Food Pleasure:
Principles & Practice

Steven Witherly, PhD
Technical Products Inc

No Theory on Food Pleasure

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Talk Outline

- Latest Research in Chemical Senses
  - How Many Senses are there?
  - Latest Taste Research
  - Latest Olfaction research
- What is Food Pleasure?
  - Pleasure Center
  - Important Food Theories
  - Food Pleasure Equation
- Some Applications

Phenomenon Explained

- Junk Food Liking
- Why is Garlic Popular?
- Why do People Like Hot Food?
- Why is Vanilla the #1 Flavor?
- What are Taste Aversions?
- Why do We Like Chocolate?

Worldwide Food Industry

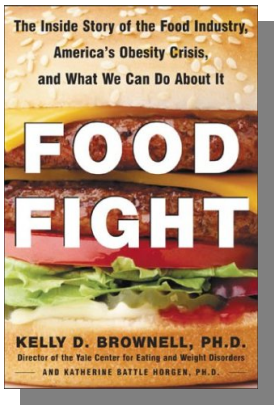
- 3.3 Trillion Dollars!

What Makes Food Taste Good?

Food Navigator 3/3/2005

Food Industry (Big Bucks)

- Food Industry is Almost a Trillion Dollar Industry!
- Fast Food alone is 100 billion!
- Snack Food 100 billion!

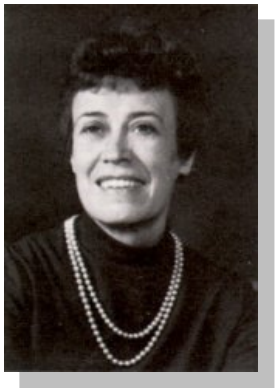


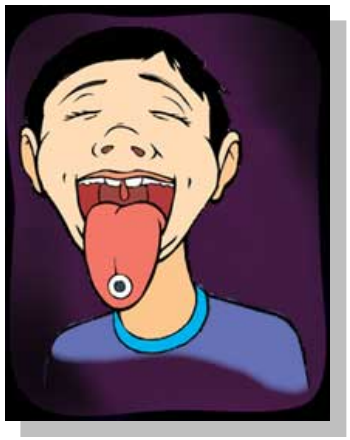
Food Theories?

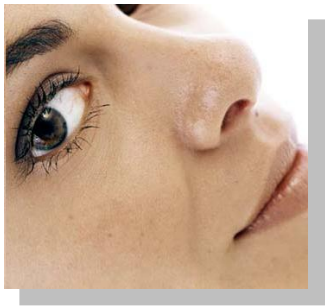
What Makes Food Taste Good?

We are All Experts?

- Pangborn told me:
  - "Since everyone has a nose and tongue we all think we are experts on good food"







Fundamental Theories

- Central Limit Theory (mathematics)
- Pareto's Principle (80/20 rule)
- Theory of Relativity (Einstein)
- Big Bang Theory
- Theory of Everything (String)
- Evolutionary Theory (Darwin)
- Entropy Theory (Thermodynamics)
- Gravitational Theory (Newton)

Food Pleasure

Physiological Aspects of Sensory Pleasure In Foods

By
Steven A. Witherly, PhD
Robert Hyde, PhD

Why Humans Like Junk Food

By

Steven A. Witherly, Ph.D.

Technical Products Inc.

Note: The Original Slide Version that Started my Research on Food Pleasure
Now Updated with **current research**!

Why Study Junk Food?

- Insights into Ingestive Behavior
- Design Healthy Foods
- Understand Obesity Crises
- Study Weight Loss Ingredients

Lecture was dedicated to Professor Rose Marie Pangborn who asked us to write about food palatability

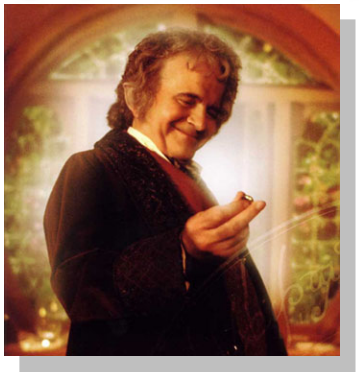
Doritos Effect

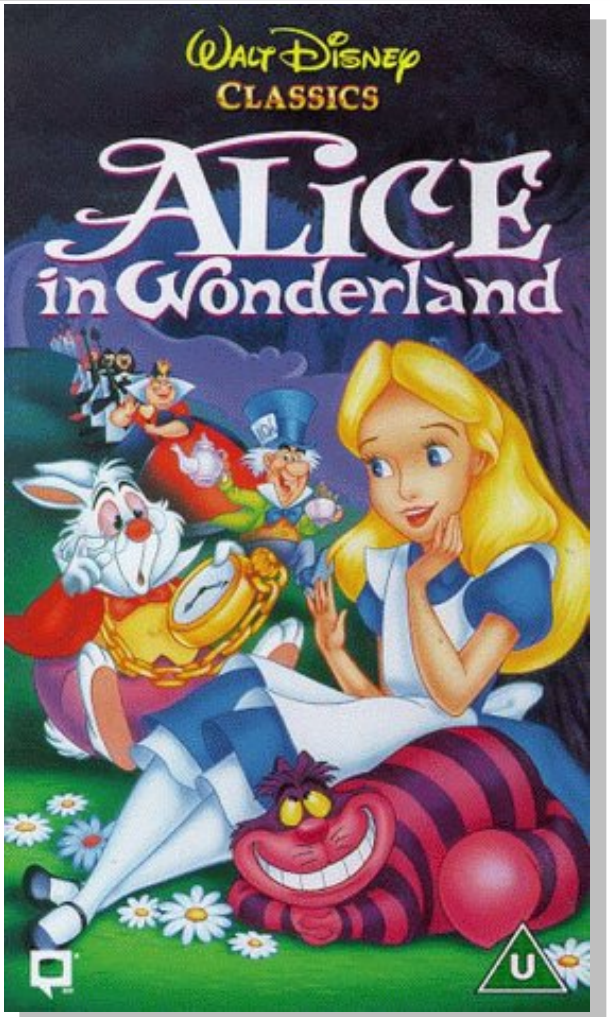
Food Company Powerhouses:

Food Powerhouses

Where to Begin?

- Let's Start with Some Fundamental Aspects of Food Intake!





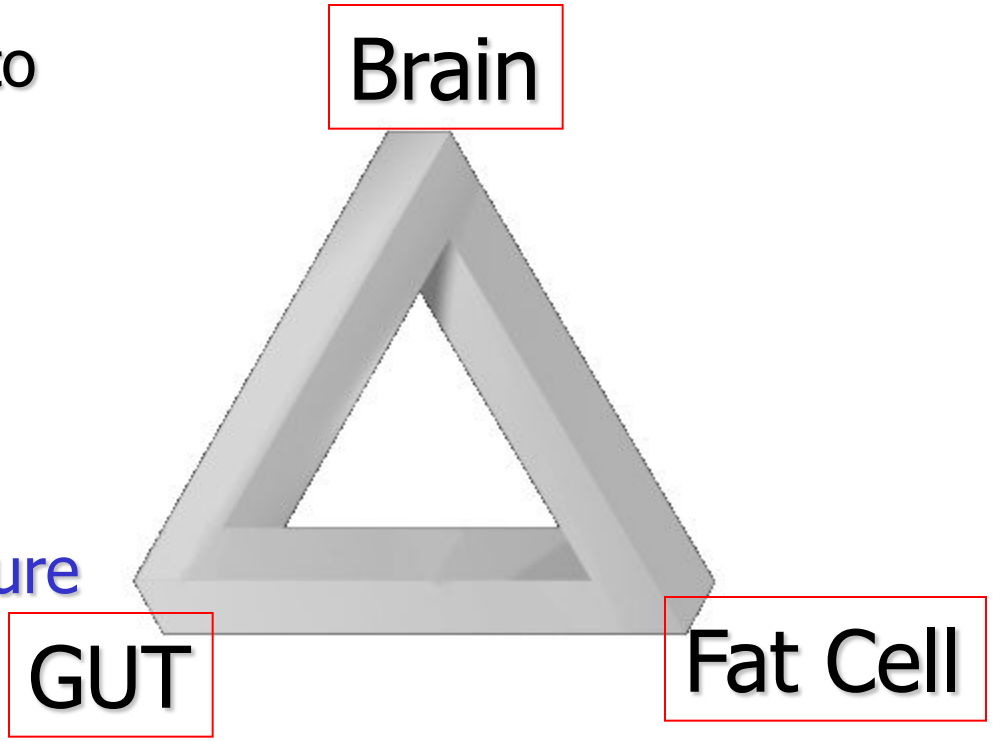
Most Fundamental of All!

