Oral perception of fat emulsions - neural imaging studies

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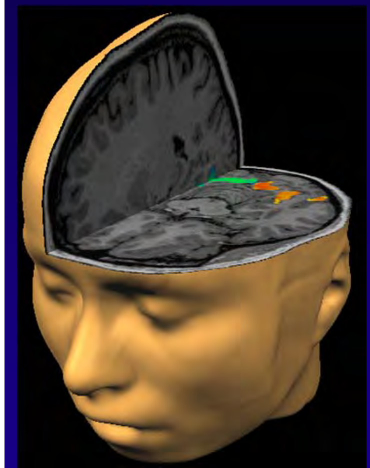
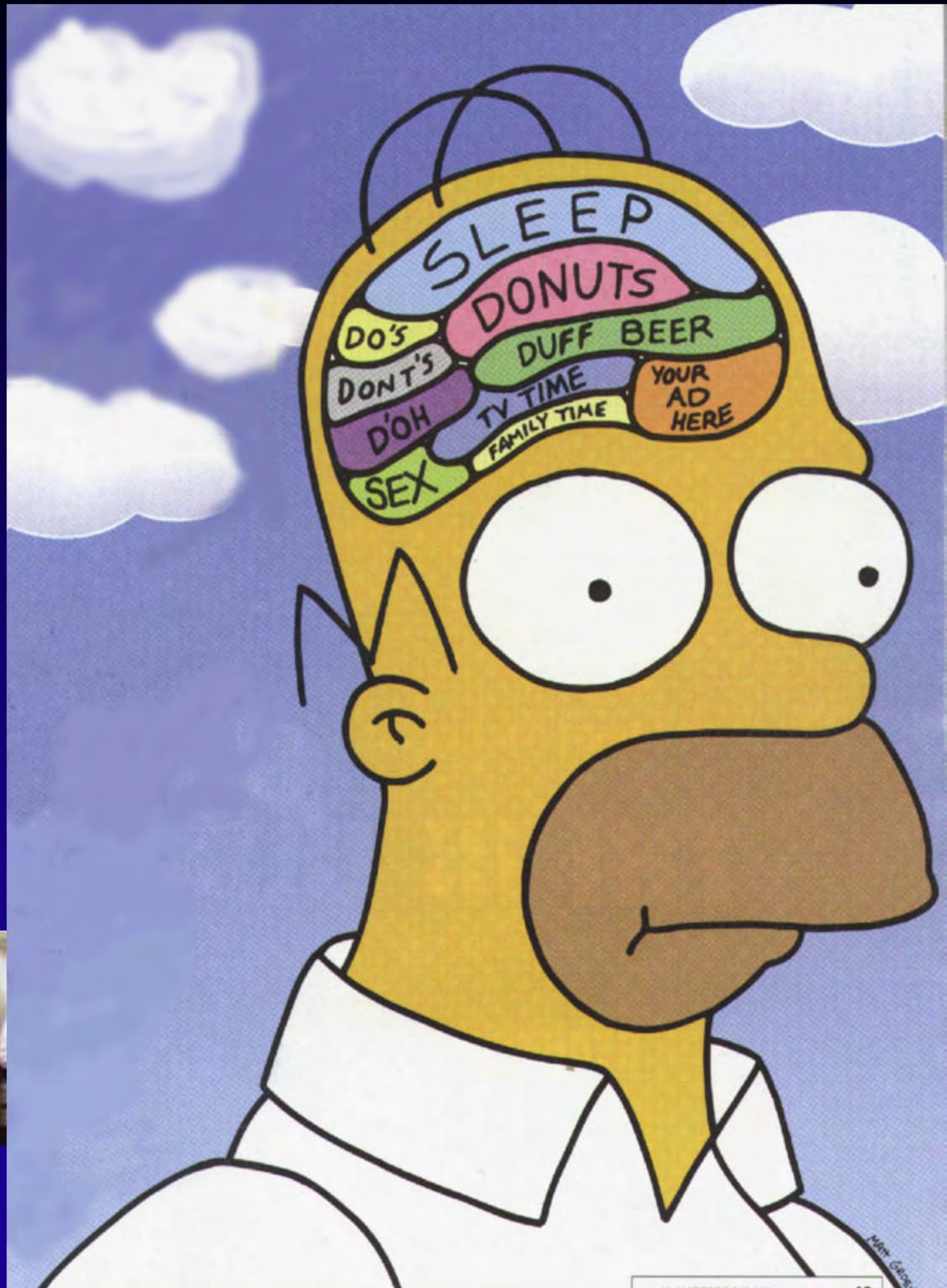
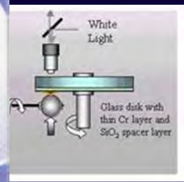
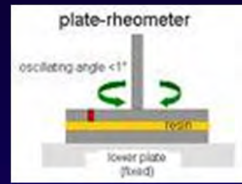


Tools in … elopment



- Instrumental

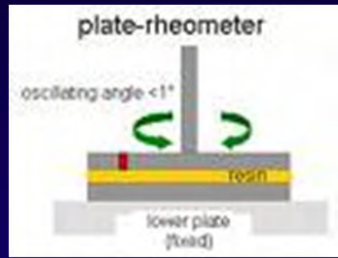


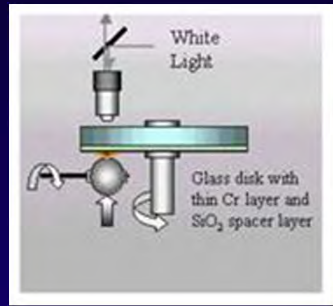


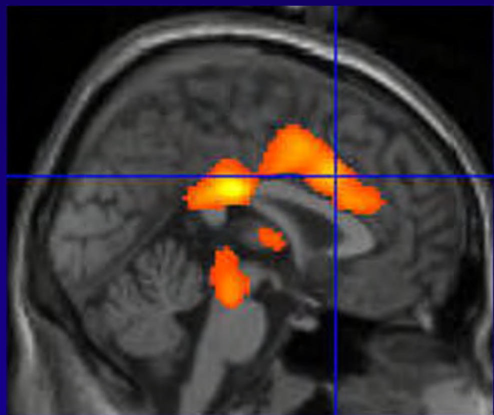
- Sensory

Tools in food research

- Instrumental

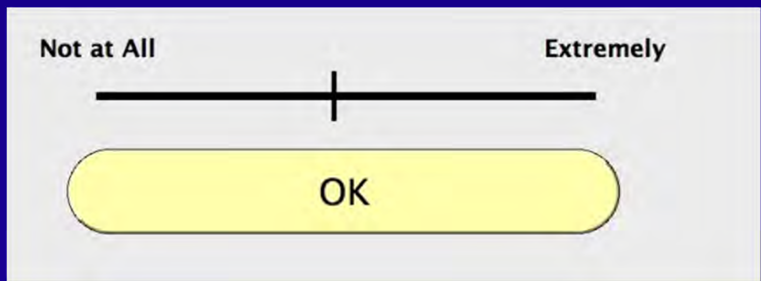






Neuroimaging

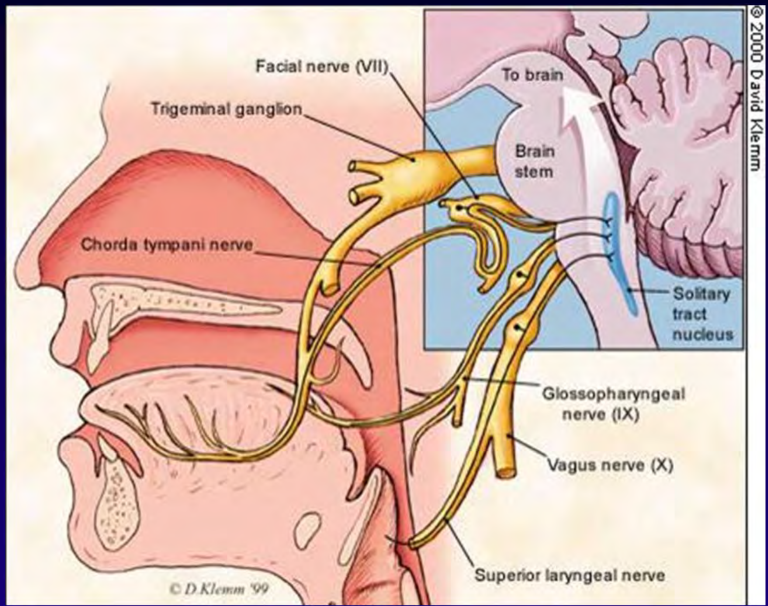
- Sensory

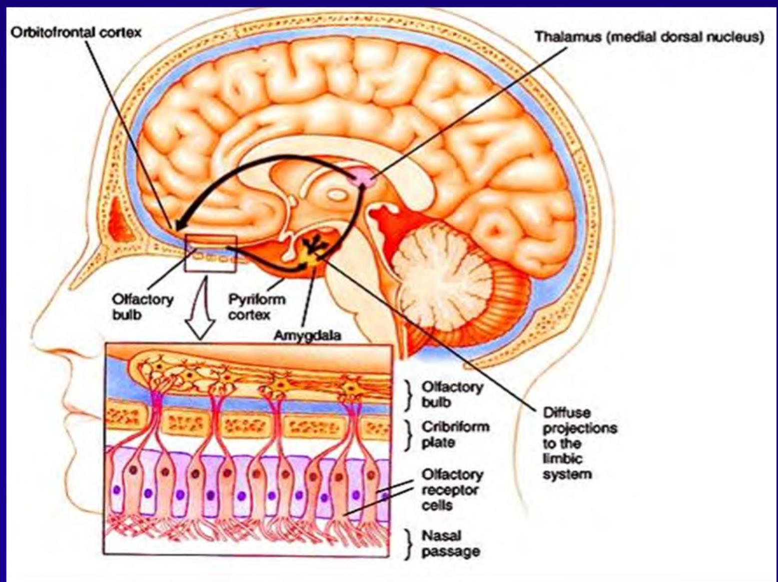


Outline

- Taste, aroma and somatosensory brain pathways
- Brief Introduction to functional MRI (fMRI) to study brain function
- The challenges in studying oral perception using fMRI
- Studies of the oral perception of fat emulsions

Taste, Aroma and Somatosensory Pathways





- Receptors
- Primary sensory areas
- Secondary areas

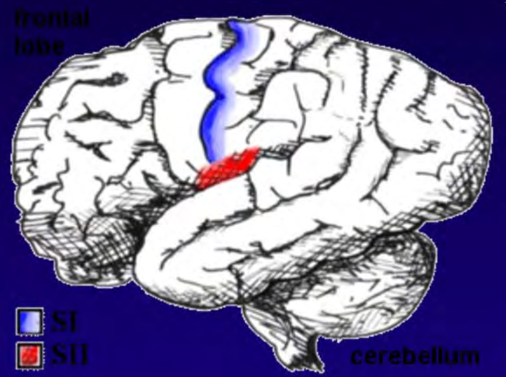
  Association areas

  Reward areas

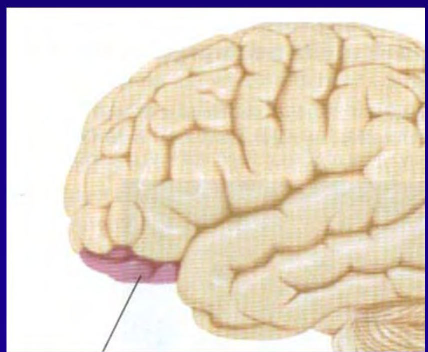
Taste, Aroma and Somatosensory Pathways

Primary Somatosensory (SI)
Secondary Somatosensory (SII)

- Temperature
- Tactile

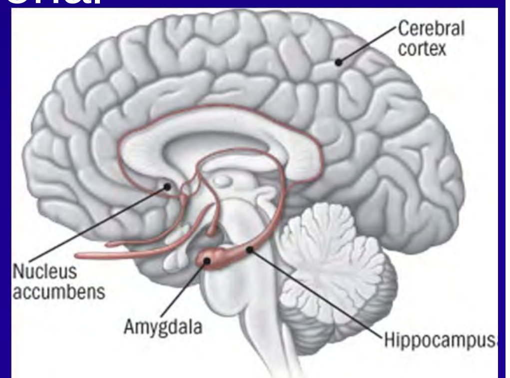


Insula
- Taste



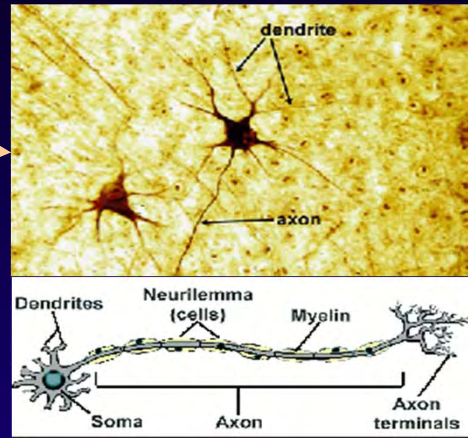
Orbitofrontal Cortex (OFC)
- Multimodal

Anterior Cingulate Cortex (ACC) and amygdala
- afferent/reward/emotional

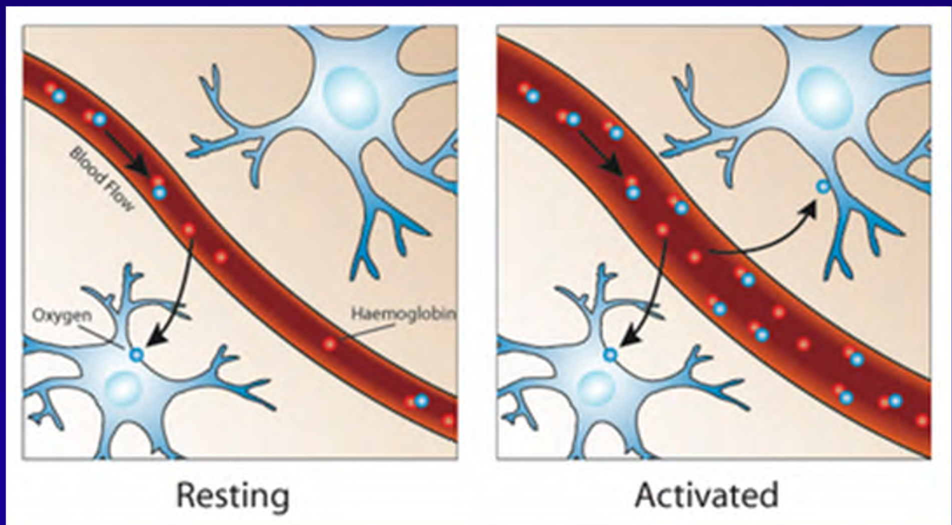


fMRI – the haemodynamic origin

The average number of neurons in the brain = 100 billion.



