Food Reward, Appetite, Satiety, and Obesity
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Brain mechanisms:
Sensory factors: modulated by satiety signals produce reward value and appetite.
Individual differences.
Effects of:
Variety Sensory-specific satiety Palatability Food concentration Portion size Ready availability

What Reward Decision/Action

Food intake control: sensory stimuli are modulated by satiety signals in the orbitofrontal cortex to produce food reward.
Obesity: enhanced sensory-produced reward over-rides satiety signals; individual differences in reward value and cognitive control.

OFC Orbitofrontal cortex taste neuron
Water
BJ
Glucose
NaCl
HCl
QHCl

Poststimulus Time (s)

Amount fed (ml)

Sensory-specific satiety in the macaque orbitofrontal cortex
Primary taste cortex: no effect of feeding to satiety with glucose on the neuronal response to glucose taste


Sensory-specific satiety for the texture of fat


Each orbitofrontal cortex neuron responds to a different combination of taste, odor, texture and temperature stimuli: as a population they provide information about a rich variety of reward stimuli; and provide for behaviours such as sensory-specific satiety that are specific to combinations. A reward representation as a goal for action must be specific for a particular reward (cf dopamine).


Some neurons encode the viscosity of oral stimuli, as shown by their responses to a viscosity series (CMC). Fat responses from these neurons can be predicted by viscosity e.g. neuron bk291c2.


Orbitofrontal cortex fat texture-responsive neurons


Fat responsive neurons respond independently of viscosity e.g. bk265

Whole Food Sensory-specific Satiety

Conclusions

- A direct correlation between the subjective state of pleasure produced by food and the activation of the orbitofrontal cortex has been demonstrated.
- The human orbitofrontal cortex, as in non-human primates, plays an important role in representing the reward value of food stimuli, including chocolate, and a food rich in umami, tomato.
- This is consistent with the hypothesis that the pleasantness of the flavour of food (with taste, olfactory and texture components) is represented in the human OFC.
- It is suggested that sensory-specific satiety is a general property of reward systems (Rolls, 2005, Emotion Explained, Oxford).


Effects of cognition on perception
Rolls and De Araujo University of Oxford

Cognitive modulation revealed by a correlation between the BOLD signal and the pleasantness ratings given to the Test odour.

Conclusions: A visually presented word label modulates representations of odors in olfactory areas in the orbitofrontal cortex, amygdala, and olfactory tubercle. Cognition can influence subjective, conscious, affective representations in the orbitofrontal and pregenual cingulate cortices.

Selective attention to affective value alters how the brain processes taste stimuli
• We delivered the identical taste (MSG) on every trial.
• Instructions were on different trials to ‘remember and rate pleasantness’ or to ‘remember and rate intensity’

Orbitofrontal and pregenual cingulate cortex
Paying attention to pleasantness vs intensity produces greater activation to taste in the orbitofrontal and pregenual cingulate cortices.

Activations were correlated with subjective pleasantness ratings.
Anterior and mid insular cortex

Paying attention to intensity vs pleasantness produced larger activations in the anterior and mid insula.

Activations were correlated with subjective intensity ratings.


Selective attention to affective value alters how the brain processes taste stimuli

- Top-down selective attention allows processing in different brain areas to be emphasized for different types of decision-making
- Decisions about affective value recruit the orbitofrontal cortex and pregenual cingulate cortex.
- Decisions about the intensity of a stimulus recruit the primary sensory (insular taste) cortical area.
- In sensory testing, psychophysics and marketing, it is important to ensure that attention is being paid to pleasantness or to the physical properties: different brain systems are engaged by these two types of attention


Do responses of the orbitofrontal cortex and pregenual cingulate cortex enable individual differences in affective behaviour and decision-making to be predicted?

Chocolate craving: a craving and a non-craving group

- Chocolate in the mouth – flavour differences?
- Sight of chocolate – conditioned cue differences?
- Sight of chocolate and chocolate in the mouth – greater supralinearity?
- Cognitive biasing: dark chocolate word label vs white chocolate word label
- Condensed milk – similar texture and sweetness to chocolate, but not craved.
- Tasteless control solution
- 8 cravers and 8 non-craver participants.
- SPM fMRI group random effects analysis with full correction or svc.