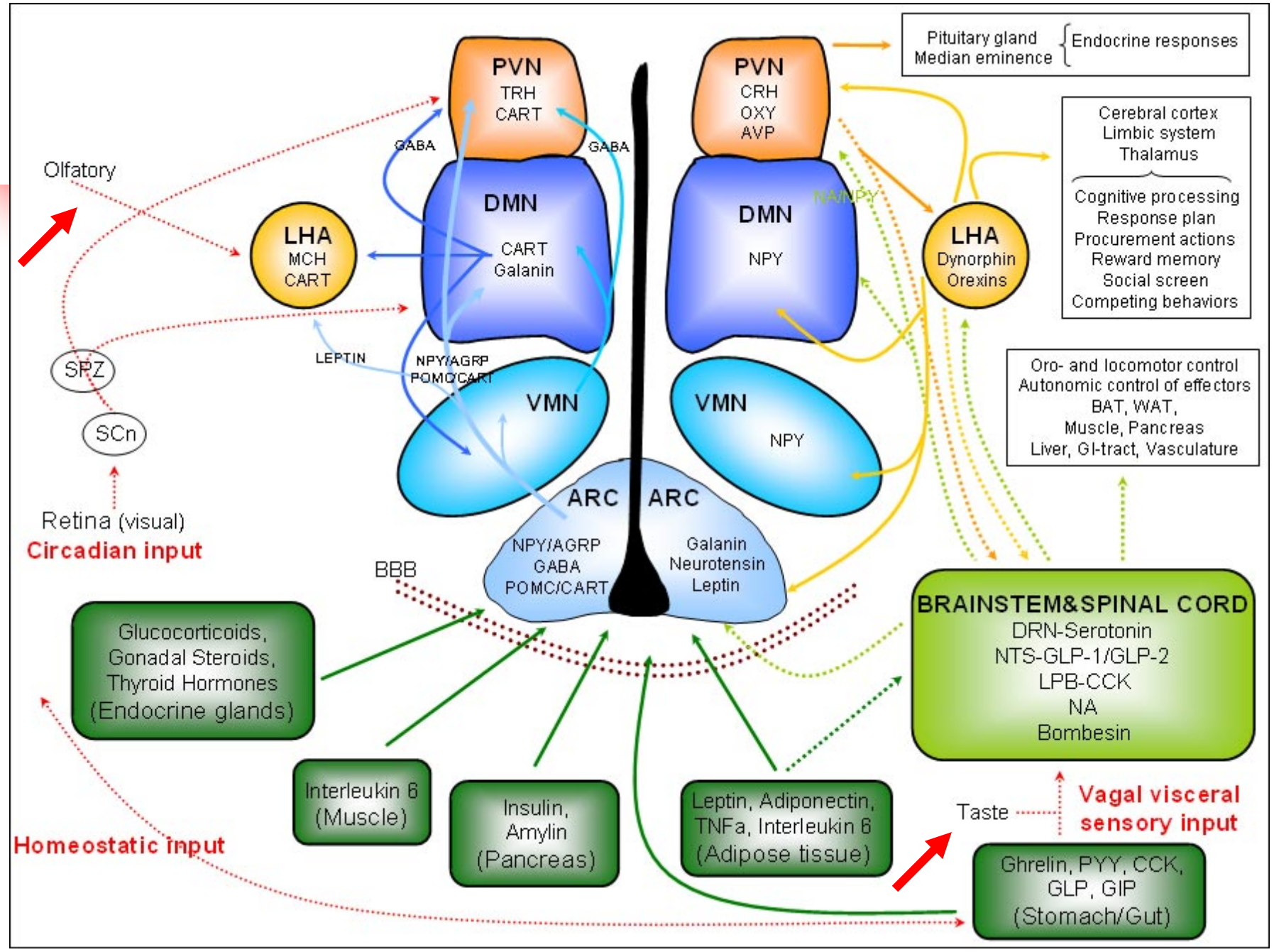
- Brain runs on:
  - Glucose—95% (FAT:ketone bodies)
- Fat Cells Run on
  - Fatty acids and Glucose
- Muscle Runs on:
  - Amino acids-branched chain AA
- Intestine Runs on:
  - Glucose/Amino acids-glutamine

Is Carbohydrate Essential?

Intake Principles

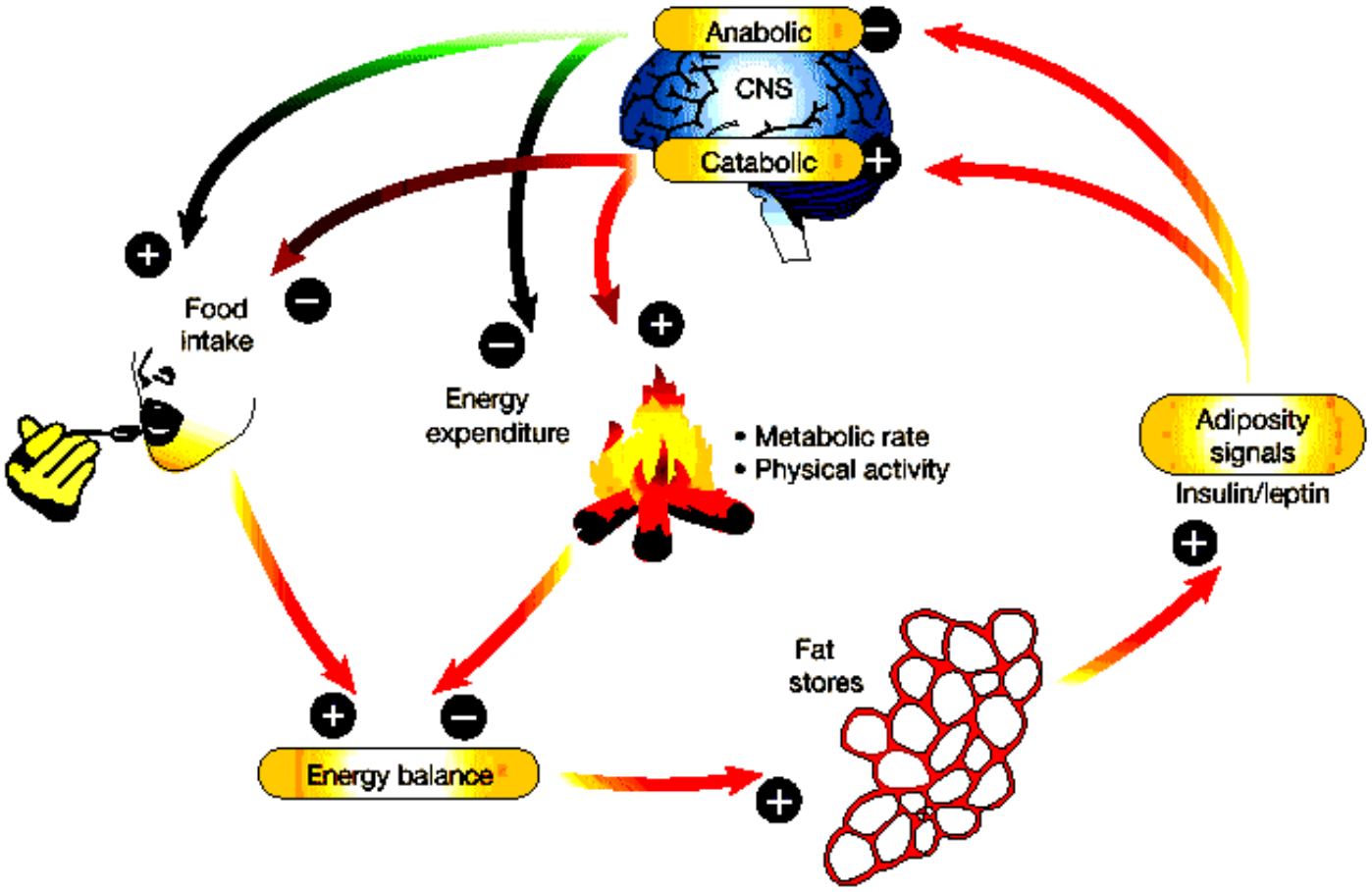
- 1. Brain Designed to Seek Calories (fat)
- 2. Each System Talk to Each Other!
- 3. System is Biased Upward
- 4. System has Long Term Memory
- 5. System uses Pleasure for Control




Pituitary gland
Median eminence
Endocrine responses
PVN
TRH
CART
PVN
CRH
OXY
AVP
GABA
GABA
DMN
CART
Galanin
DMN
NPY
NA/NPY
Olfatory
LHA
MCH
CART
LHA
Dynorphin
Orexins
Cerebral cortex
Limbic system
Thalamus
Cognitive processing
Response plan
Procurement actions
Reward memory
Social screen
Competing behaviors
LEPTIN
NPY/AGRP
POMC/CART
SPZ
SCn
VMN
VMN
NPY
Oro- and locomotor control
Autonomic control of effectors
BAT, WAT,
Muscle, Pancreas
Liver, GI-tract, Vasculature
Retina (visual)
Circadian input
ARC
ARC
NPY/AGRP
GABA
POMC/CART
Galanin
Neurotensin
Leptin
BBB
BRAINSTEM&SPINAL CORD
DRN-Serotonin
NTS-GLP-1/GLP-2
LPB-CCK
NA
Bombesin
Glucocorticoids,
Gonadal Steroids,
Thyroid Hormones
(Endocrine glands)
Interleukin 6
(Muscle)
Insulin,
Amylin
(Pancreas)
Leptin, Adiponectin,
TNFa, Interleukin 6
(Adipose tissue)
Taste
Vagal visceral
sensory input
Homeostatic input
Ghrelin, PYY, CCK,
GLP, GIP
(Stomach/Gut)