Electrical activity of neurons

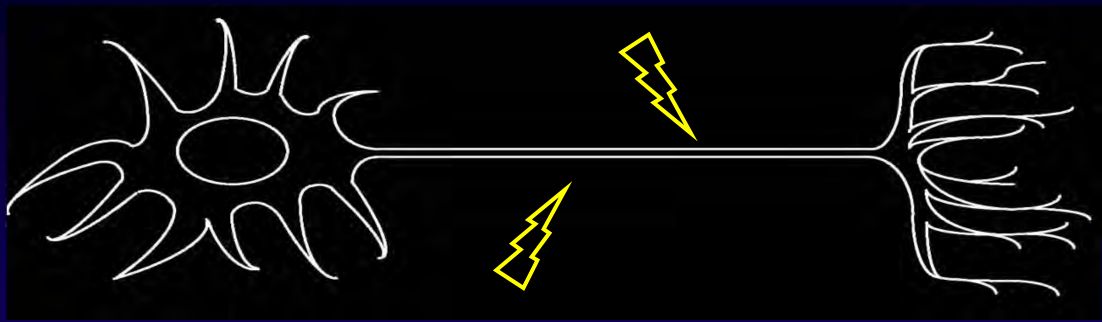


When neurons are active they consume more energy and need more oxygen

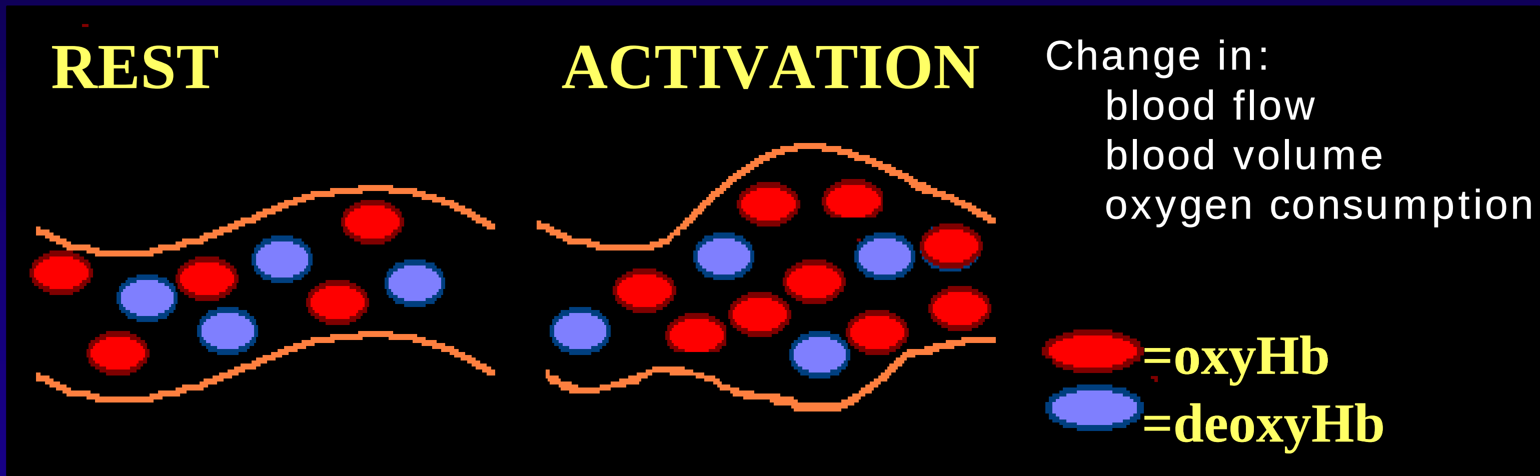
Brain separated into grey and whiter - Grey matter contains neurons

fMRI – how it works

neuron



capillary



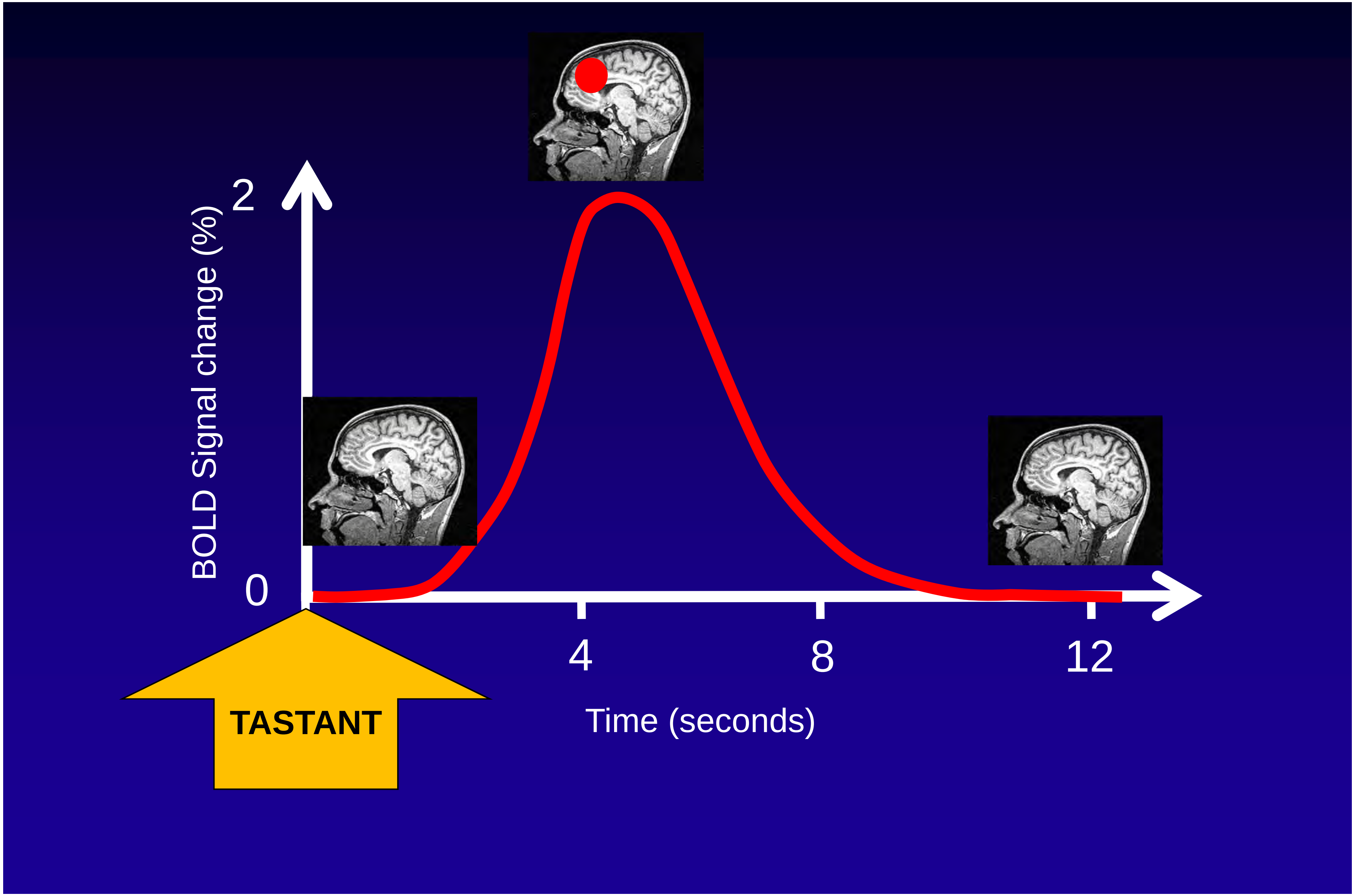
INCREASE IN BLOOD OXYGEN LEVEL IN ACTIVE AREAS

Blood Oxygen Level Dependent = BOLD response

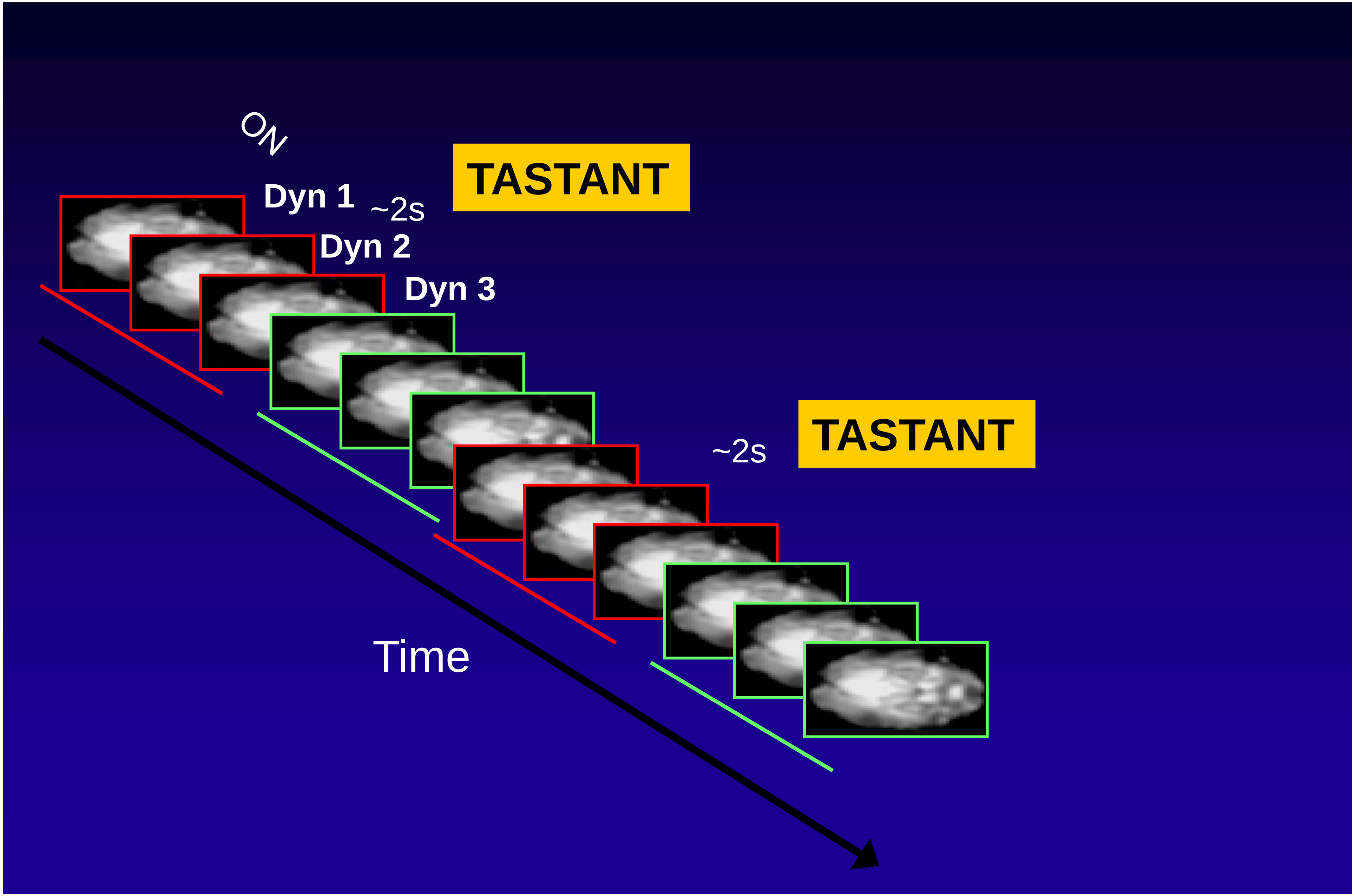
= 1-2% increase in image intensity in active brain areas

Measure with functional Magnetic Resonance Imaging (fMRI)

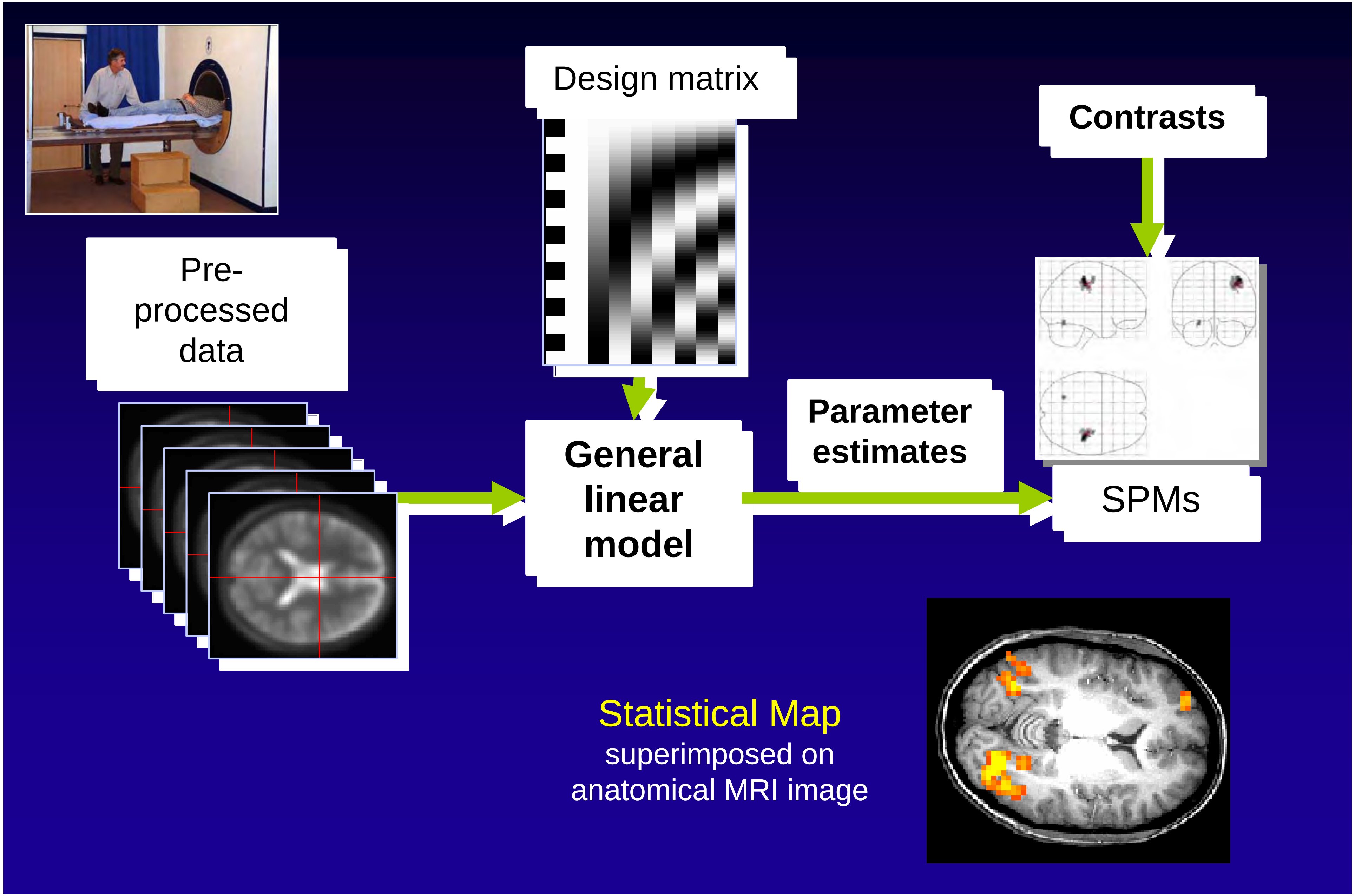
fMRI – how it works



fMRI – how it works



fMRI – how it works



fMRI of Oral processing

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- AIM: To develop fMRI protocols in synergy with the sensory and flavour labs