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The effects of chocolate in the mouth: activation of the insular primary taste cortex. This was the same in cravers and non-cravers.


The flavour and sight of chocolate combination: more activation was found in the cravers than in the non-cravers in the anterior and pregenual cingulate cortex, and in the ventral striatum.

Chocolate in the mouth with sight of dark chocolate: cravers vs non-cravers

Sight of chocolate

a. More activation of mid and medial orbitofrontal cortex in cravers than non-cravers
b. More activation in the ventral striatum in cravers than non-cravers

c. More activation in the ventral striatum in cravers than non-cravers

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**Imaging of chocolate craving:** individual differences in brain activations predicting craving and food intake

- There were no differences between chocolate-cravers and non-cravers in responses to the flavour of chocolate in the primary taste cortex. Moreover, the activations in the primary taste cortex were not correlated with the subjective pleasantness of chocolate, or physical sensitivity to taste and oral texture, that separated the cravers from the non-cravers.
- The flavour of chocolate produced more activation in cravers than in non-cravers in the medial orbitofrontal cortex.
- The sight of chocolate produced more activation in chocolate-cravers in the medial orbitofrontal cortex (OFC) and ventral striatum.
- A combination of the sight and flavour of chocolate produced more activation than the sum of the components in the medial orbitofrontal cortex, pregenual cingulate cortex, and striatum.
- This non-linearity was greater in the cravers than in the non-cravers.
- The subjective pleasantness ratings of the chocolate and chocolate-related stimuli had higher positive correlations with the fMRI BOLD signals in the pregenual cingulate cortex than in the orbitofrontal cortex.
- The amount of chocolate eaten on a regular basis was higher in the cravers (370 g/week) than the non-cravers (22 g/week).
- Understanding individual differences in brain responses to very pleasant foods helps to understand the mechanisms that drive the liking for foods, and thus food intake and decision-making. Individual differences and personality.

**Orbitofrontal cortex neuroimaging**

- Taste: Both pleasant and unpleasant tastes are represented
  - Amygdala: pleasant tastes are as much represented as unpleasant tastes
  - Orbitofrontal cortex: pleasantness assessed with a rating task and fMRI
  - Correlation of OFC activation with subjective pleasantness of the food
  - Different types of gene-specified reward are represented in different regions of the OFC
  - Primary oral texture is represented in the insula and amygdala
  - Anterior cingulate cortex: anterior - pleasant touch, mid - pain
  - Correlation of OFC activation with the subjective pleasantness of the food
- Oral viscosity and fat texture: insula and orbitofrontal cortex
  - Flavour: olfactory-taste convergence
  - In the orbitofrontal cortex and agranular insula: MSG+unary odor
- The primary taste cortex in the insula is modular
  - Individual differences: chocolate craving: orbitofrontal cortex and pregenual cingulate
  - Somatosensory pleasure and pain more than neutral
  - Correlation of OFC activation with subjective pleasantness and pain
  - Anterior cingulate cortex: anterior - pleasant touch, mid - pain
  - Abstract (monetary) reward and punishment (loss) in a reversal task
  - Separate representations of the magnitude of the gain (medial) and loss (lateral)
  - Anterior cingulate cortex: anterior - pleasant touch, mid - pain
  - Face reversal cued by changing face expression: reward prediction error
  - OFC activation related to an angry expression when it is used as a reversal cue
  - Activation in the fusiform face area does not reflect the reversal cue
  - Amphetamine activates the medial orbitofrontal cortex
- Cognitive affective modulation of taste, flavour, odour and touch is implemented in the orbitofrontal and pregenual cingulate cortex.

**Orbital frontal cortex**

- Anterior cingulate cortex
  - Reward: Correlation with subjective pleasantness.
  - Pain: Correlation with subjective unpleasantness.
- Prefrontal cortex: top-down biased competition

**Pleasure map**

**What Reward Decision/Action**

**Personality and reward systems in the brain**

- Each specific type of reward (taste, flavour, water, touch ...) is represented by different neurons.
- Each specific type of gene-specified reward is subject to variation between individuals as part of evolution by natural selection.
- Therefore individual differences may have different sensitivity to different specific types of reward, non-reward, etc.
- This variation may contribute to personality, and to high dimensionality of the space.
- This may be reflected in differential sensitivity in different individuals in how brain reward systems respond to different reinforcers.