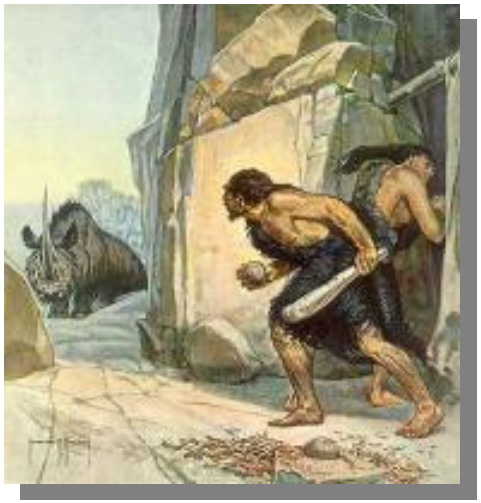
Simplified Food Intake

Chemical Senses



Human Diet Evolution

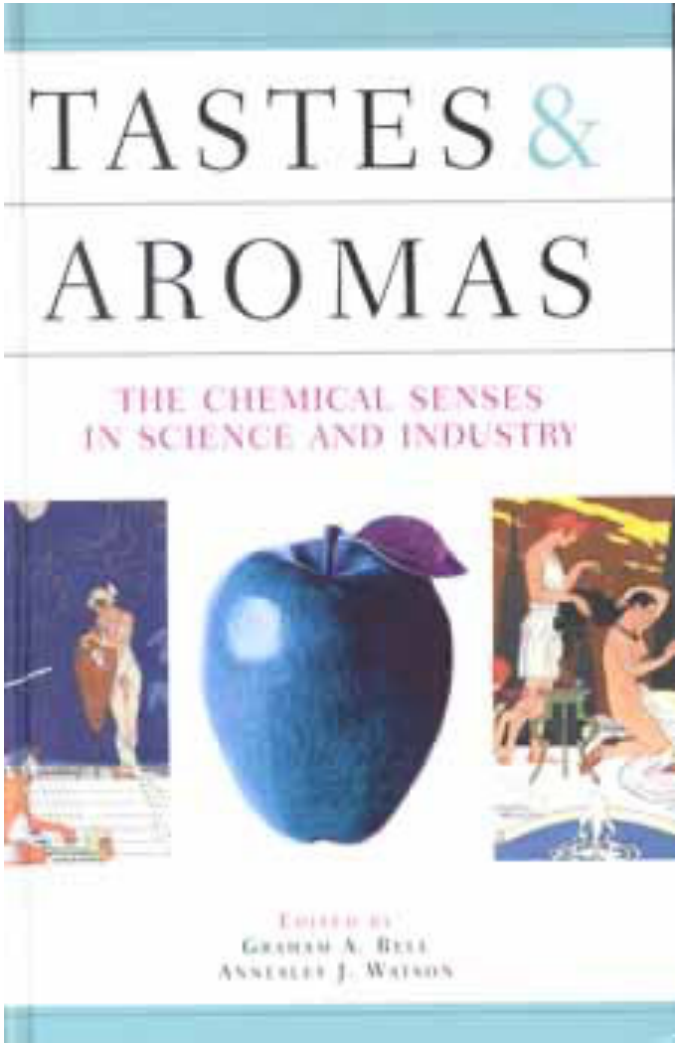
- Salt, fat and sugar scare in Past!



Lean meats, berries, whole grains, vegetables, fruits, honey

Thrifty Gene Hypothesis

Chemical Senses



Chemical Senses Overview

- Sense of Taste
  - The basic tastes
  - Additional taste sensations
- Sense of Smell
  - Aroma sense
  - Trigeminal sense
- Brain Flavor Processing (OFC)

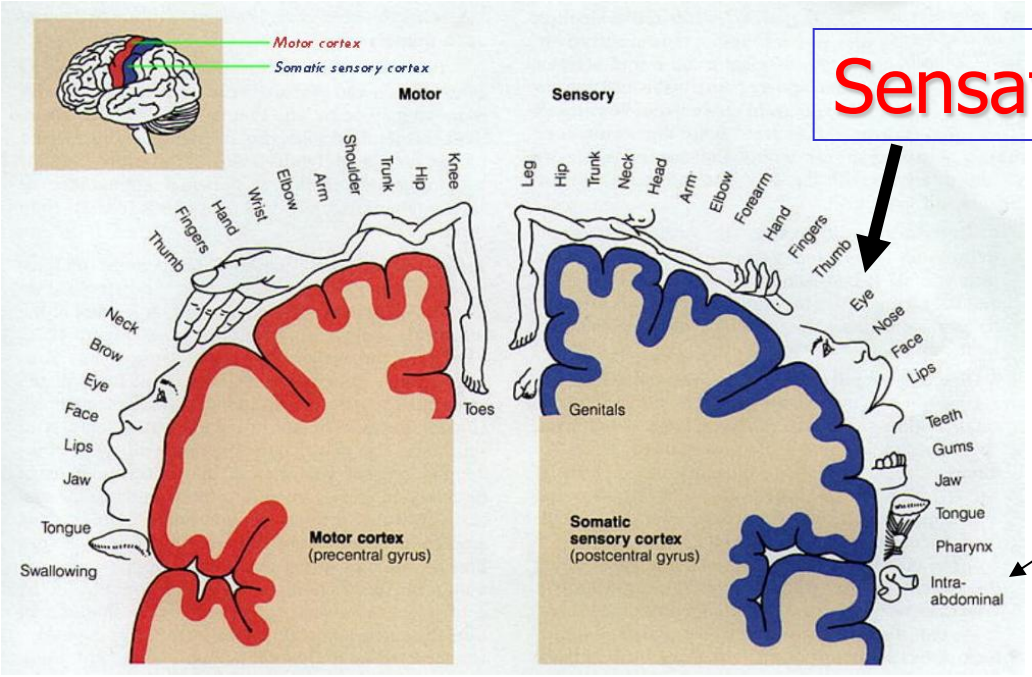
Number of Senses?

- Just the Classic Five?
  - I don't think so!
- More than 20!
  - Erotic skin receptors
  - Positional Sense
  - MSG
  - Heat & Cold Perception
  - Hot Pepper (Vanilloid)

Bruce Durie, New Scientist Magazine

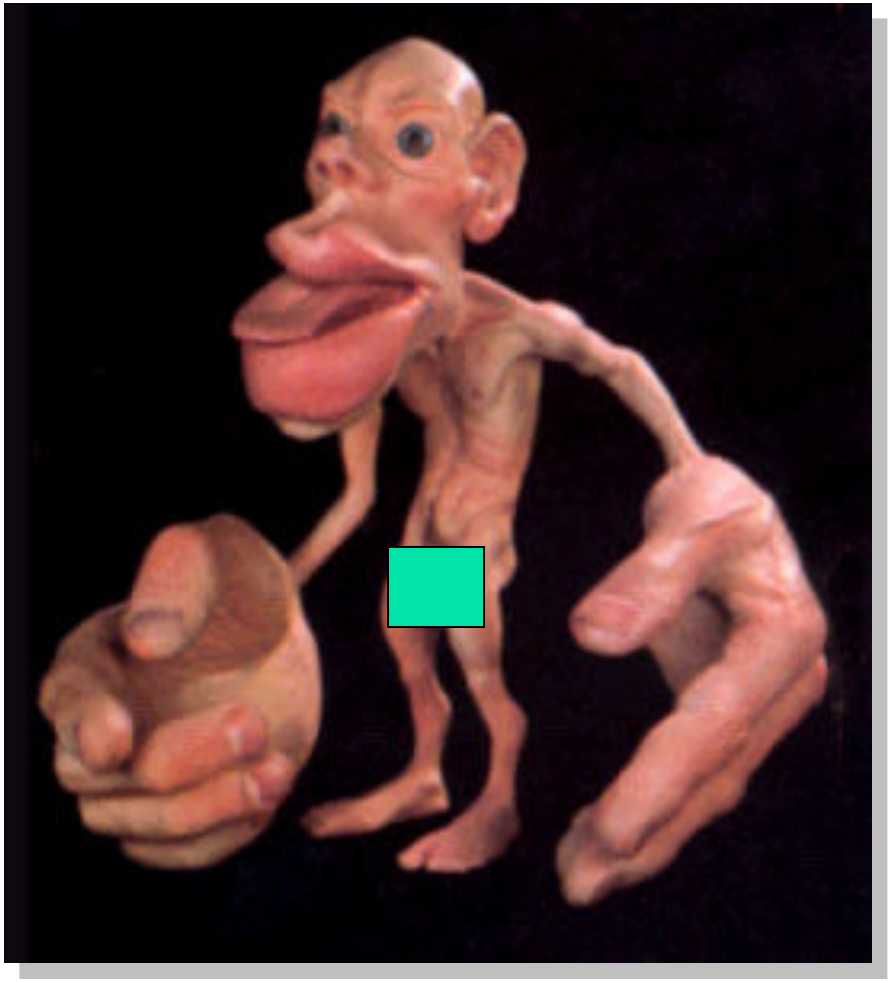
Sensory Homunculus I

- 40% of all sensation from the mouth and face
- Intestines about 5% of sensation



What You Look Like!

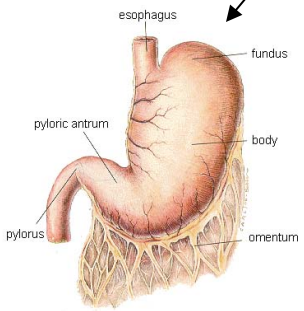
Sensory Input To Brain



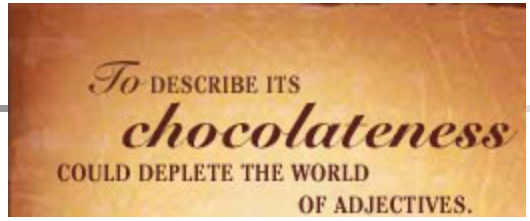
Stomach: 2nd Oral Receptor System

- The stomach contains:
  - Osmoreceptors
  - Sense organs for:
    - Amino acids
    - Fatty acids
    - Glucose
    - Acids
  - Noiciception (vanilloid)
  - Mechanoreceptors
  - Texturoreceptors
- Bodies 2nd chance to evaluate food!

Bitter taste receptors!



Starbucks Chantico: Drinking Chocolate



Liquid Gut Bomb!

Equally rich is Chantico's caloric content. A six-ounce cup of Chantico contains 390 calories, 20g of fat and 50g of carbs.

Sense of Taste

- Motivates and Directs Ingestion
- Differentiates toxins from nutrients

- Nutrition repletion causes hedonic appeal

Scott, Prog. Psychobiol. Physiol. Psy., 15:231 (92)

Taste is Number One

- "However, I can tell you that taste is always No. 1 and food cost is always last"
  - John Buchanan, Lettuce Consulting Group, New Products Mag., feb. 2004
- Good taste drives the ingestion of all food!

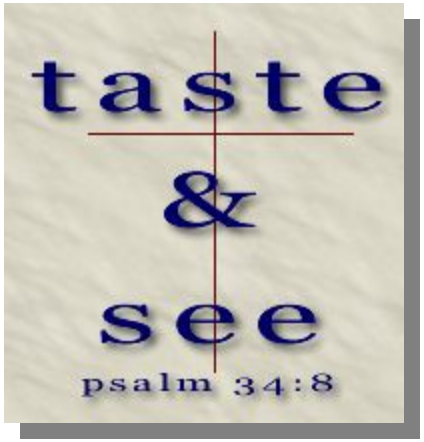
Orosensation-what is it?

- Orosensation (somatosensory)
  - Vast Trigeminal innervation of mouth
    - Texture, Touch
    - Temperature
    - Mouth burn and pain
  - Trigeminal system contributes to both the sensorimotor and motivational control of ingestive behavior (Zeigler)
  - Somatosensation stronger than taste!