  – Deliver controlled stimulus (emulsion) under given conditions

  = inside scanner + lying down

  – Realistic sample volume to be presented to the subjects

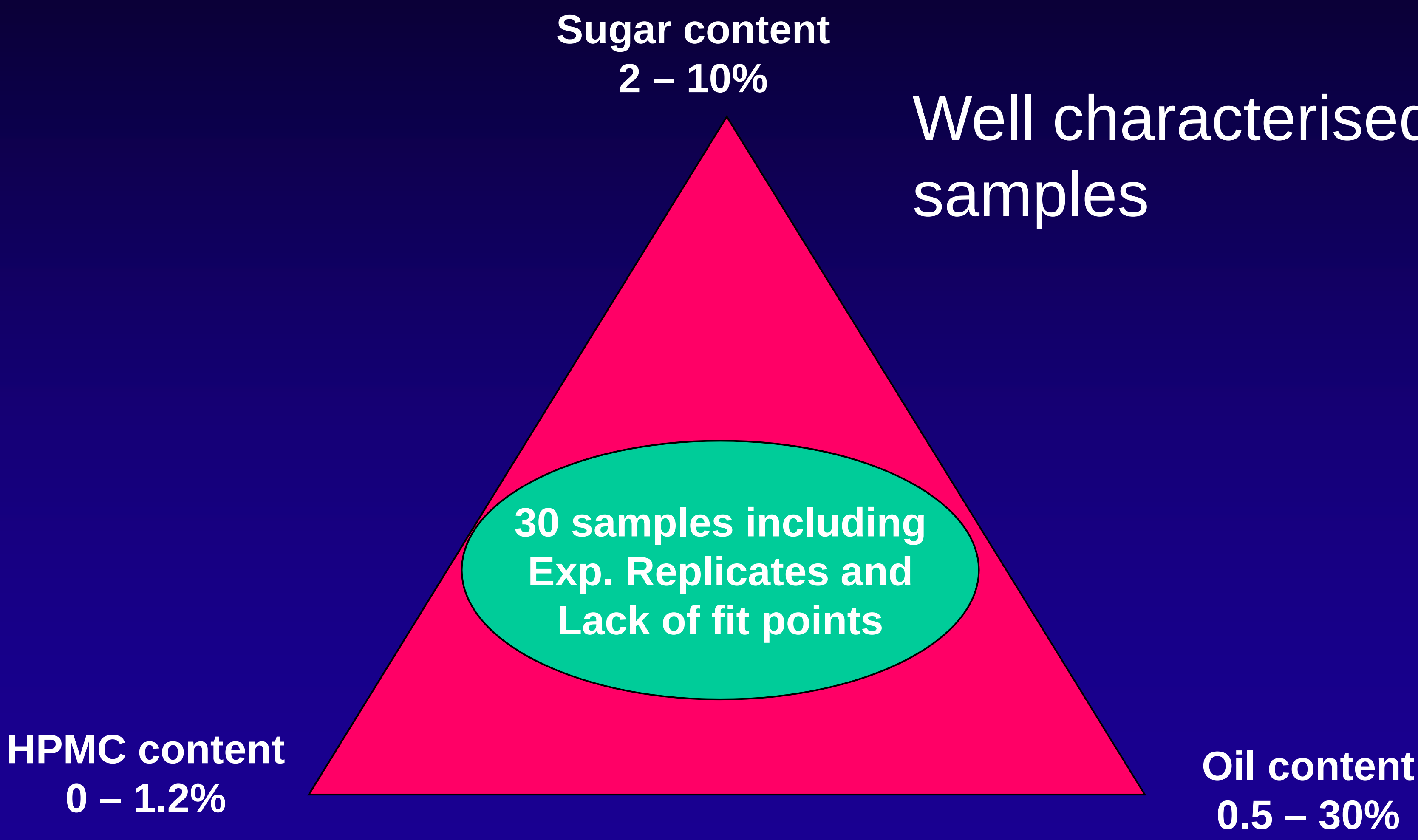
  = mL as opposed to µL

  – Deliver as it typically occurs during food and beverage consumption

  = including swallowing

Controlled Oral stimuli

Well characterised samples

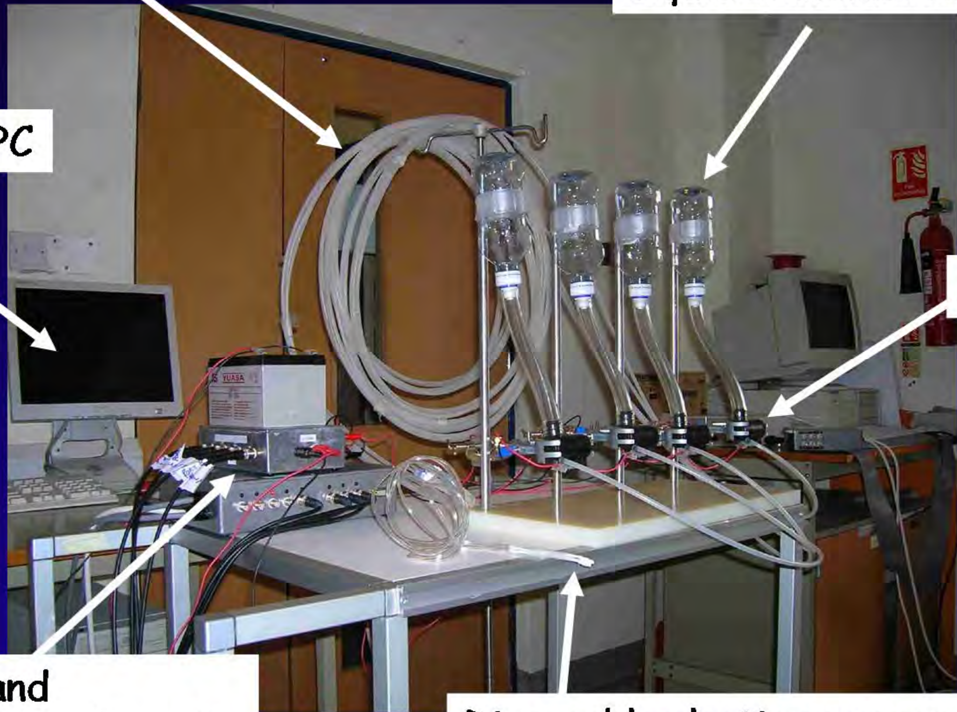


Delivery of fat emulsions

The University of Nottingham

Oral stimuli delivered via long tubes, pumps away form large magnet used in MRI

Delivery of fat emulsions

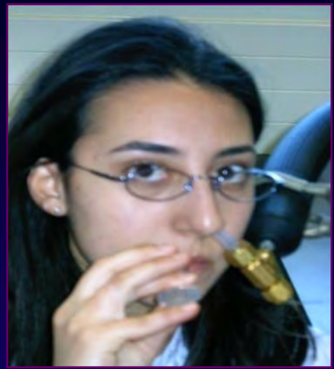


Delivers a gentle spray to cover oral surfaces at a rate of 1 ml/s

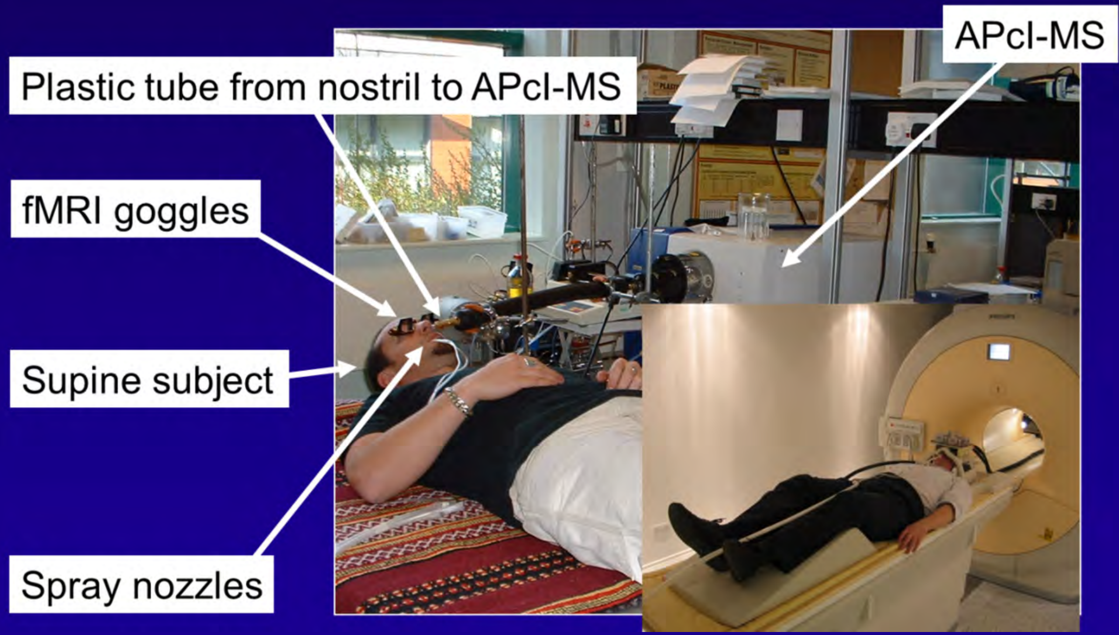
L Marciani et al. Improved methods for fMRI studies of combined taste and aroma. *Journal of Neuroscience Methods,* 158:186-194, 2006.

Effect of body position

Aroma release
lying down/sitting up



No significant effect of body position on aroma release or perception



J Hort et al. The effect of body position on Flavour release and perception: implications for fMRI studies. Chemosensory Perception, 1(4): p 253-7, 2008.

Delivery of fat emulsions

- In the sensory lab: panelists sip a spoonful of a liquid sample, swallow, assess the properties of the sample and then clean their palate with a dry water biscuit, a lime juice drink and a water drink

- Validity of the models: spraying versus sipping

- Mimic sensory experiment

Delivery of fat emulsions

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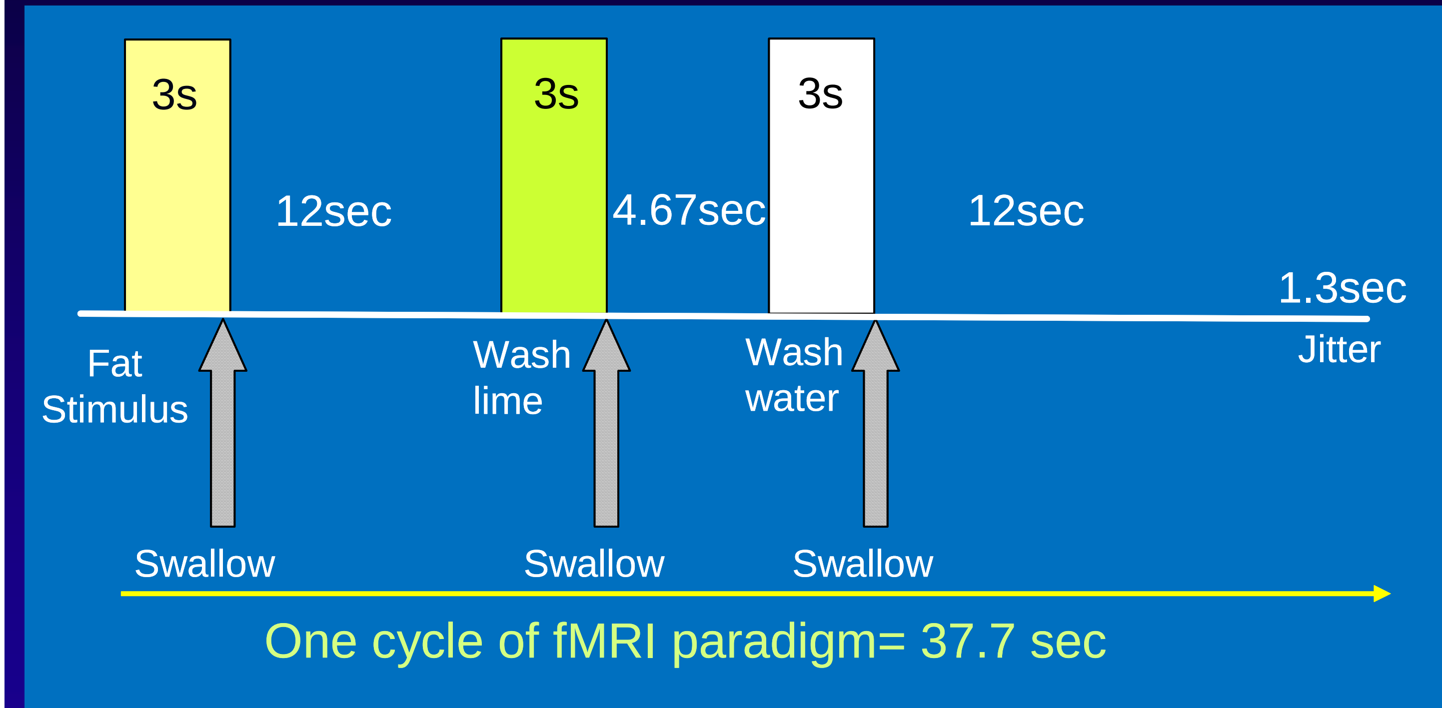
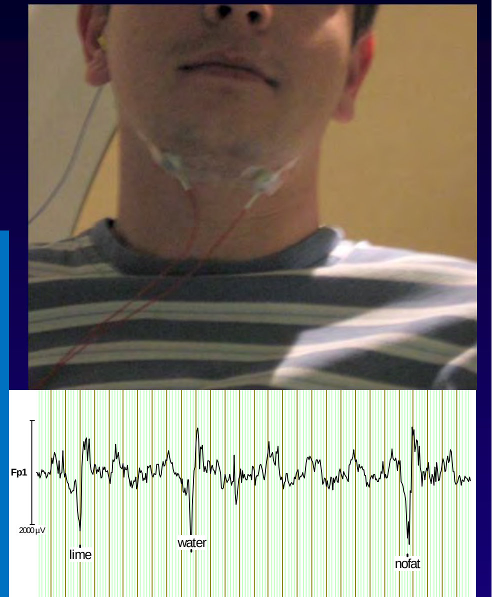
Paradigm



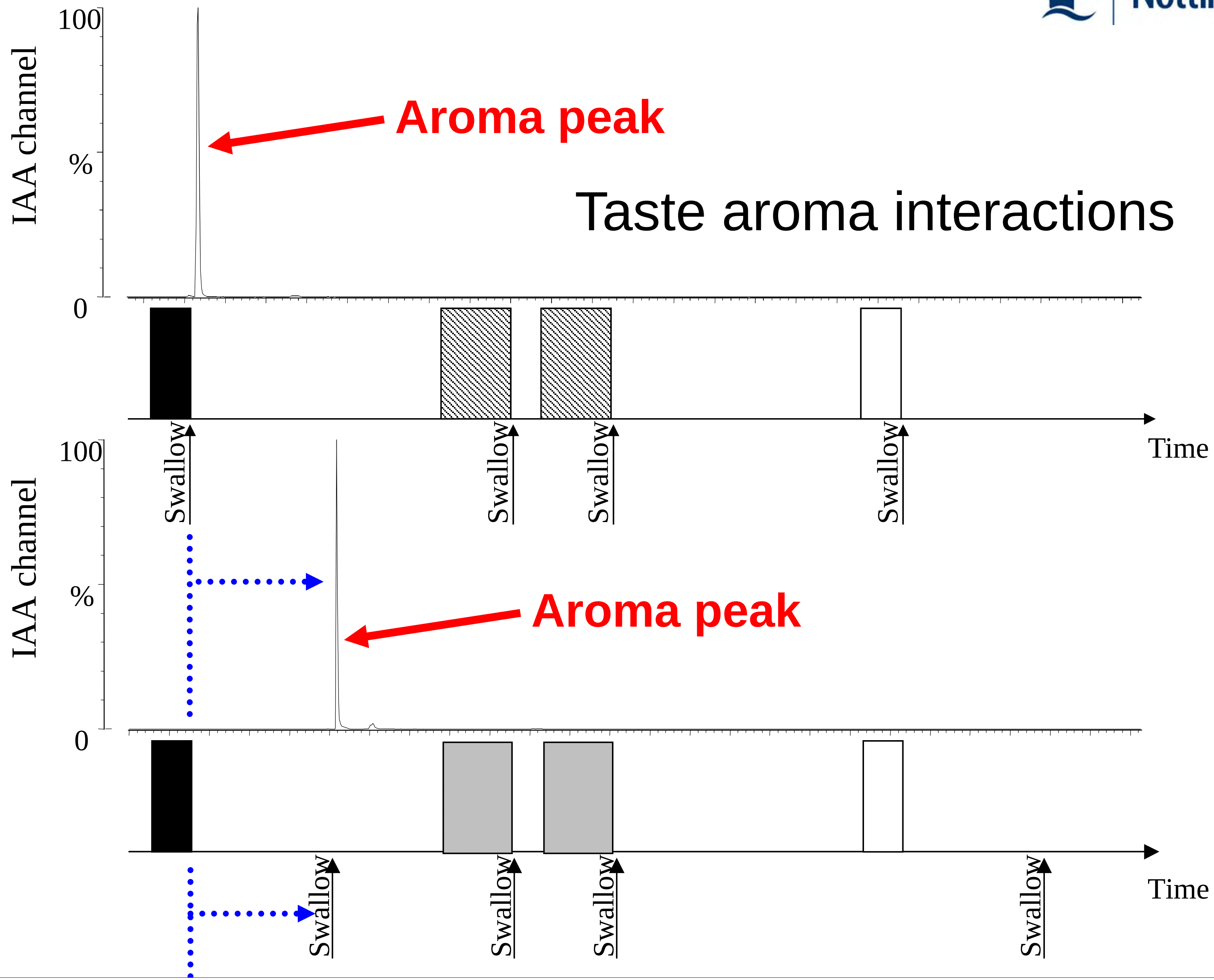


EMG monitors time of swallow

Eldeghaidy, S. et al. Use of an immediate swallow protocol to assess taste and aroma integration in fMRI studies Chemosensory Perception. 4, 163-174, 2012.