**Principles of the cortical processing of taste, texture and odor**

- Taste reward and subjective pleasantness is represented in the orbitofrontal (secondary taste) cortex (OFC)
- Taste identity and intensity is represented in the primary taste cortex
- Olfaction and taste converge in the OFC onto the same neurons.
- In the OFC, odor is mapped by some neurons from molecular to taste space by associative learning.
- In the OFC, odor reward is represented.
- Visual to taste associative learning occurs in the OFC in 1 trial.
- Oral texture (viscosity, fat texture, capsaicin, roughness) and oral temperature are combined with taste in the primary and OFC taste cortex.
- Fat sensing is oral texture based, and is independent of fatty acids such as linoleic, and of viscosity.
- OFC oral texture channels reflect the crispness / freshness of a food.
- Fat texture pleasantness is represented in the OFC.
- Texture variability can increase appetite for a food: sensory-specific satiety for oral texture.
- Sensory-specific satiety is implemented by OFC combination-sensitive neurons.
- Cognition and attention modulate affective value representations in the OFC: a biased activation theory of selective attention.
Obesity: overstimulation of the food reward system in the brain

1) Any of the factors described may promote over-eating and obesity:

- 1) Edmondson and genetic factors: e.g. hypothyroidism or leptin deficiency. (More = cannot account for the three-fold increase in humans with BMI > 30 since 1980)
- 2) Externality: Schachter: obese people may be more reactive to the sensory properties of food.
- 3) Sensory specificity: Enhanced palatability in human diet, leading to imbalance between orosensory control signals, and gastrointestinal and post-absorptive satiety signals.
- 4) Variety: Enhanced variety in human diet, which leads to increased food intake because satiety is partly sensory-specific.
- 5) Meal pattern: Sensory-specific.
- 6) Variety: Enhanced variety in human diet, which leads to increased food intake because satiety is partly sensory-specific.
- 7) Regulation to internal signals is poor - e.g. 2 weeks to adjust to altered caloric composition of the diet;
- 8) Stress-induced eating.
- 9) Decision-making: the explicit reasoning vs the emotional system.
- 10) Exercise.

Future investigations:

- 1. What can we learn from the detection of brain reward system in obesity? (Some gut taste cells may have multiple types of taste receptor: Margolskee.)
- 2. Does MSG in the gut reduce the palatability of the flavor of protein?
- 3. Does MSG in the gut reduce the palatability of sweet taste?
- 4. Does MSG in the gut reduce dietary induced obesity (K.Tori)?
- 5. Can the food industry develop very palatable foods, but with good nutrition, e.g. fat substitutes?
- 6. The same may be true in overeating and obesity.

For example, does glucose in the gut reduce the palatability of sweet taste?

Obesity, addiction and the mismatch hypothesis

1. Mismatch hypothesis: food palatability, availability, variety, and exposure by advertising have increased food reward in the last 30 years yet the satiety signals remain unchanged, and this contributes to overeating.

2. The control of eating is different from typical addictions in that eating is controlled by satiety signals from the periphery, and by sensory-specific satiety.

3. Typical drugs of addiction bypass the orbitofrontal cortex and amygdala where these satiety controls operate, and instead operate in regions to which they project, such as the ventral striatum.

4. Nevertheless, very pleasant foods (chocolate, ice cream) may produce so much reward, in some individuals, that dopamine is released, and this may introduce some similarities of the behavior to addiction.

5. In addiction, the conditioned stimulus has a potent control on behavior.

6. Limiting exposure to such potent conditioned stimuli (the sight and smell of food, advertising of high fat foods with poor nutrition) may help.

Relation to impulsiveness.

7. A large-scale database of brain imaging results using a set of agreed measures (e.g. responsiveness to the sight and flavor of fatty foods, BMI, questionnaire, genetic biomarkers) with a BMI follow-up might allow identification of which factors correlate with BMI, and a tendency for BMI to increase, and what subgroups there may be.

Dual routes to emotion


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