8 Basic Tastes, Many Sensations

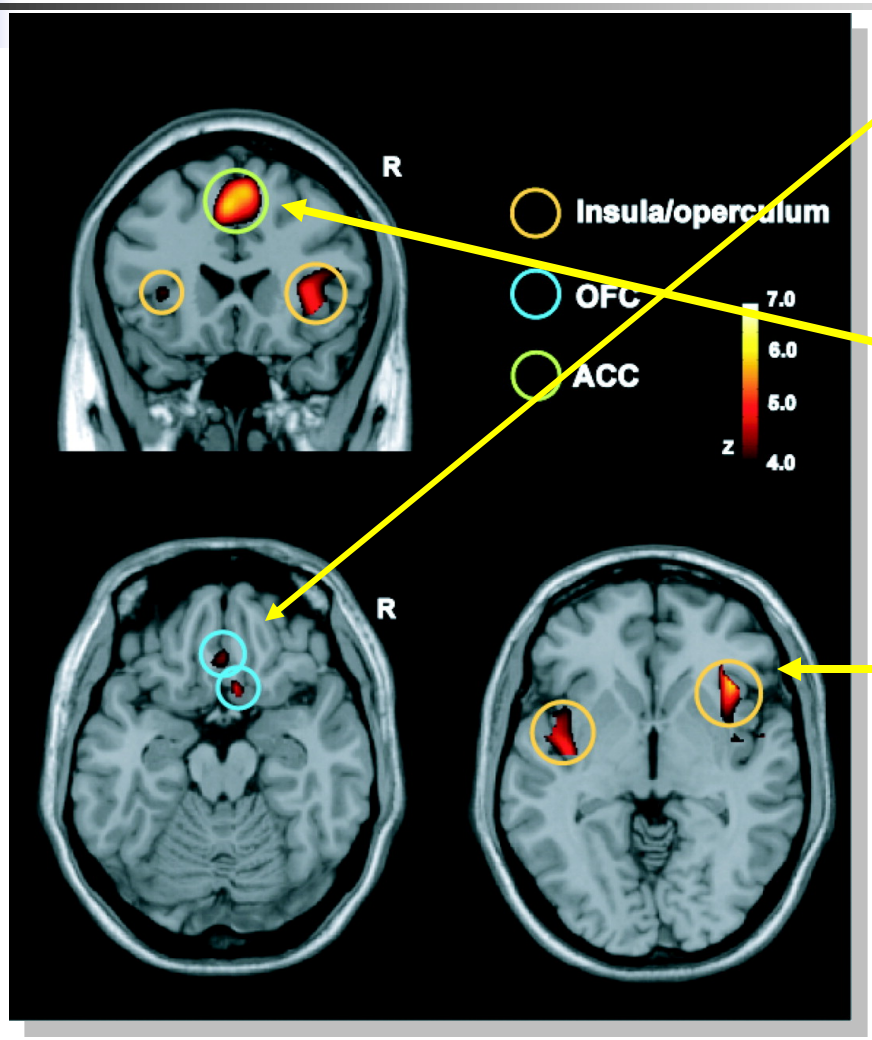
- Hedonic Tastes
  - (1) Salty
  - (2) Sweet
  - (3) Umami
  - (4) Water Taste (Rolls)
- Aversive Tastes
  - (5) Bitter
  - (6) Sour
- Energy Tastes
  - (7) Fatty acid taste?
- Heat Taste
  - (8) Vanilloid receptor

- Taste Sensations
  - Astringent
  - Electric taste
  - Alkaline taste
  - Alcohol taste
- Orosensation (trigeminal)
  - Touch
  - Temperature
  - Pain
  - Pressure



Water Taste!

Innately Pleasurable



Orbital Frontal Cortex:
- Pleasantness

Anterior Cingulate Cortex:
- Secondary taste area
- Emotional connection

Insula:
- Primary Taste Cortex
- Codes Quality & Intensity

ET Rolls

How Powerful is Taste?

- 3rd Most Potent Pleasure stimulator behind:
- Drugs (meth)
- Sex
- Sucrose/Salt

Fat Taste I

- "Orosensory" Perception [Feel]
- "Fat, Fatty Acids activate taste cells in tongue, throat and upper third of the esophagus…sending pleasurable signals to brain.
- "Thrilling Pleasure" (Rolls)

Schiffman, Current dir. Psych. Sci., 7:137 (98)

Mattes/Lermer, Prog. Lipid Res. 38:117 (99)

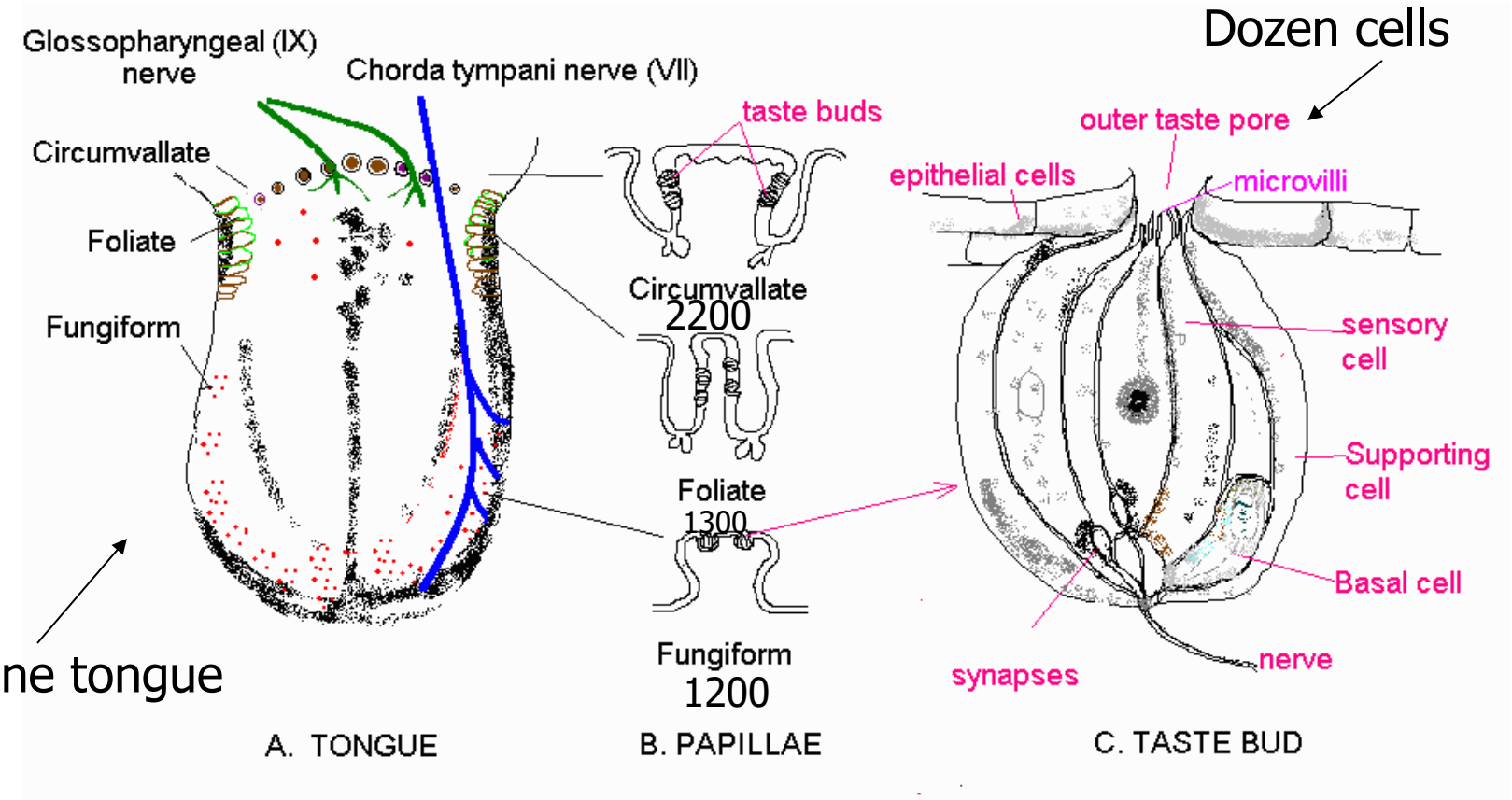
Why the Brain Prefers Fat

- If Glucose runs the Nervous System why does the Brain Prefer Fat?
  - Brain is 65% Fat!
  - Body Can't Store Much Glucose
  - Fat Breaks Down to Glycerol which Converts to Glucose
  - Ketone Bodies are Brain & Muscle Friendly!