Aroma release– APcI-MS validation

Taste aroma interactions



fMRI Studies of fat emulsions

(I) Viscosity in the mouth

(II) Cortical processing of fat

(III) Subject Phenotype and cortical response to fat

(IV) Effect of fat on the cortical response to flavour

(V) Influence of prior GI exposure on cortical response to fat

(I) Viscosity in the mouth

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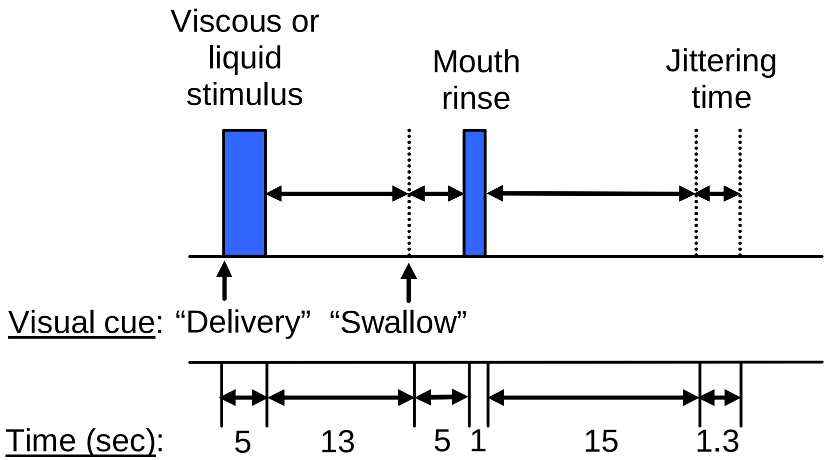
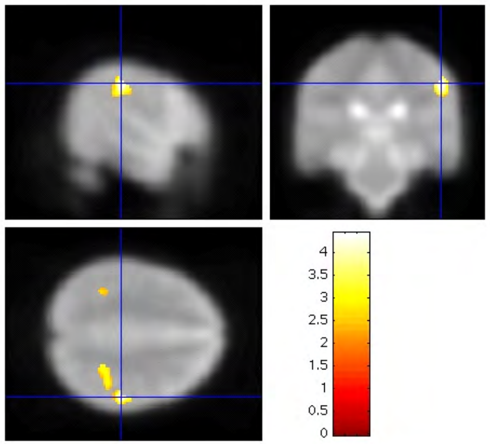
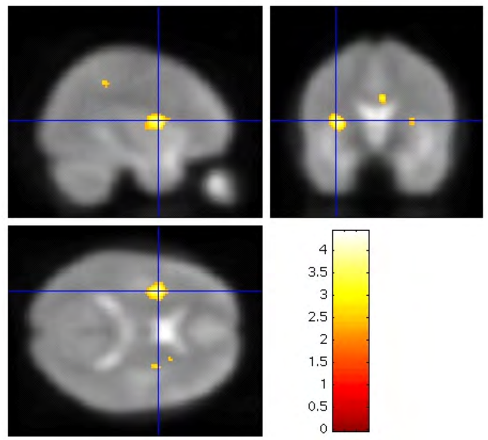
4 ml of a viscous stimulus (a 1.25% manugel alginate solution) or of a control (water) stimulus (randomly ordered) were manually delivered using syringes and small plastic tubes held between the lips of the supine subject.



Oral viscosity



Parietal operculum



Left insula

De Celis Alonso, B., et al. Functional magnetic resonance imaging assessmentof the cortical representation of oral viscosity Journal of Texture Studies. 38(6), 725-737, 2007.

(II) Cortical Processing of Fat

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- Investigate the cortical response to increasing fat concentrations in iso-viscous fat emulsions using a protocol close to typical consumption of liquid fatty foods.
  - Samples have the same sensory properties but different fat contents

Eldeghaidy S, et al. 2011. The Cortical Response To The Oral Perception Of Fat Emulsions And The Effect Of Taster Status. Journal Of Neurophysiology. 105(5), 2572-81

(II) Cortical Processing of Fat

- Subjects: Scanned 14 right-handed subjects (10 male, 4 female). Subjects asked to consume a non-fatty dinner and light breakfast at least 2 hr before scanning.

- Fat emulsions: Characterised in sensory lab.

Iso-viscous: **5% fat**
10% fat
20% fat
30% fat

(II) Cortical Processing of Fat

The University of Nottingham

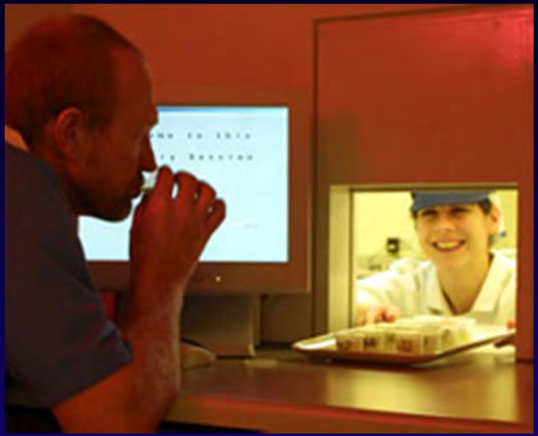
Fat emulsions: Characterised in sensory lab.

- Fat emulsions prepared from: sucrose stearate emulsifier (E-473), rapeseed oil, hydroxypropyl methylcellulose (HPMC), and mineral water. Emulsifier, oil, and HPMC were chosen for their low odor and taste characteristics .
- Emulsion samples varied in fat content (5, 10, 20, and 30% wt/wt) – to represent range of fat concentrations found in food products, viscosity of ~ 5 cP measured at 50/s.
- To isolate the impact of fat, emulsion samples designed to vary in fat content but not to elicit any significant sensorial differences in 5 perceptual attributes: sweetness, thickness, stickiness, mouth-coating, and dispersiveness.

Hollowood T, et al.. Modelling sweetness and texture perception in model emulsion systems. Eur Food Res Technol227: 537–545, 2008.

Sensory Attributes

- 12 assessors
  - – Generated well defined list of 5 discriminating attributes



Attribute	Definition
sweetness	of sugar
thickness	assessed by pressing tongue to roof of mouth and feeling the resistance to the movement
mouth-coating	quantity of bulk sample still stick to the inside of the mouth after first swallow
dispersing	speed with which the sample dissolves into saliva and is ready for swallowing
stickiness	the resistance of pulling the tongue away from the roof of the mouth after assessing the thickness

MR protocol

- 3 T Philips Achieva scanner, using 8-element SENSE head coil.

- fMRI data acquired with double-echo gradient EPI (Echo times (TE): 30 ms, 49 ms). 64 x 64 matrix size, 4 x 4 x 4 mm^3 voxel size, 36 transverse slices, TR = 2.6 s.

(II) Cortical Processing of Fat

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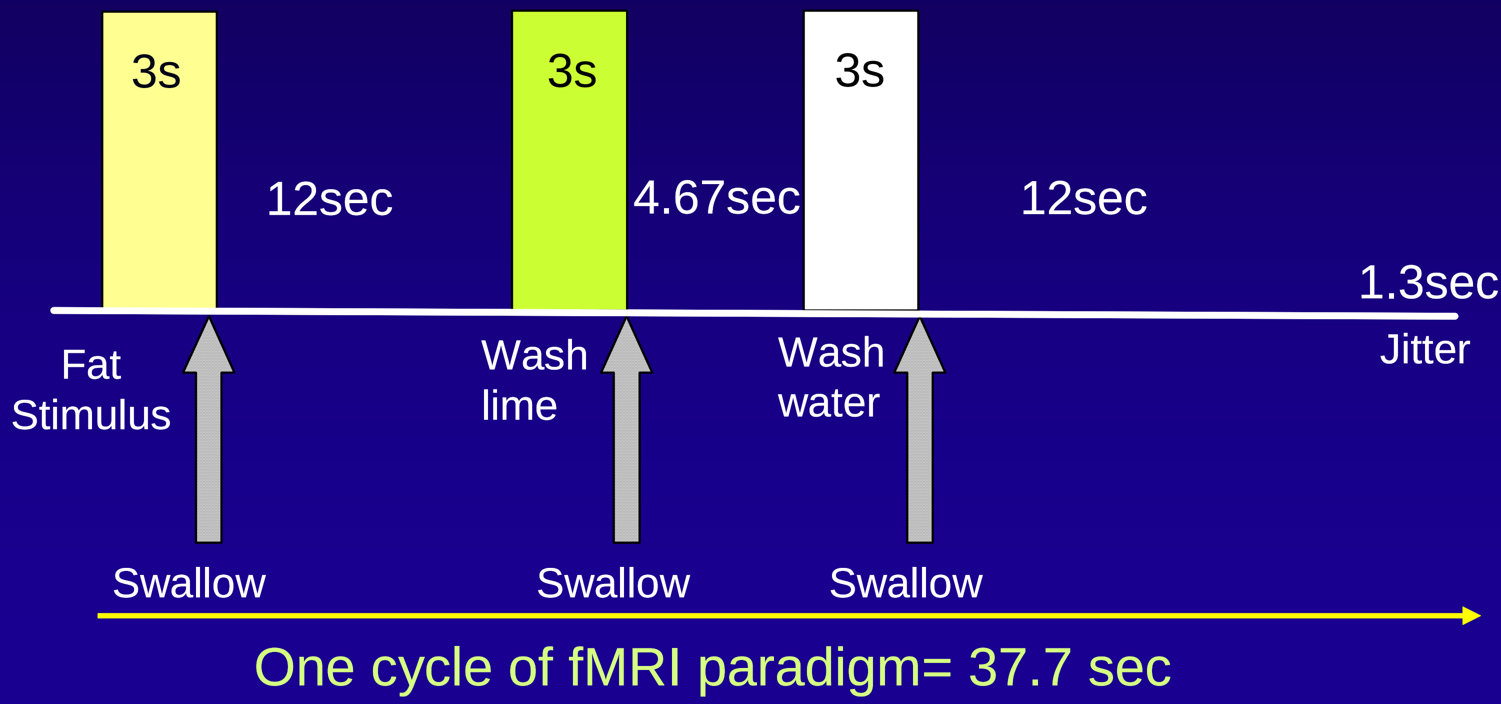
For each subject 36 cycles of fat stimuli at different levels (5%, 10%, 20% or 30% w/w) were delivered in a random order.



(II) Cortical Processing of Fat

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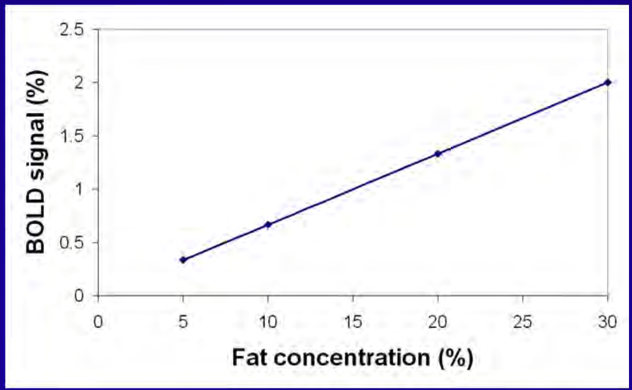
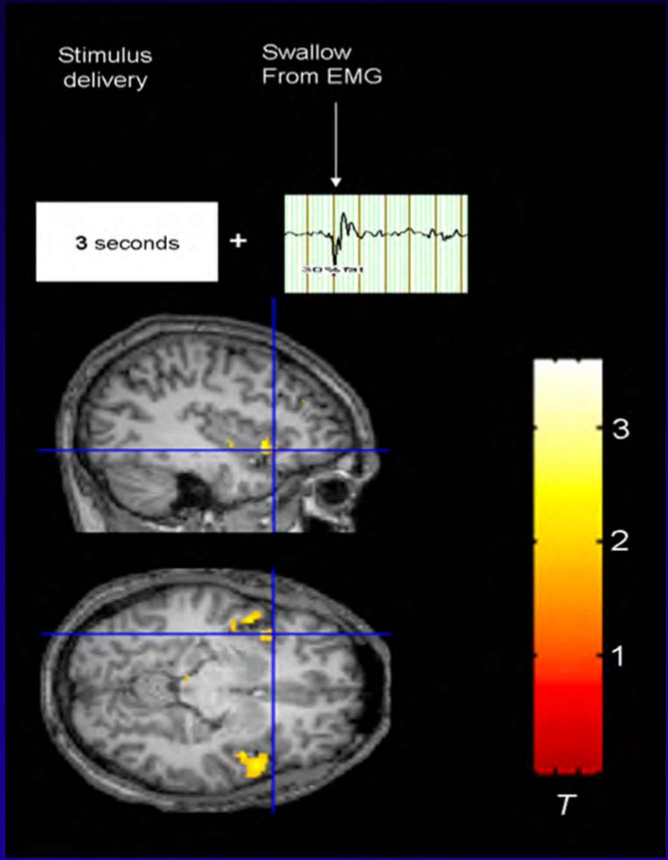
- Activation maps generated to
  - (1) Identify areas activated to all the fat stimuli: "all fat"
  - (2) Identify areas linearly correlated with fat levels: "parametric" so fat reponse





