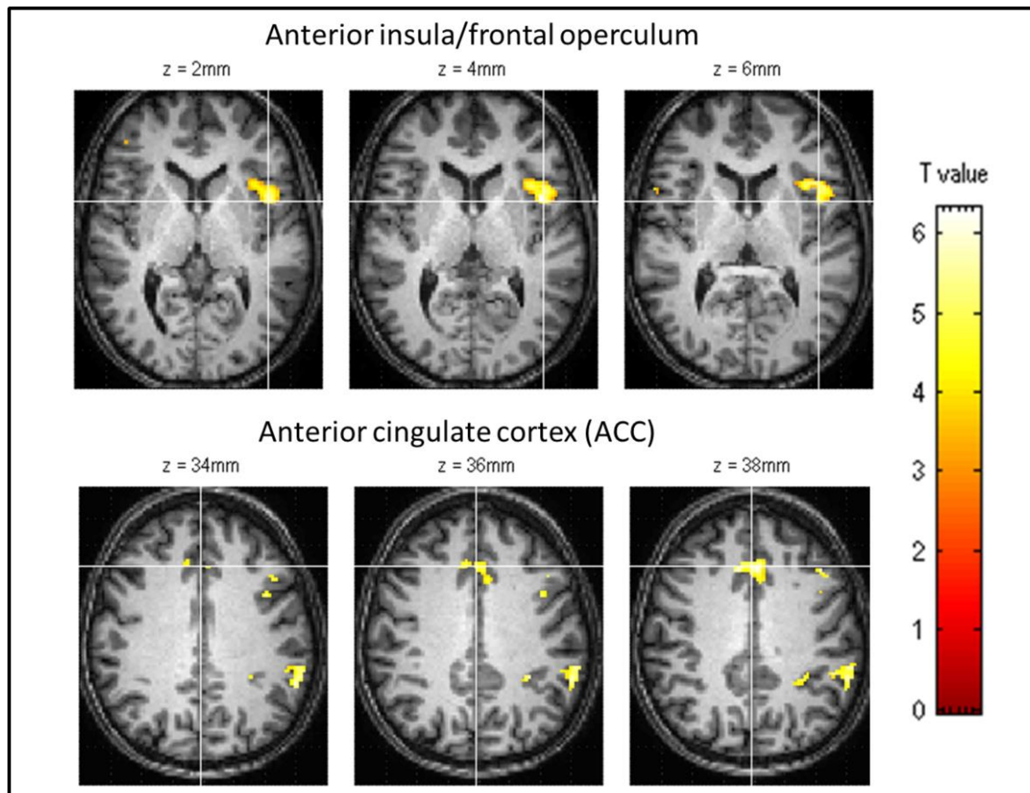
fMRI: Subjects scanned during a paradigm in which the oral probe is heated and cooled.

Time course of perceived taste

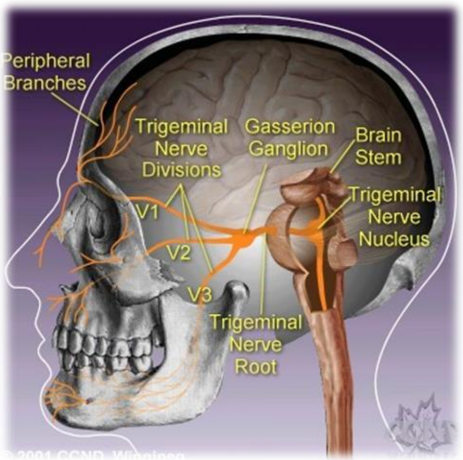


Cortical response to taste

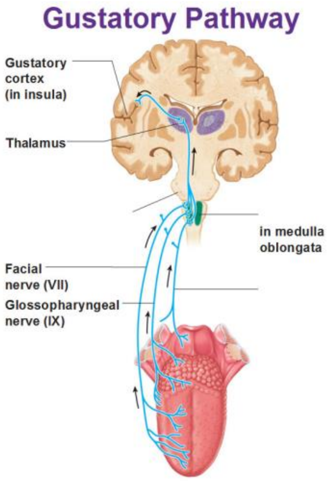


Understanding thermal taster status

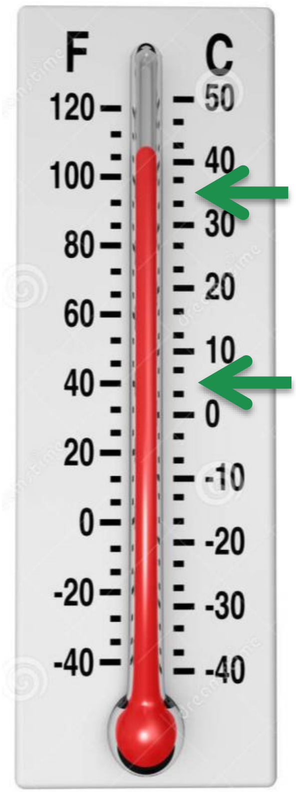
Could co-innervation of gustatory & trigeminal nerves innervating the fungiform papillae be involved?



(Talavera et al, 2005)



(Hort et al, 2016)



Conclusion

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- Taste phenotypes are important characteristics to consider when exploring taste perception and food choice.
  - Could this influence product development?
  - Target products to suit TT's?
  - Could impact dietary intake, health/nutrition status
- We are studying:
  - effect of phenotype in taste perception using fMRI
  - phantom taste using fMRI.
- High resolution fMRI is a valuable tool to utilise.
- **TASTEMAP bridges the gap between sensory science and brain imaging.**

Acknowledgements

Taste Map team

- Sue Francis
- Joanne Hort
- Sally Eldeghaidy
- Martha Skinner
- Rebecca Ford
- Anna Thomas
- Marko Hoeskma
- Timo Giesbrecht

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Sensory Science Centre

Unilever

BBSRC
bioscience for the future