Atkin's Diet

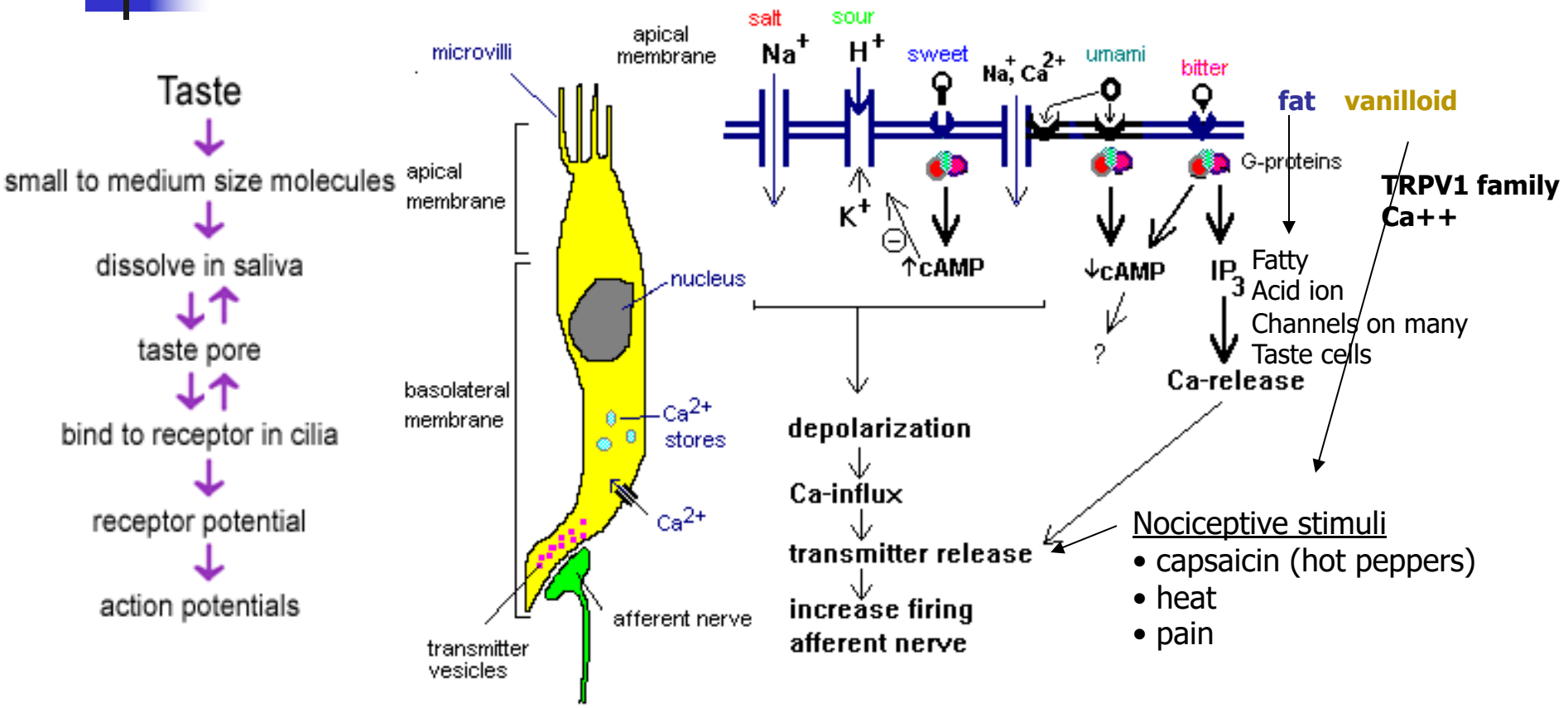
Taste Buds

- 5000 taste buds/tongue
- 30-100 tb's per papillae
- 2500 taste buds elsewhere in mouth



http://www.cf.ac.uk/biosi/staff/jacob/teaching/sensory/taste.html

General Taste Transduction



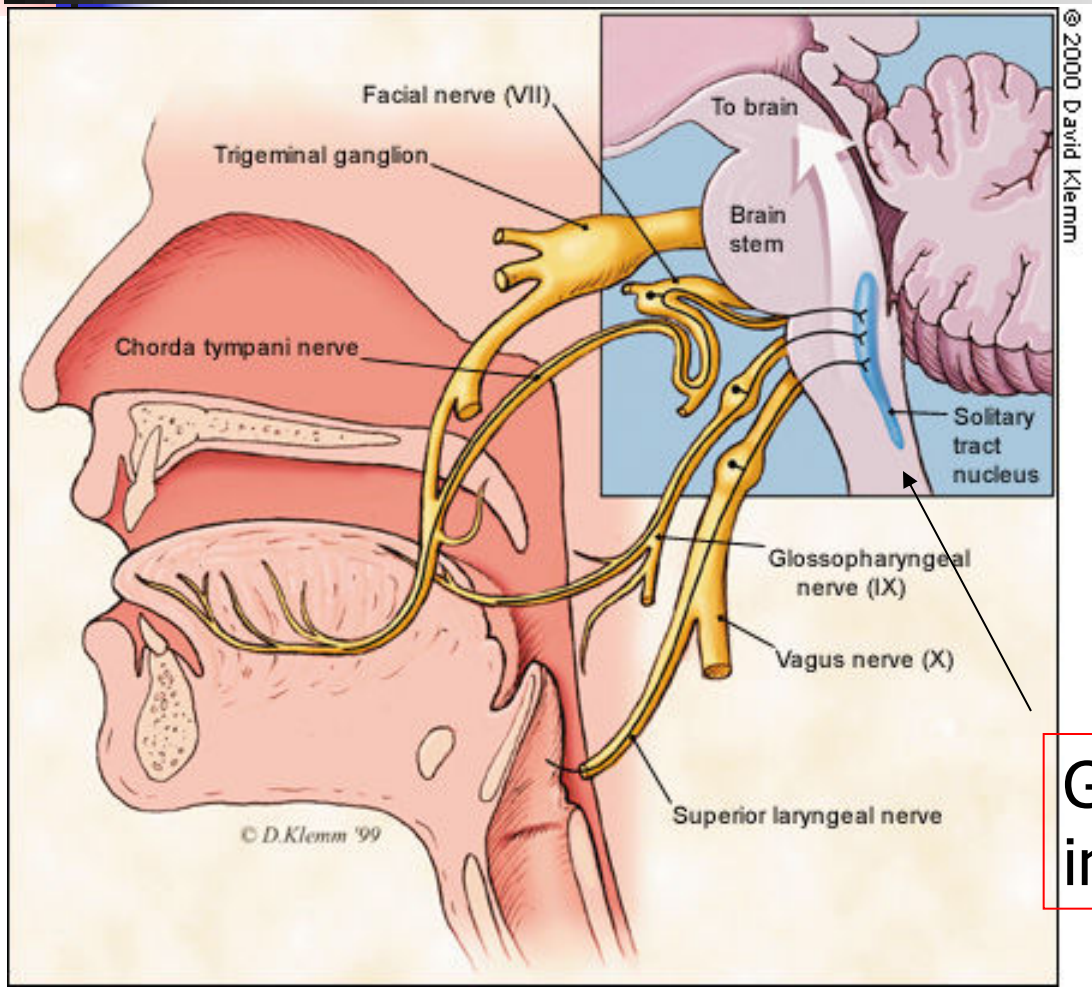
http://www.cf.ac.uk/biosi/staff/jacob/teaching/sensory/taste.html

Taste & Individuality

- Single gene codes multiple taste receptors
- Some feel that taste evaluates metabolic consequences!
- Wide variation in Bitter Perceptions
  - 100's of different genes!
  - Basically: taste vs non-taster

Current Biology, Feb 22, 2005

Taste Pathways



•The **Gustatory Nucleus** receives projections from the taste buds of the tongue via cranial nerves VII (facial nerve), IX (glossopharyngeal nerve), and X (vagus nerve). The paired gustatory nuclei are located in the medulla, and are often called the ***solitary nuclei*****.** Neurons within these nuclei encode the acceptability of a taste as well as its quality. For example, dangerous sour and bitter substances are encoded as bad tasting and are spit out, while life-sustaining sweet and salty substances are encoded as good tasting and are swallowed.

• The **gustatory nuclei** send profuse projections to a number of brain regions including the pons, lateral hypothalamus, amygdala, ventral posterior thalamic nucleus, and the primary and secondary gustatory cortical regions. Gustatory projections to the hypothalamus (**pleasure center**) may play a role in the reinforcing effects of sweet and salty tastes when we are hungry.

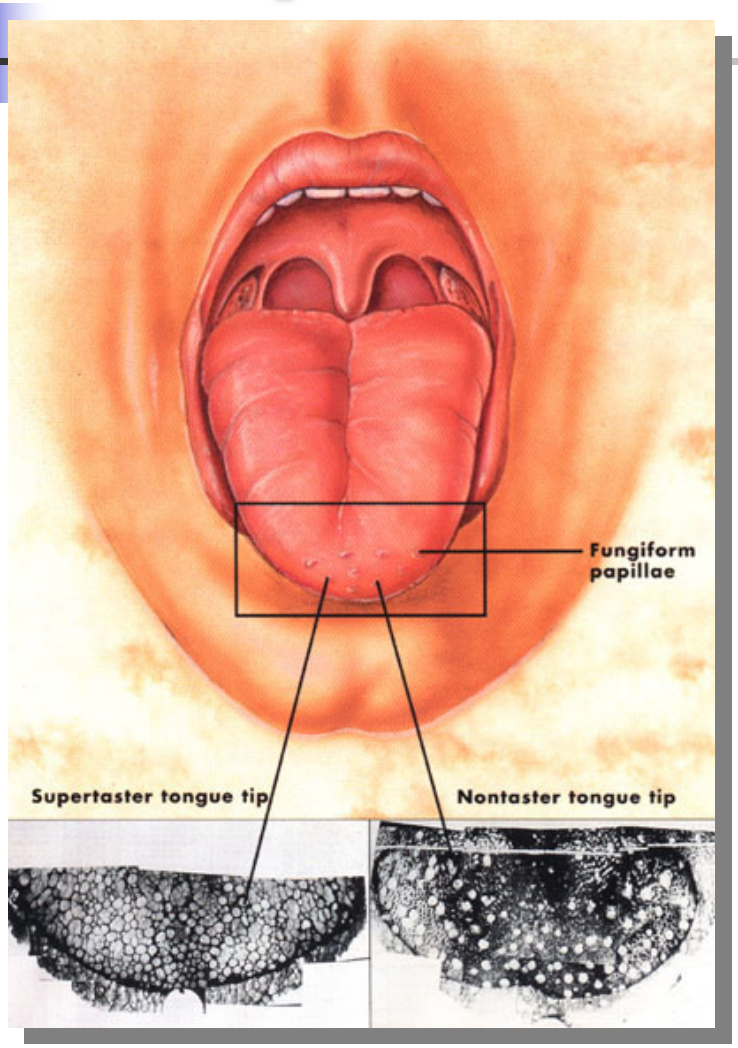
Gastrointestinal input into solitary nuclei!

Sensory Variability

"We live in our own sensory world - individual differences in sensory functioning…even with simple aromas and flavors…will not be similarly perceived as acceptable."