Cortical Response to fat stimulus

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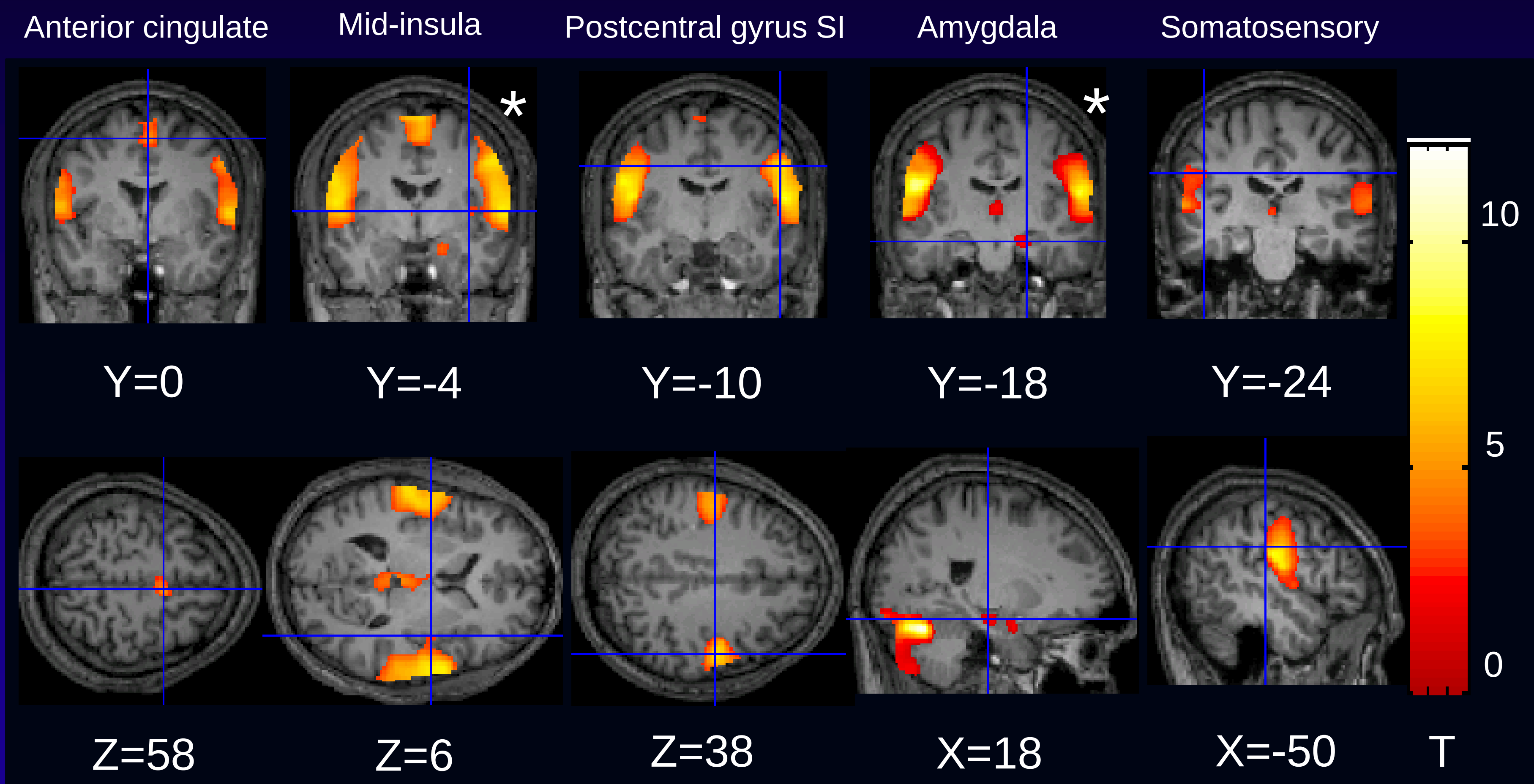
"all fat"

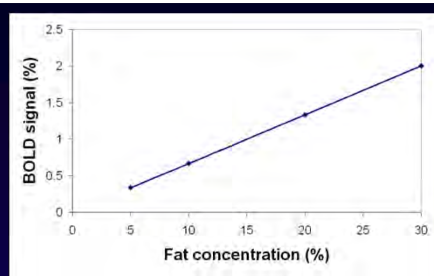


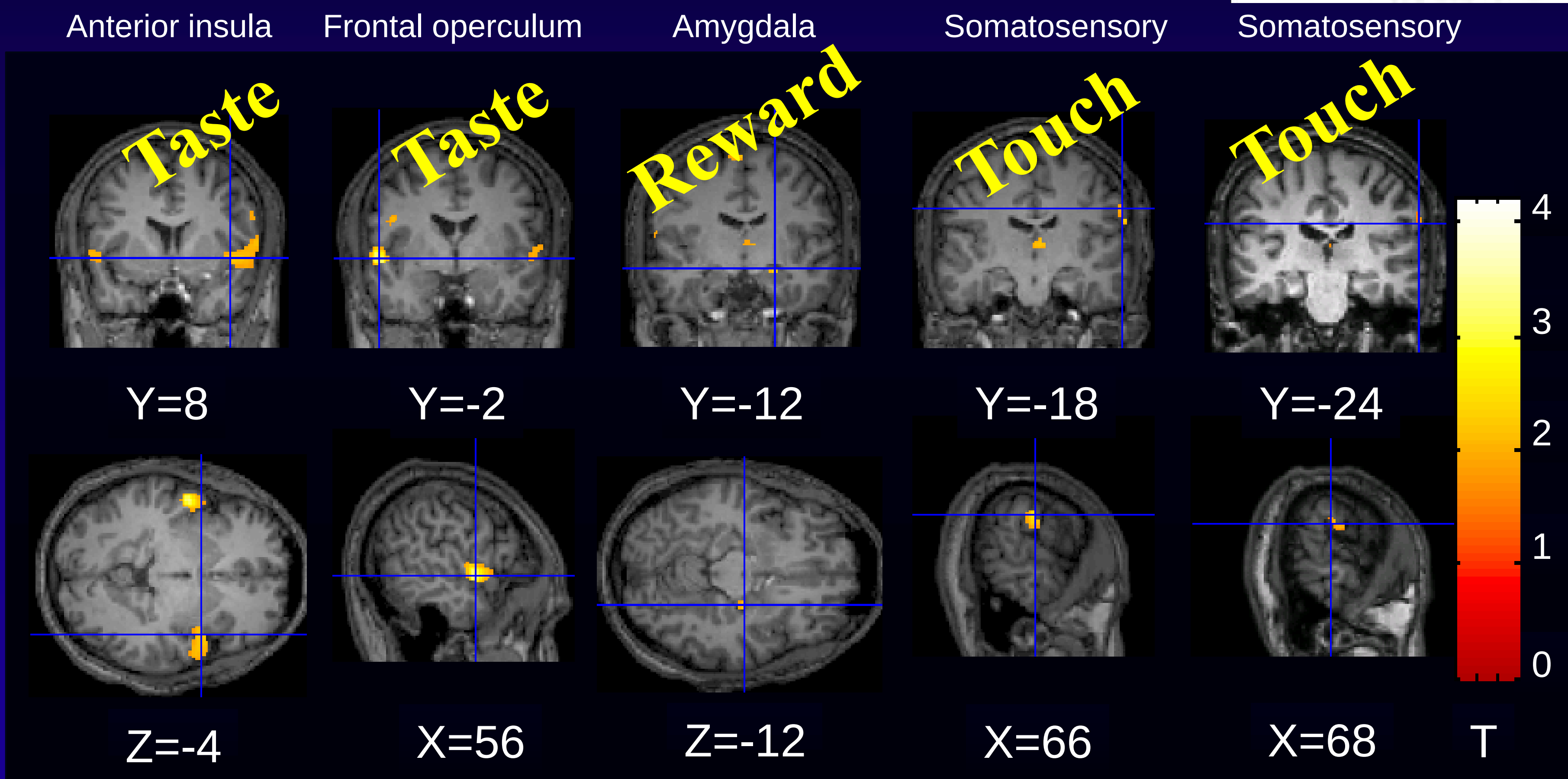
Displayed with $p<0.005$ corrected FDR, overlaid to T_1 images

* Displayed with $p<0.05$ corrected FDR, overlaid to T_1 images

Isolating effect of increase fat level

“parametric - positive correlation with fat levels”





Displayed with $p<0.05$ uncorrected, overlaid to T_1 images

Positive correlation with fat level

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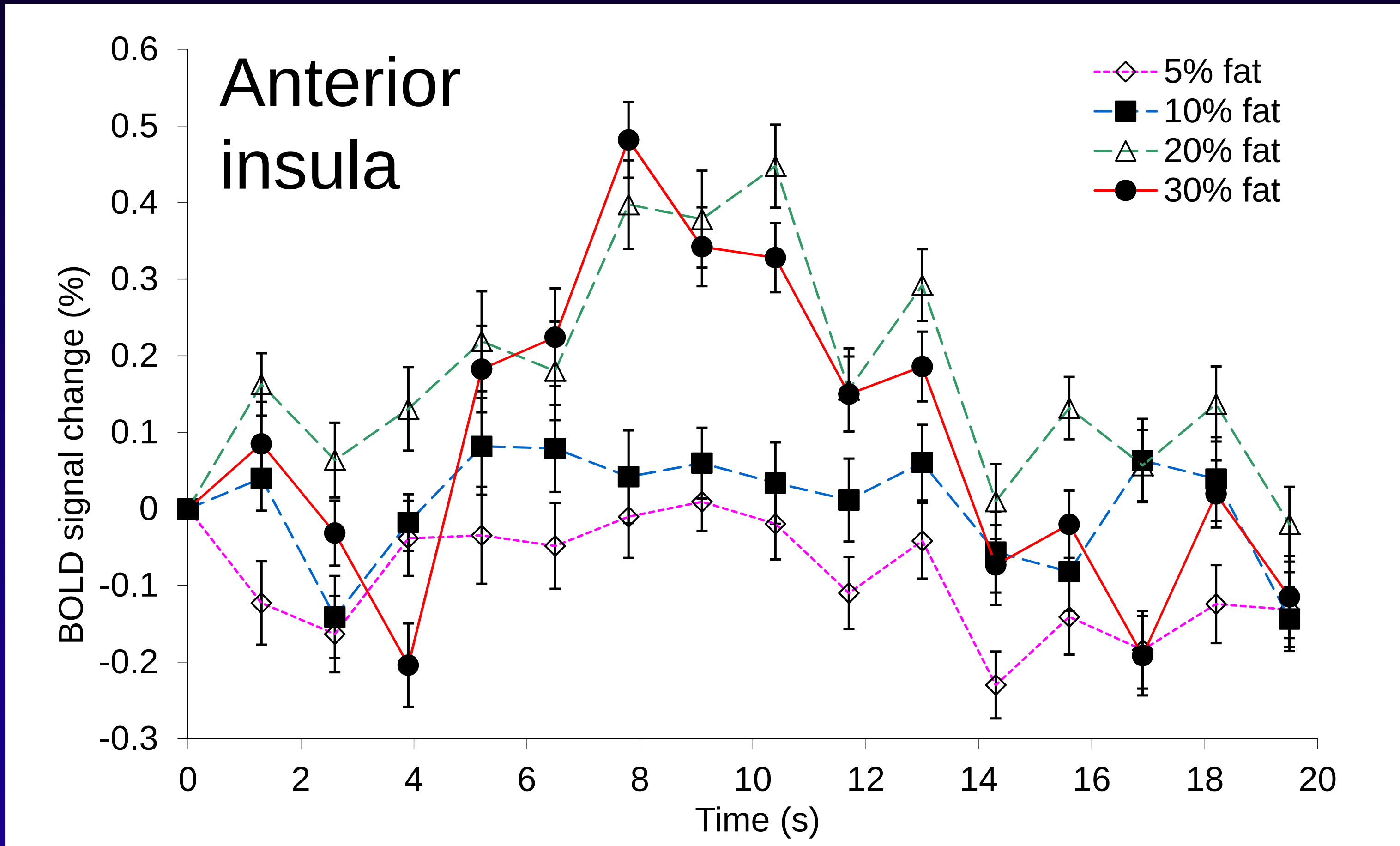

Somatosensory, primary taste and reward areas correlate with fat levels, and thus fat itself.

(III) Subject Phenotype: Taster status

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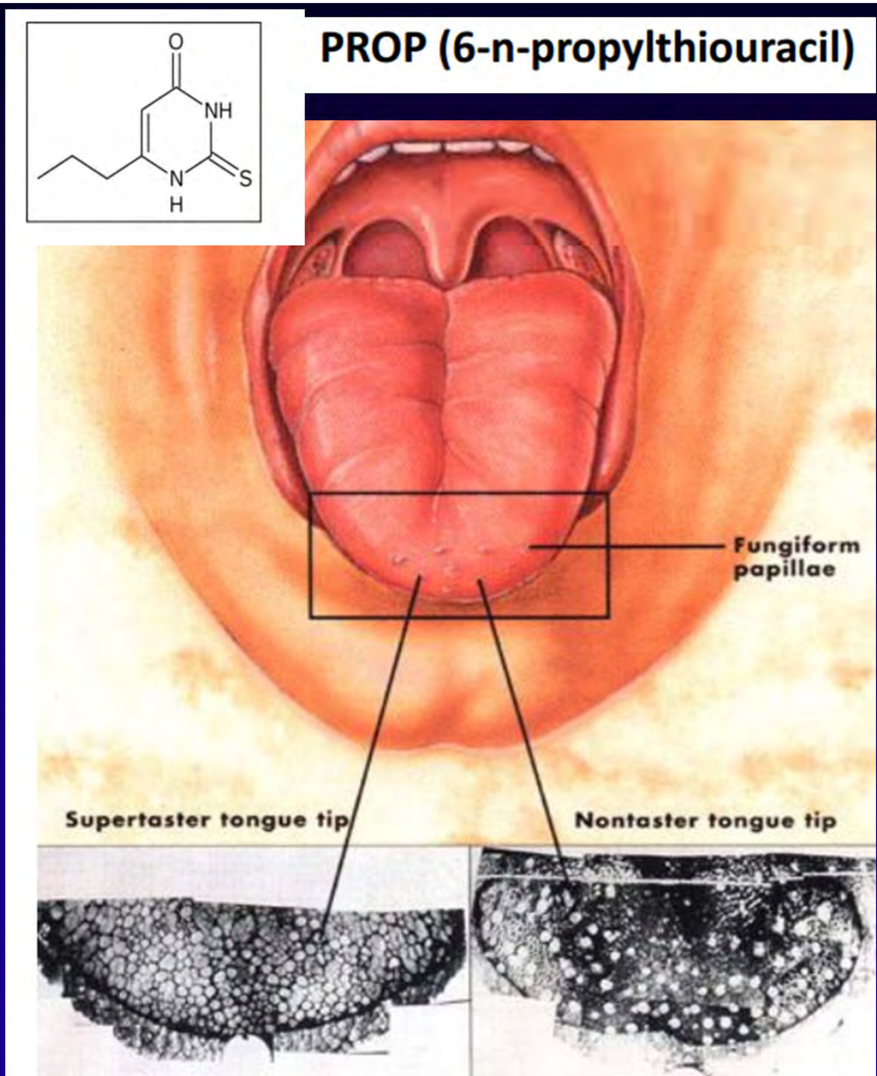
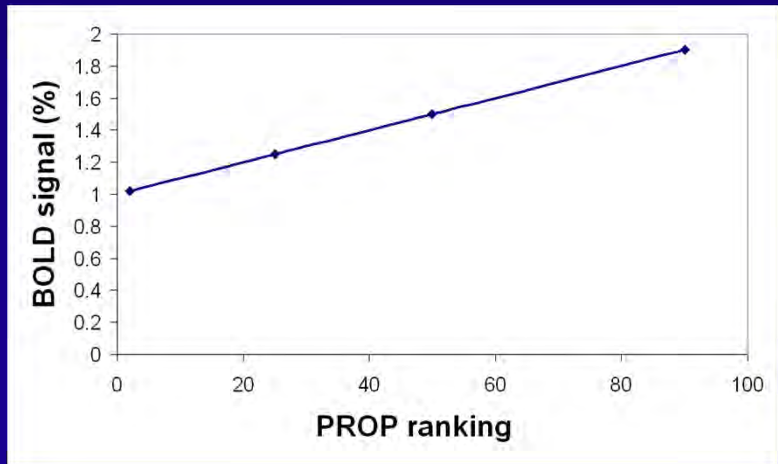


- Impact of PROP taster status on cortical response

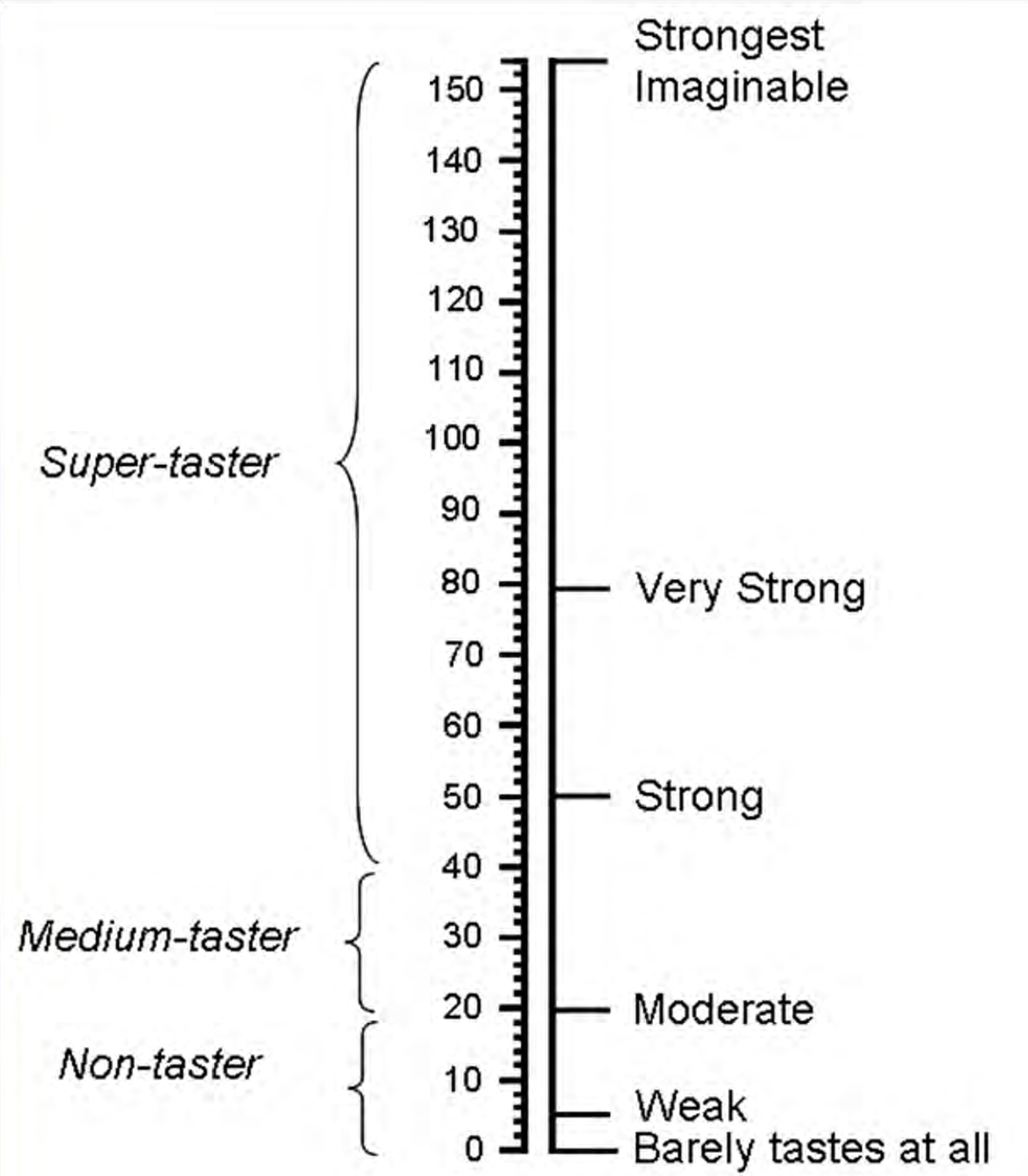
- Non-tasters ~ 30%
- Tasters
  - Medium ~ 45%
  - Super ~ 25%



Eldeghaidy S, et al. 2011. The Cortical Response To The Oral Perception Of Fat Emulsions And The Effect Of Taster Status. Journal Of Neurophysiology. 105(5), 2572-81

(III) Subject Phenotype: Taster status

The University of Nottingham



- Taster status: PROP test
- Preference rating: Subjects asked to rank preference to 5, 10, 20 and 30 % fat sample to determine if any perceptual preference existed between the samples.

Sample preference

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Sample preference

Procedure
You are presented with four samples, each labelled with a 3 digit code. Taste the samples in the order presented, from left to right, and rank them in order of preference (1^{st}, 2^{nd}, 3^{rd} and 4^{th}).

1^{st} = most preferred
4^{th} = least preferred

Clear your palate with cracker and water between each sample.

Record your results below

Rank order	Sample number
1^{st} (most preferred)	
2^{nd}	
3^{rd}	
4^{th} (least preferred)	

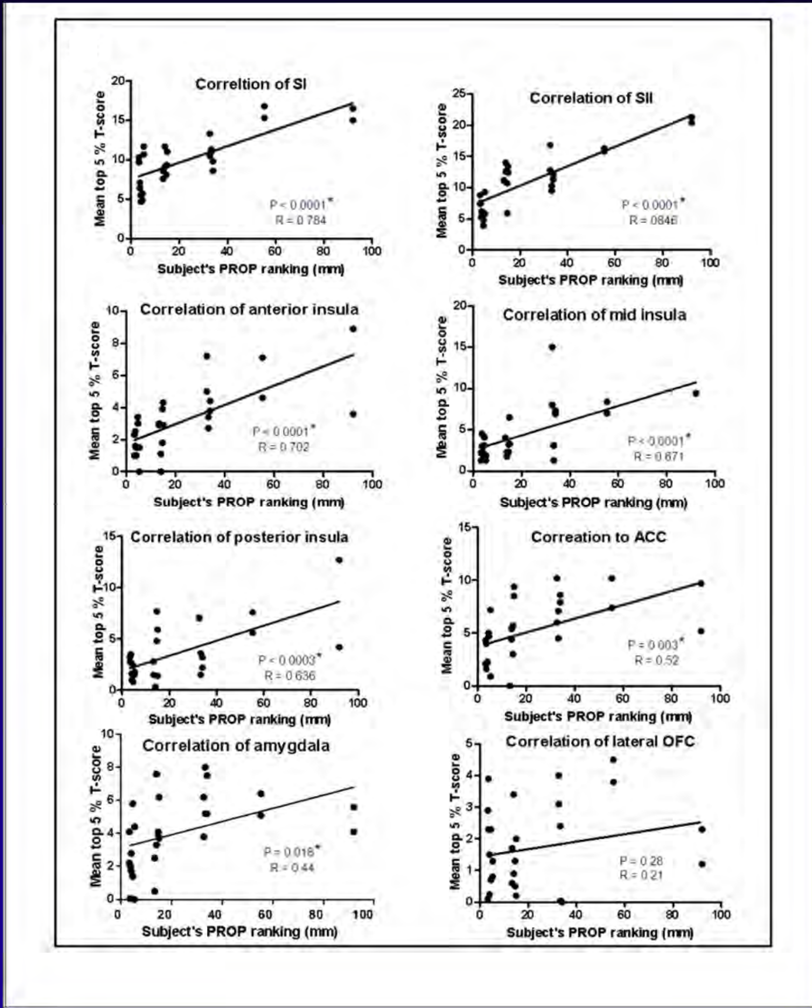
If you would like to make any additional comments please use the space below

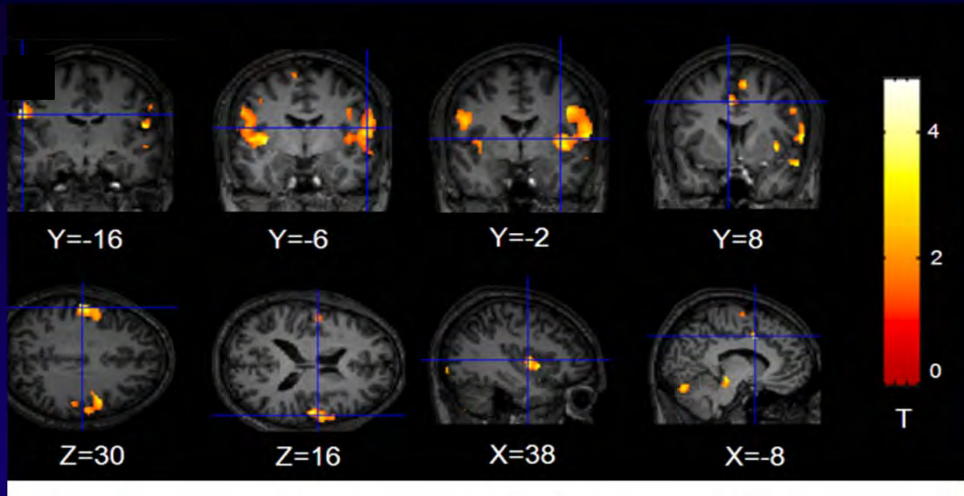
Additional comments

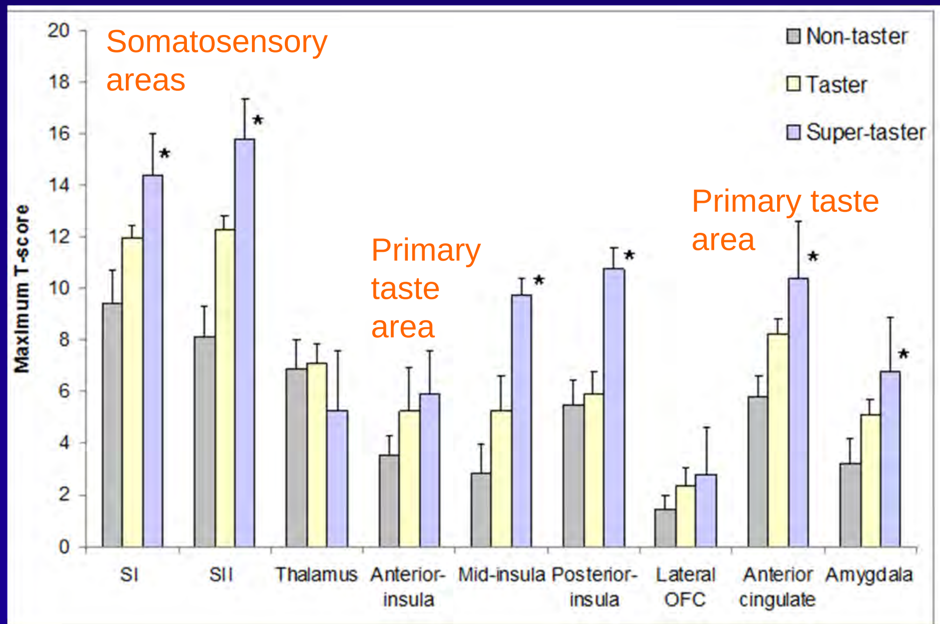
Thank-you for participating in this test

- Preference test: 30 and 20 % emulsions significantly preferred to the 10 and 5 % emulsions ($P < 0.05$).
- All subjects with high PROP levels ranked emulsions in order of fat concentrations for preference (30 % fat most preferred).
- Subjects with low PROP levels showed no consistent preference ranking.

Taster status and brain activity







(III) Subject Phenotype: Taster status

- Subject's PROP ranking is highly correlated to the cortical response in somatosensory (SI, SII, mid- and posterior insula), reward (amygdala and anterior cingulate), and taste areas (anterior insula).

- The variance in BOLD response can be improved by selecting subjects with a particular taster status for group analysis, subjects with high PROP ranking improving detection power.

(IV) Does fat effect the cortical response to flavour?

- Understanding the effect of fat on the perception and cortical response to flavour will aid the design of healthier and tastier low fat foods

- Increasing body of evidence of perceptual interactions between the senses
  - After stimulation at the receptors multi-modal interactions

Eldeghaidy, S. et al. Does fat alter the cortical response to flavor? Chemosensory Perception., In Press. 2012.

(IV) Effect of fat on Flavour processing

The University of Nottingham

– Create palatable emulsions with specific sensory and volatile release properties
  - Iso sweet
  - Iso thick
  - Iso flavour release or perception

Flavouring:
- Palatable
-Recognisable
-Instrumentally detectable
-Not too persistent
-Volatiles similar log p

Red Fruit Flavouring:
-Benzaldehyde (50ppm)
-Iso-amyl acetate (100ppm)
-Ethyl butyrate (200ppm)
-Ethyl acetate (100ppm)

Oil 0.5-30%,
Sucrose 2-10%,
'Flavour cocktail' 6-25%
Thickener (HPMC) 0-1.2%,
(n = 30)

+ 1% sucrose stearate & Mineral water

Sensory assessment of samples

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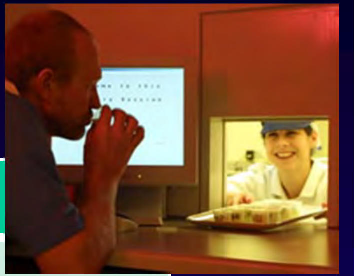
- Assessors generated well defined list of discriminating attributes



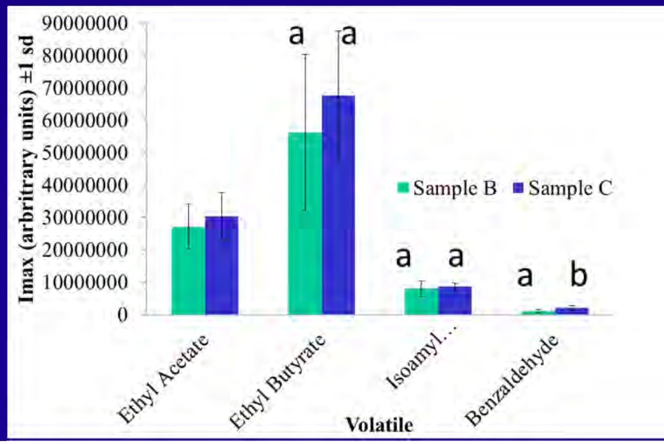
Attribute	Definition
Fruit flavour intensity	Intensity of ‘mixed frui’t flavour
sweetness	Of sugar
thickness	assessed by pressing tongue to roof of mouth and feeling the resistance to the movement
mouth-coating	quantity of bulk sample still stick to the inside of the mouth after first swallow
dispersing	speed with which the sample dissolves into saliva and is ready for swallowing
stickiness	the resistance of pulling the tongue away from the roof of the mouth after assessing the thickness
oiliness	Greasy film/ residue in mouth as slide tongue over inside of mouth after swallowing
bitterness	Characteristic bitter taste associated with caffeine or aspirin

Samples

Sample	Flavouring ml kg^{-1}
A:unflavoured fat control	0
B: flavoured no fat control	6.25
C: flavoured fat, iso-volatile to B	13.6
D: flavoured fat, iso-perceiveto B	18.63

- Areas showing differential response to fat and flavour stimuli (B vs. A)
- Areas showing a differential response to flavour alone (B) and fat+flavour stimuli. (B vs. C; B vs. D)
- Areas showing differing response to iso-release and perceive. (C vs. D)

APcI-MS Validation of iso-volatile between B and C



(IV) Effect of fat on Flavour processing

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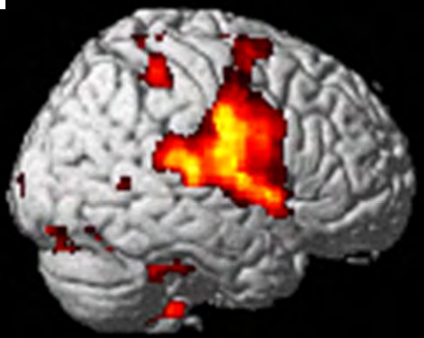
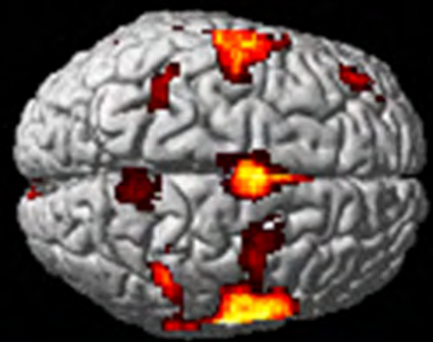
Sample B: Flavoured no fat



Insula (primary taste area)
and somatosensory cortices



Anterior cingulate (ACC)