David Mela, Prepared Foods, July, 1996

Supertasters



Supertasters have higher number of Taste buds…foods In general are too intense for these folks. Beware of these People in taste panels

Photos courtesy of Linda Bartoshuk, Ph.D.
Yale. Illustration by Lydia Kibiuk.

Supertasters and Pleasure

- Individuals sensitive to [PROP]
- Groups: non, medium, supertasters
- ST = greater oral sensation
  - Linked with Food aversions
  - Bitter vegetable rejection
  - High Fat perception

Bartoshuk, Neurosci & Biobeh. Review 20:79 (96)
Drewnowski, Ann. NY.Acad. Aci., 855:797 (98)

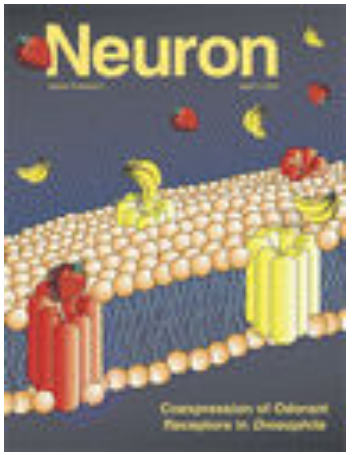
Taste & Self Stimulation (SS)

- Taste stimuli activates same area as activated by SS" (Stellar & Stellar 1985)
- Relation between sweet taste and drug reward
  - Am J Clin Nutr. 2003 Oct;78(4):834S-842S
- **Insular Cortex** combines: Gut+Taste+Reward Signals.
  - Brain Res. 2000 Jul 28;872(1-2):134-40

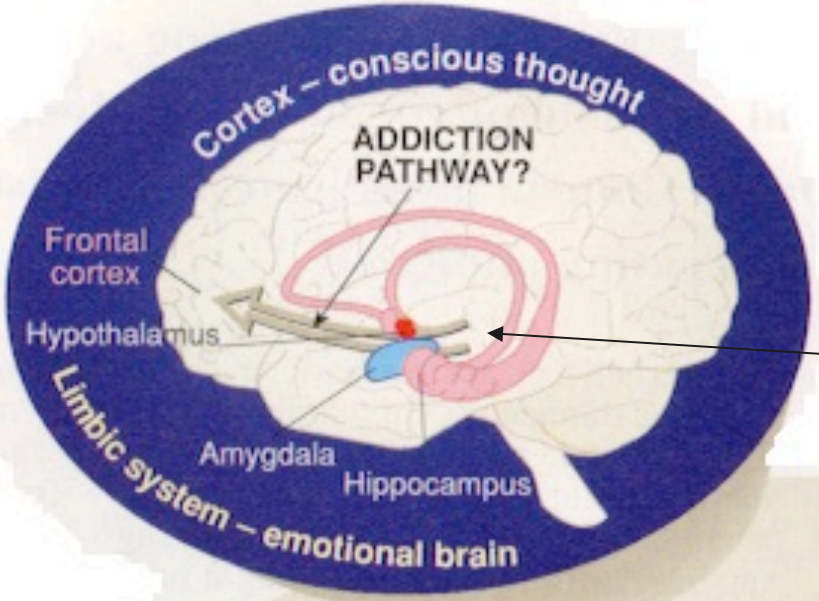
Taste direct access to pleasure!

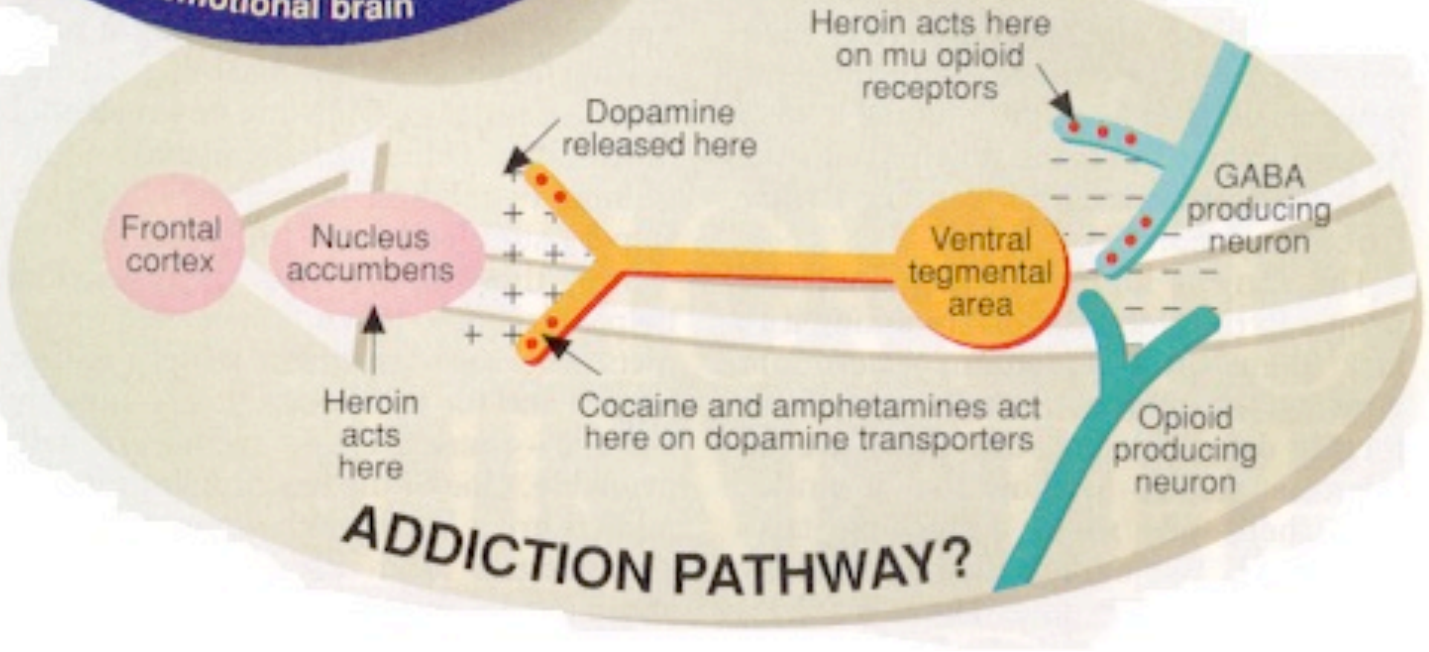
Pleasure Center & Food Choice

- Nucleus Accumbens:
  - Codes for Taste Pleasure
  - Part of Pleasure/Memory Circuit
  - Rewarding and Aversive Circuits



Medial Forebrain Bundle

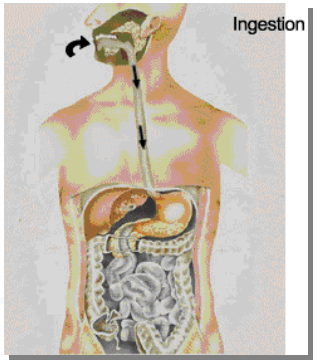




Function of Tastes

- Prepare Body for Ingestion
- Encourage eating thru pleasure
  - Sugars, Fat the biggest pleasure whack
- Select toxins from foods
  - Most bitter compounds are poisonous
- Ensure adequate caloric ingestion
  - Sense high calorie foods
- Ensure proper nutritive ingestion
  - Eat protein (MSG or umami taste)
  - Essential fatty acids taste
  - Vitamin C
  - Glucose for the neurons

Taste Drives Ingestion



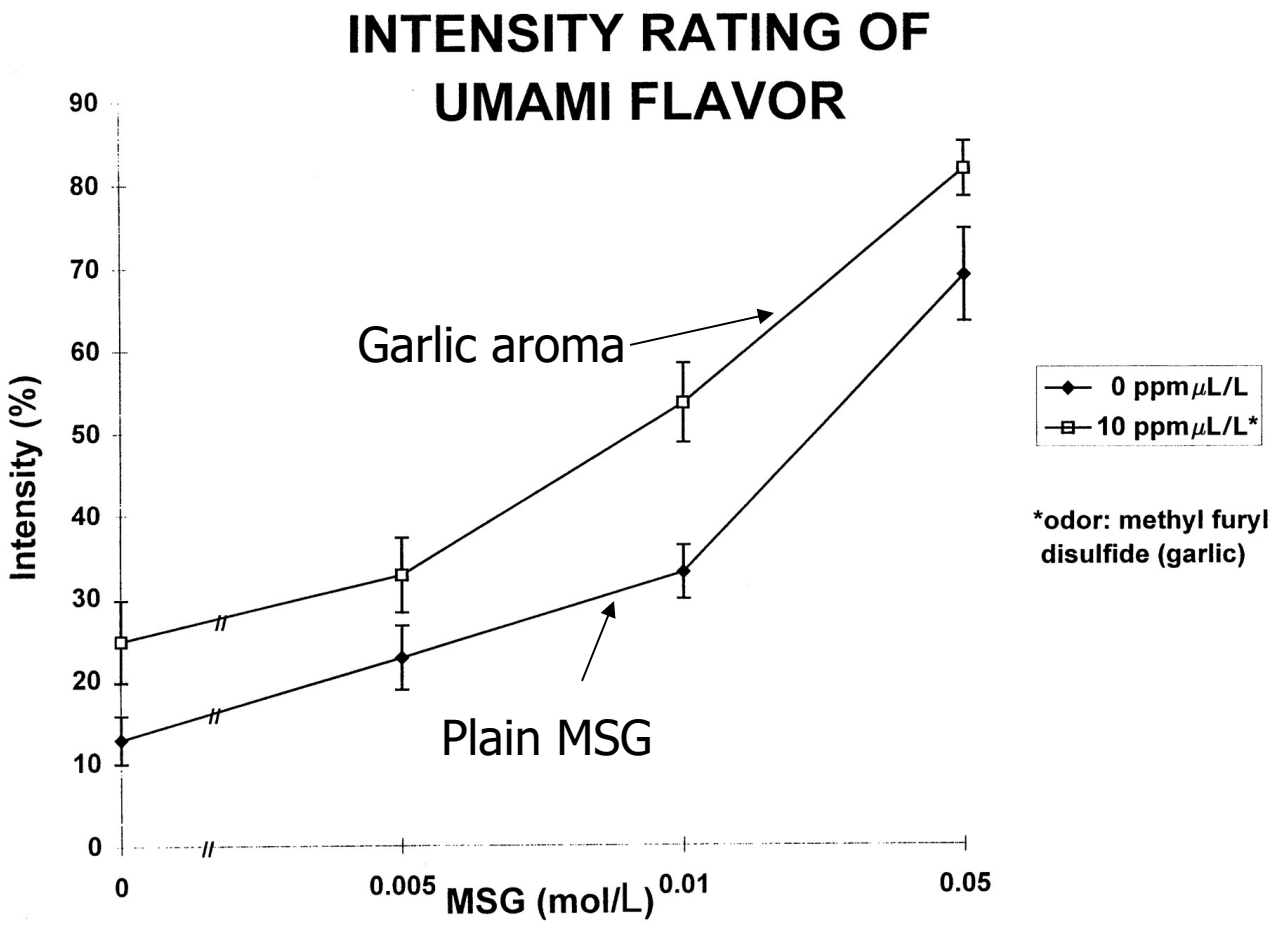
- Taste drives ingestion and way out of proportion to the other elements of food
- Taste is the #1 reason for food purchase
- Low salt foods simply cannot be made tasty (maybe Cardia salt)