Sample
A:unflavoured fat control
B: flavoured no fat control
C: flavoured fat, iso-volatile to B
D: flavoured fat, iso-perceive to B

B > C

B > D

○ Insula (primary taste area) ○ Anterior cingulate (AC) gyrus

(IV) Effect of fat on Flavour processing

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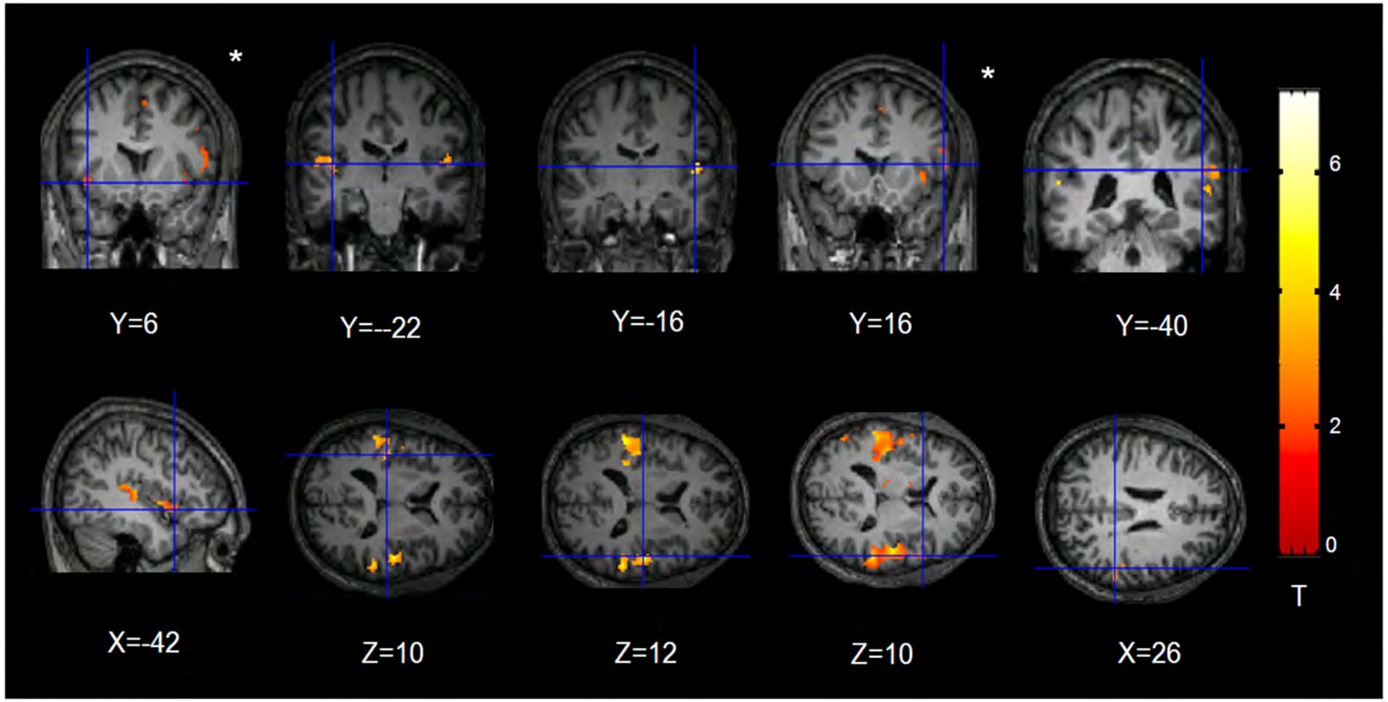
D > C



Sample
A:unflavoured fat control
B: flavoured no fat control
C: flavoured fat, iso-volatile to B
D: flavoured fat, iso-perceive to B

D results in significantly greater response in primary taste areas compared to C.

(IV) Effect of fat on Flavour processing

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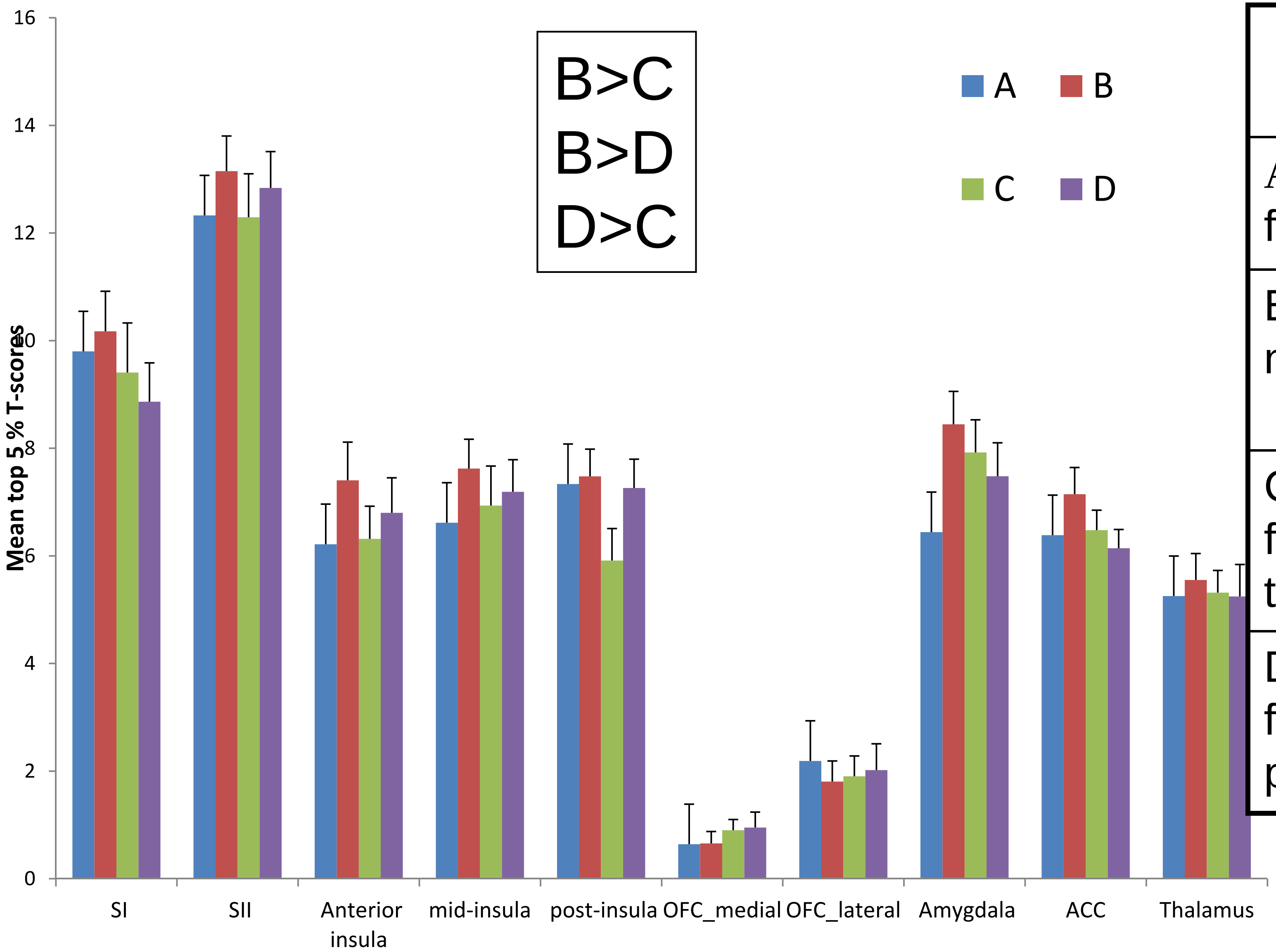

Sample
A:unflavoured fat control
B: flavoured no fat control
C: flavoured fat, iso-volatile to B
D: flavoured fat, iso-perceive to B

(IV) Effect of fat on Flavour processing

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- Fat reduces the cortical response to flavour in areas relating to reward, taste, aroma and somatosensory processing (Sample B vs C, and Sample B vs D).
- Only perceivable difference between flavour no fat stimulus (Sample B) and fat emulsions (Samples C and D) was the level of oily/greasy film/residue left in the mouth -‘oiliness’. Indicates this to be an important stimulus for the presence of fat in the oral cavity.
- Dampening effect of fat on cortical activity was somewhat reduced by increasing the volatile component of the stimulus without changing the perceived flavour (Sample D vs. C).

(V) GI exposure on fat processing

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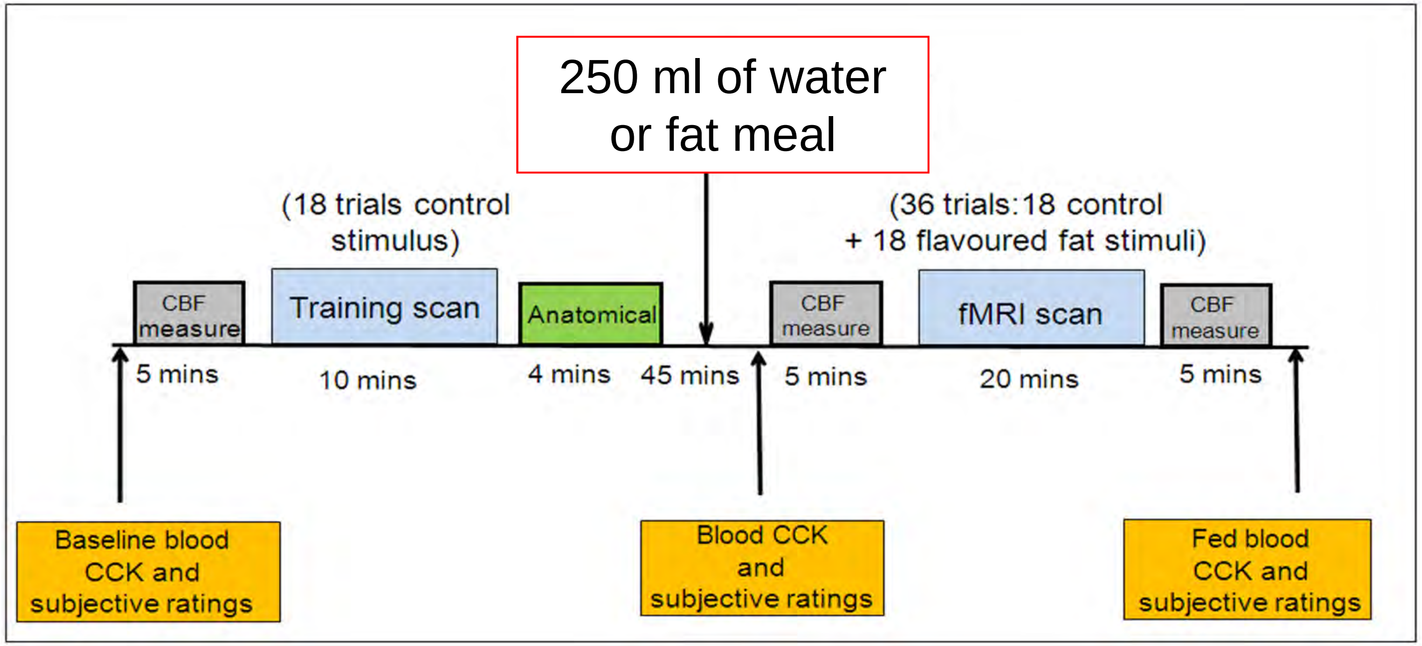

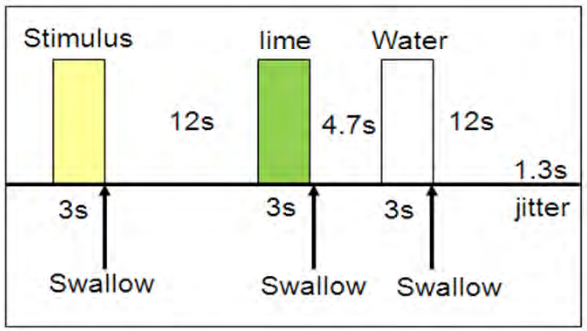

fMRI paradigm

CCK = gut peptide secreted in upper gastrointestinal tract to mechanical/chemical stimuli including fat. Release shown to promote the cessation of food intake.

(V) GI exposure on fat processing

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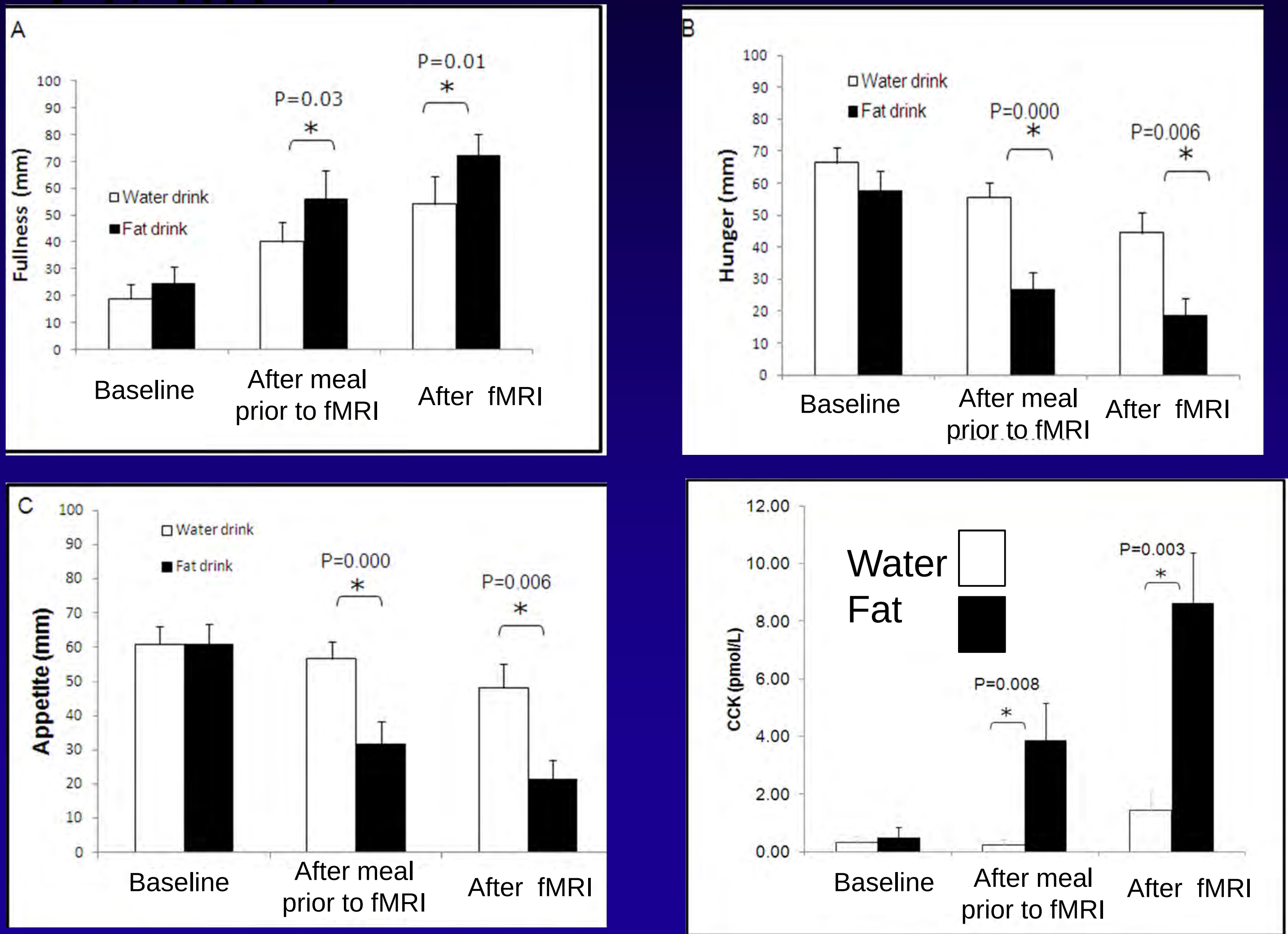
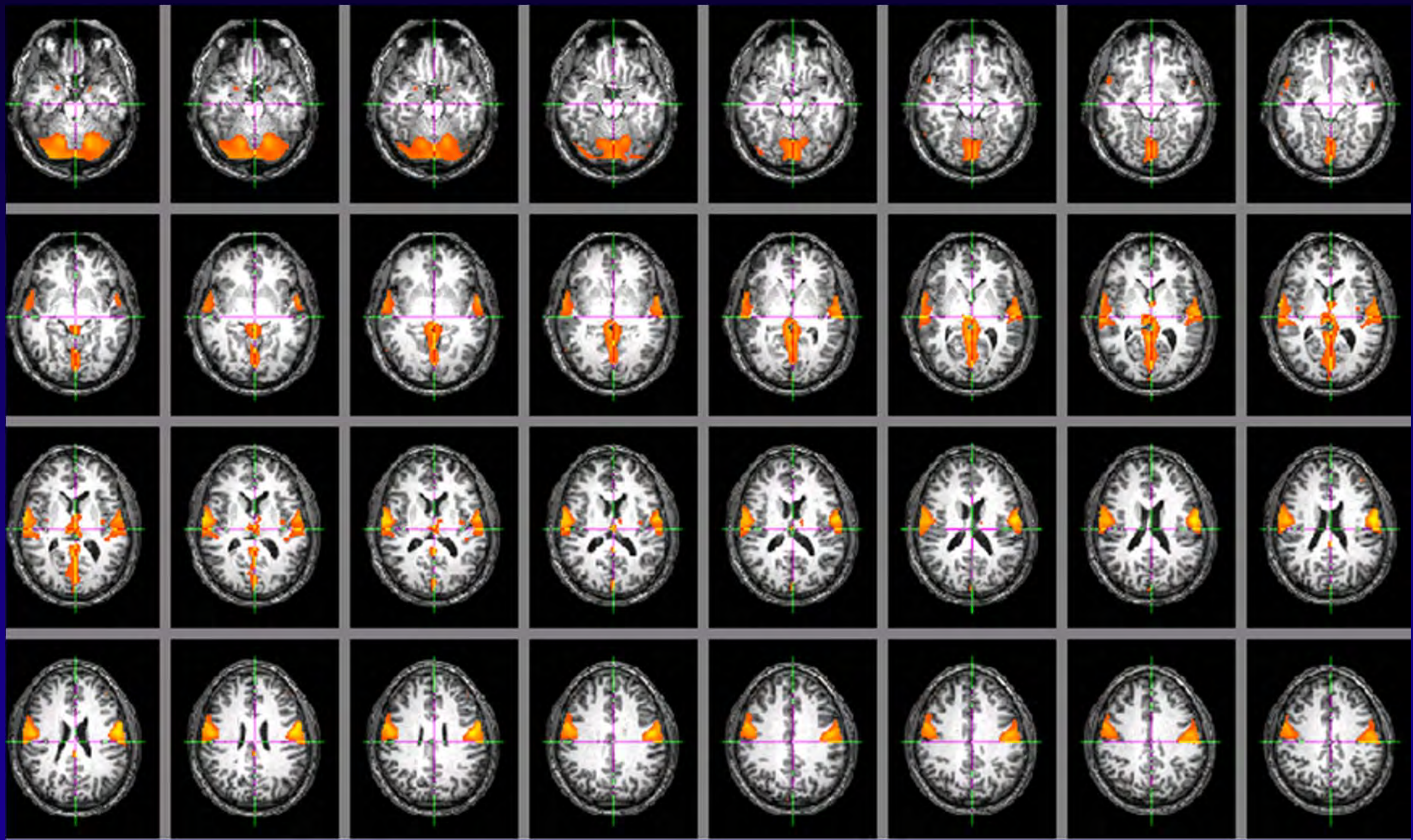
Behavioural and CCK measures

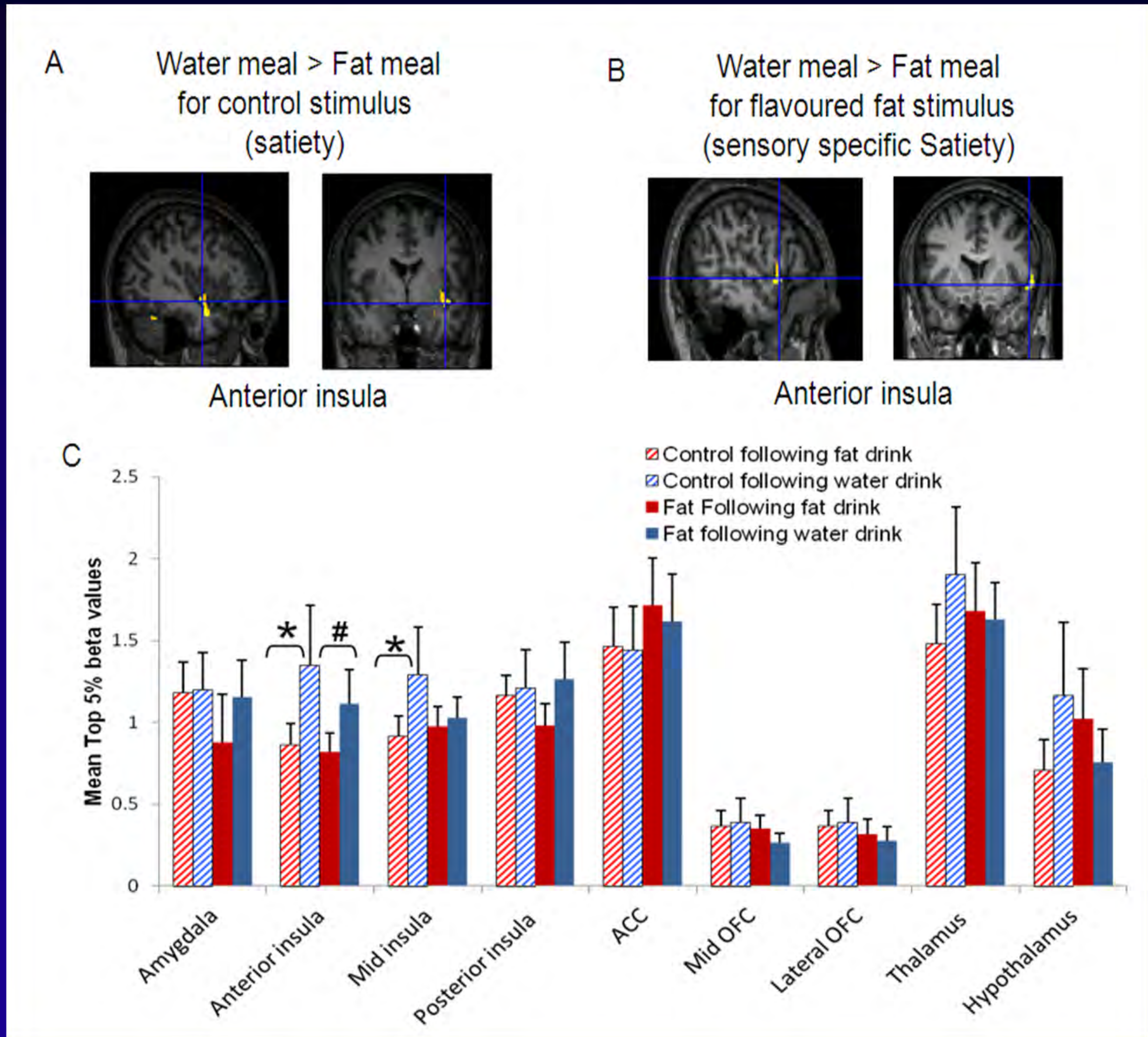


(V) GI exposure on fat processing



Cortical response to fat stimulus

(V) GI exposure on fat processing



Greater suppression of responses following fat meal (red< blue)

(V) GI exposure on fat processing

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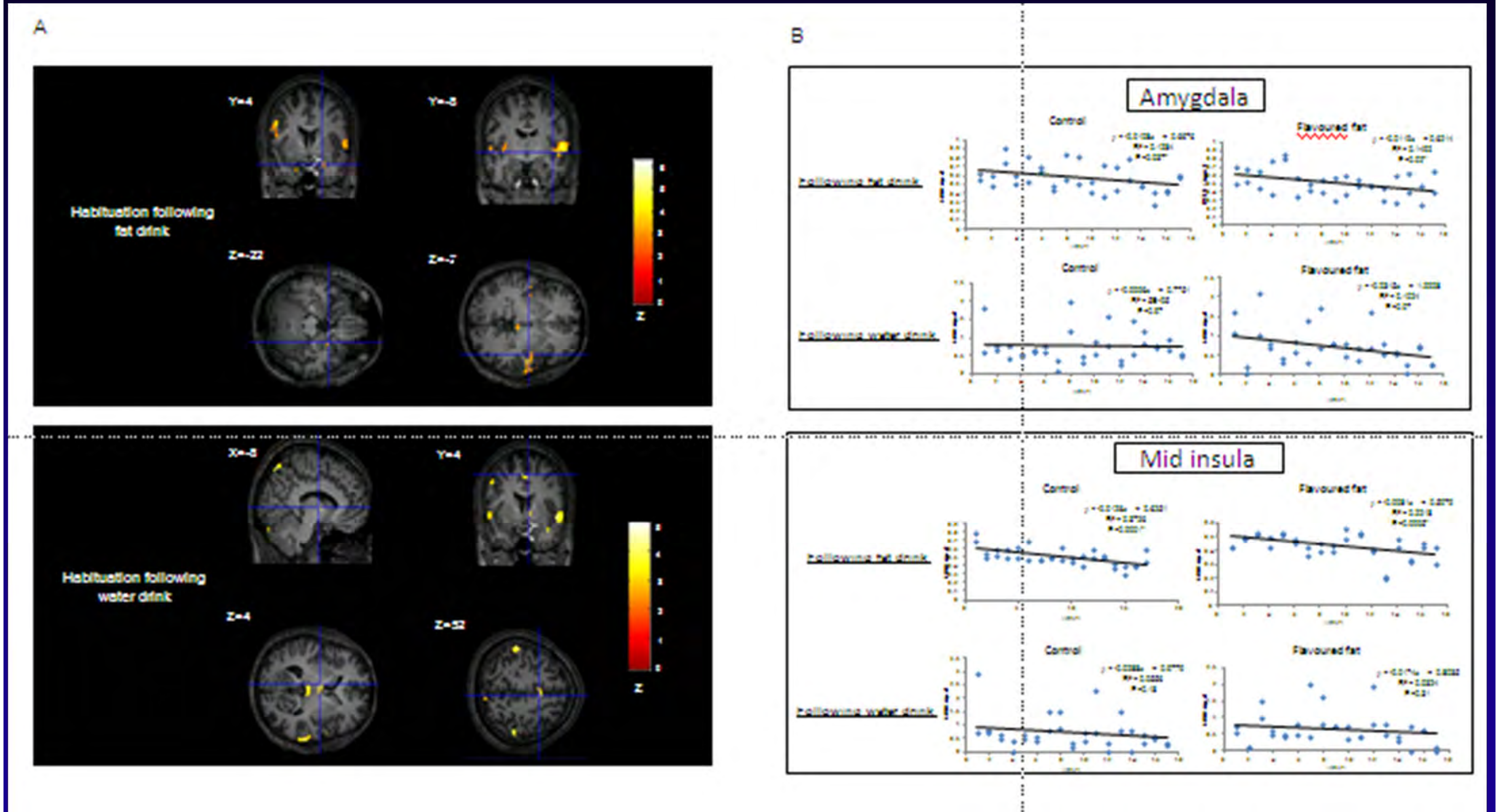
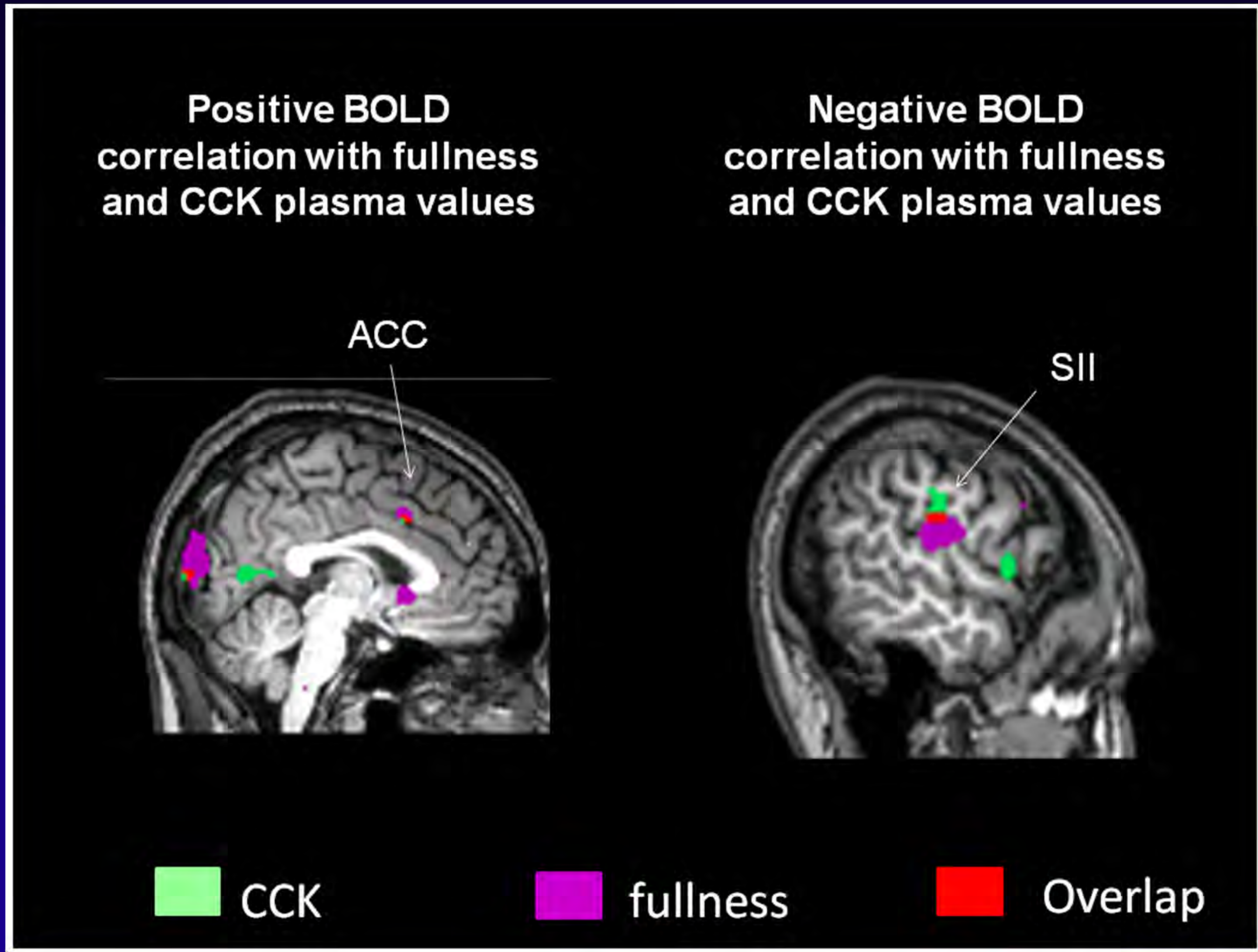


Greater habituation across stimuli following fat meal

(V) GI exposure on fat processing



Cortical areas which correlate with fullness and CCK

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