Hedonic solutes

- NaCl (huge)
- Sugars, hi intensity sweeteners
- Umami:
  - MSG
  - 5 prime nucleotides
  - **Garlic** derivatives
- Flavorants:
  - Lactones
  - Maltols
  - Chlorogenic acids
  - Many taste-active flavor compounds

Amino acids
Peptides
Fatty acids
Glycoconjugates
Maillard comps

Garlic boosts Umami



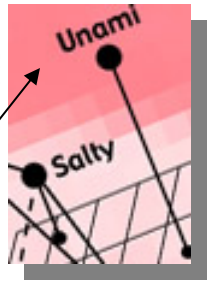
Sugar and Fat Pleasure

- Pleasure magnified when mixed with fat (1)
- Ventral striatal medium spiny neurons mediate the affective or hedonic response to food ('liking' or food 'pleasure‘)
- Heroin, morphine, alcohol, and cannabinoids, interact with this system

(1) Emulsion pleasure theory

MSG Coated Salt (Aji-Shio)

- MSG Coated salt (10% MSG)
- Absolutely wonderful salt
- And, I think, very addicting!



That should be umami!

Foods High in MSG

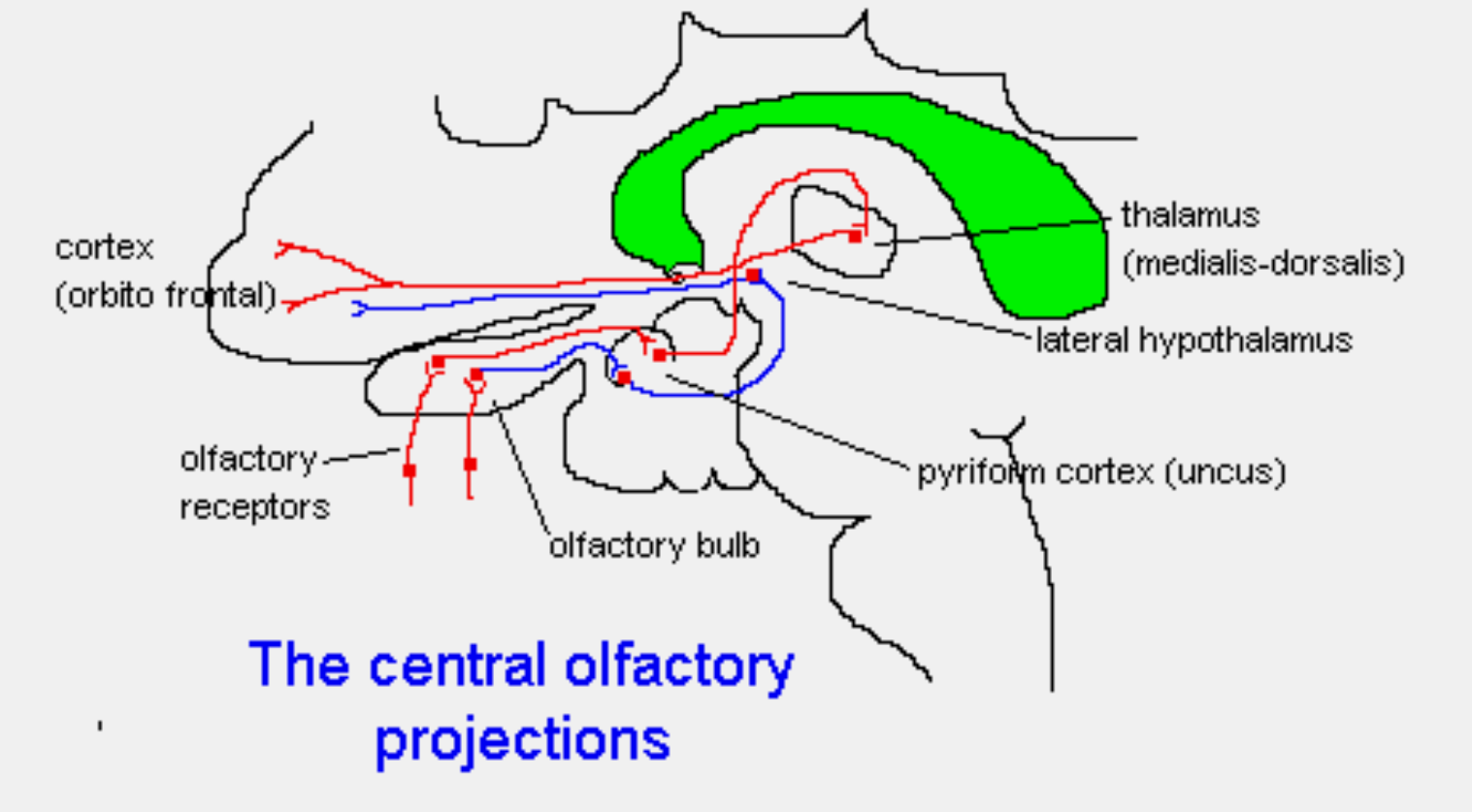
- Many preferred food are naturally high in MSG:
  - Soy Sauce
  - Parmesan cheese
  - Tomato
  - Potato
  - Breast Milk!
  - Sardines
  - Fish Sauces

Taste & Doritos

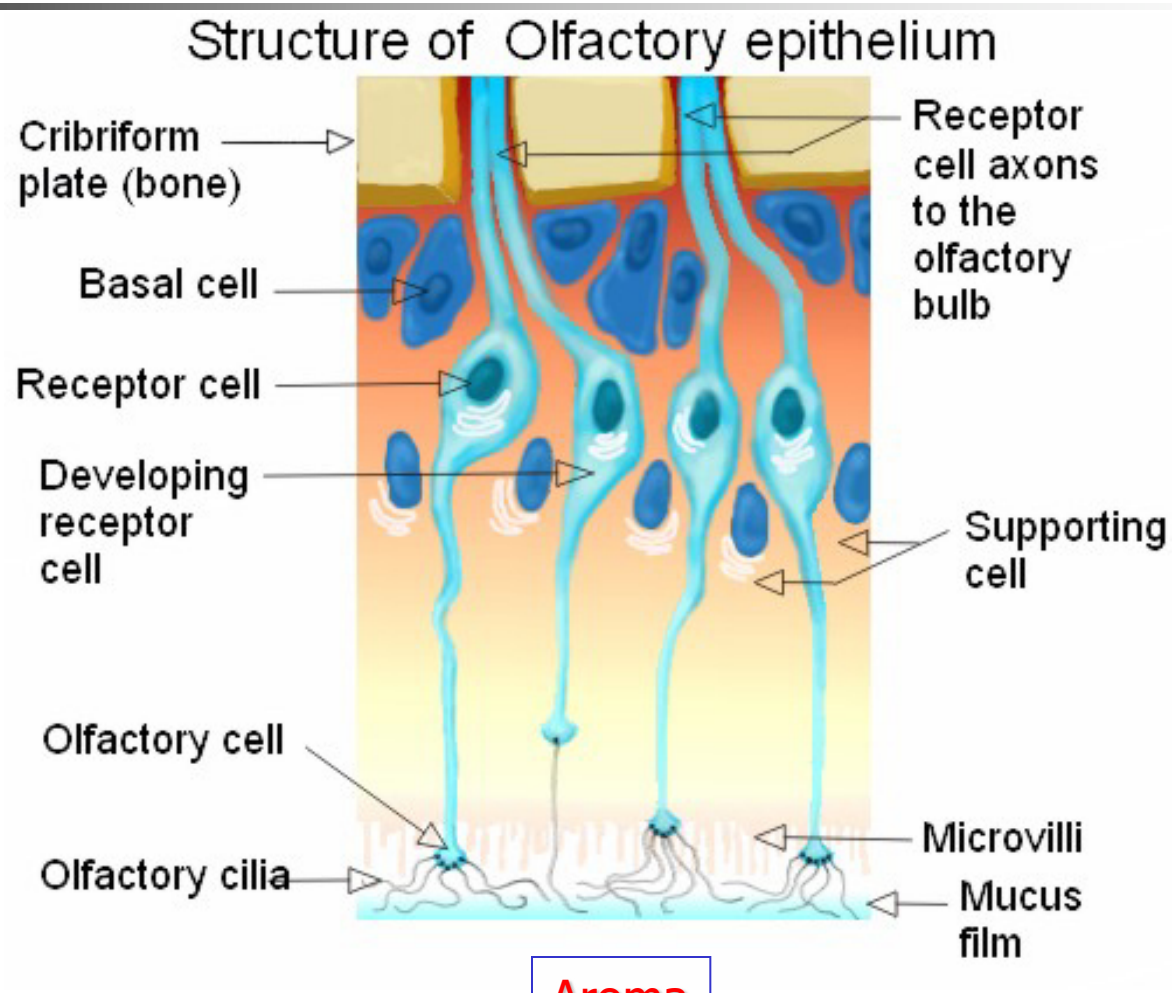
- Loaded with Taste Active Compounds
  - Salt
  - Sugars:
    - Dextrose
    - Sugar
  - Acids
  - 5’Nucleotides
  - Monosodium glutamate

No Salt Chips?

Olfaction


cortex
(orbito frontal)
thalamus
(medialis-dorsalis)
lateral hypothalamus
olfactory
receptors
olfactory bulb
pyriform cortex (uncus)
The central olfactory
projections

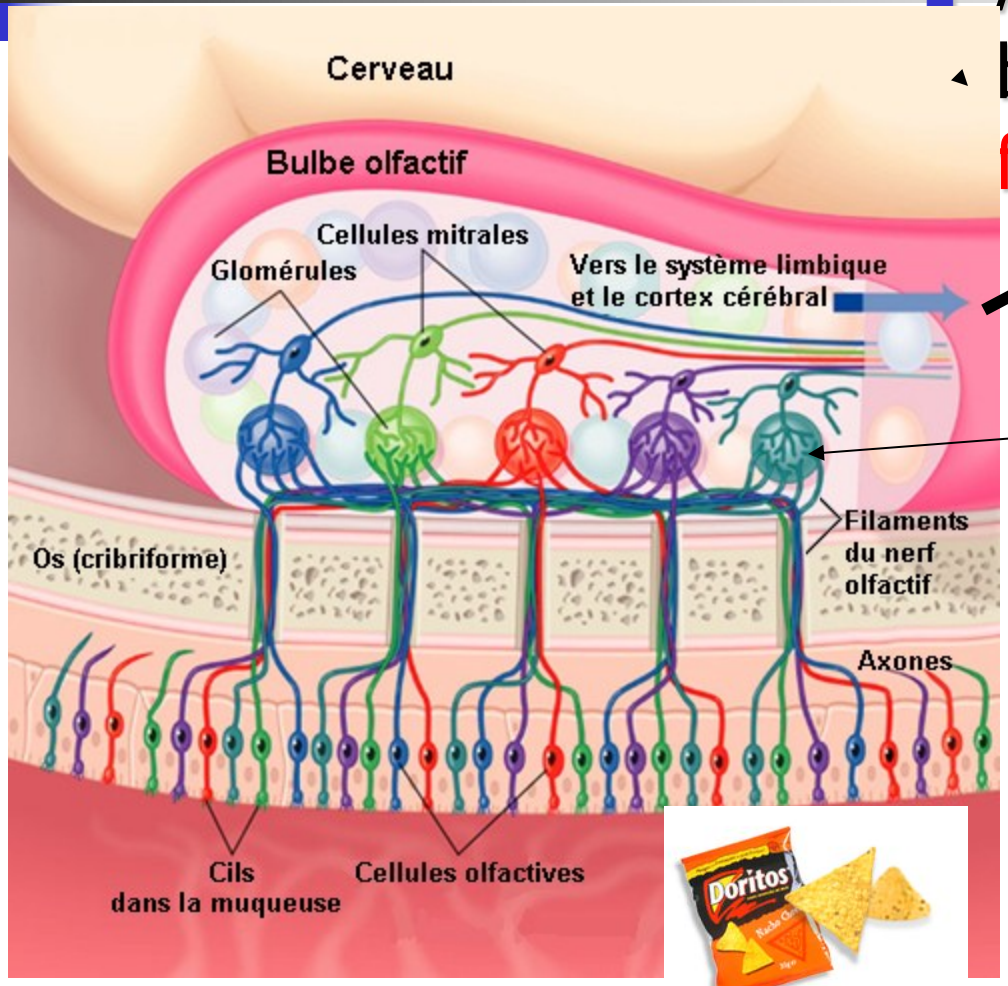
Sense of Smell- basics



Aroma

Olfaction Brain Pathways

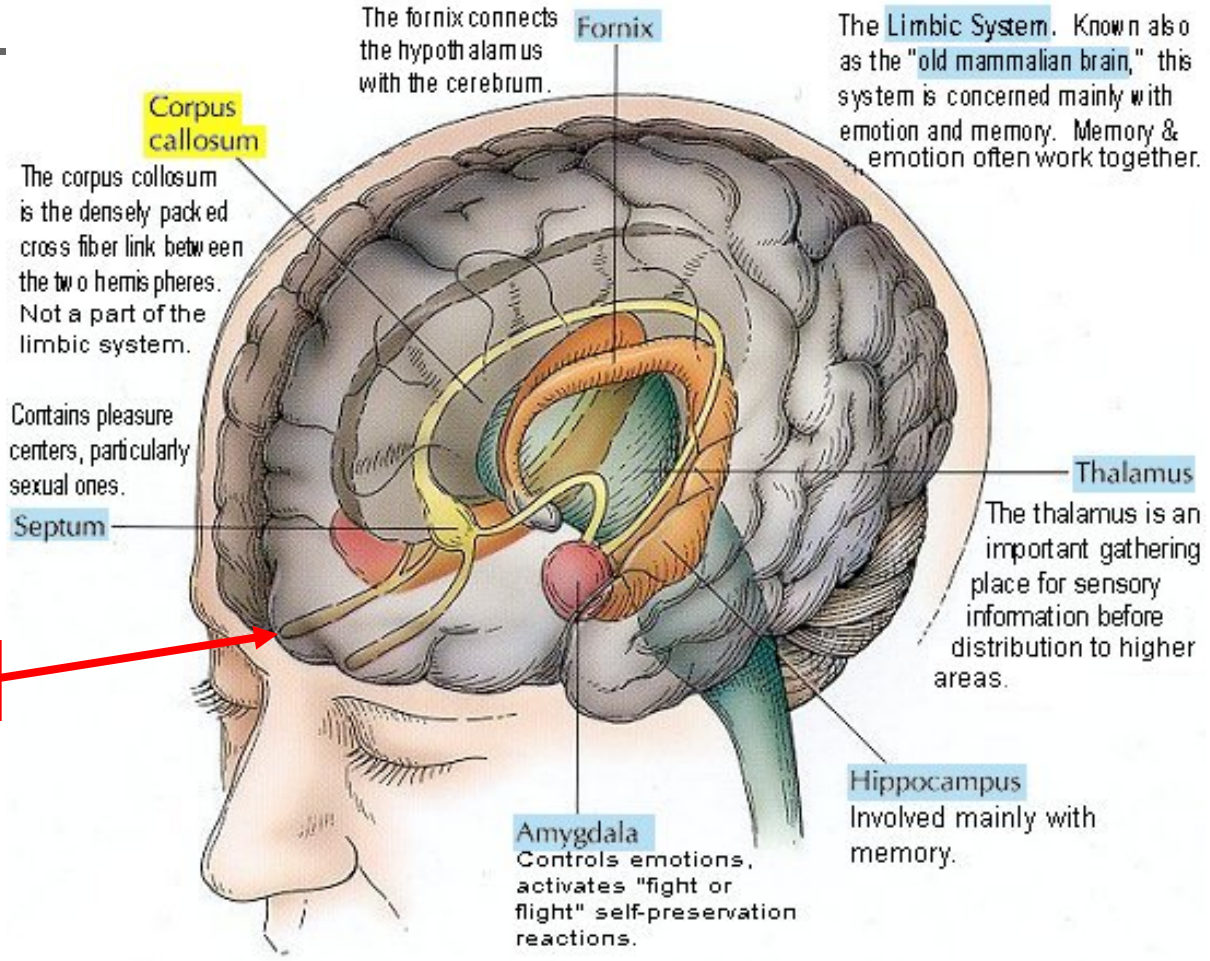
- Aromas processed by the limbic system first!



10,000 Glomeruli

40 million receptors

Limbic System



The major brain structures associated with the limbic system

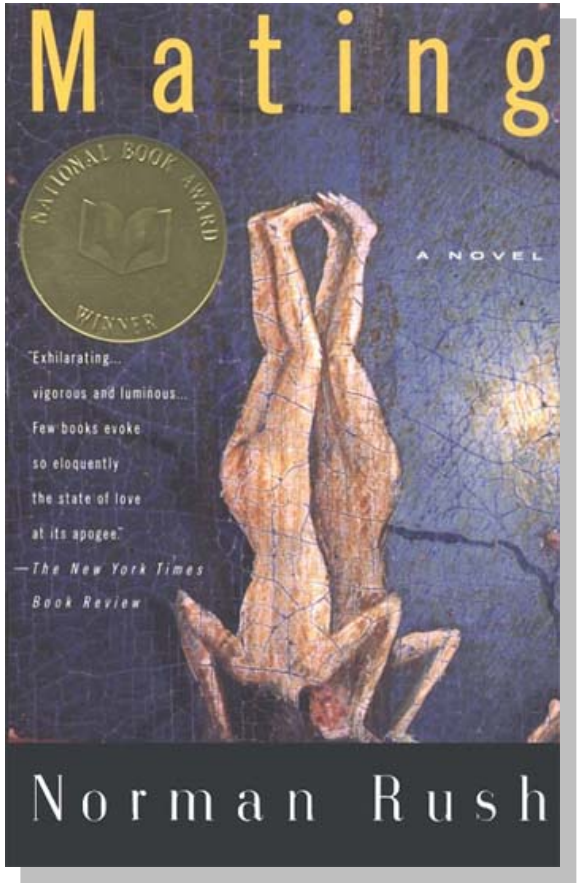
Olfaction

- Aroma:
  - Importance Depends on Significance!
  - Taste & Aroma Special Place in Brain!

Major function

Olfaction: Most Important

- Food Selection
- Mate Selection!
- Best Mate Smells:
  - Different Genes

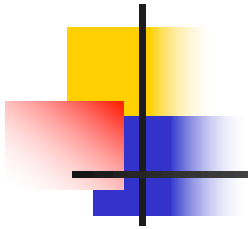


Olfaction Puny in Humans!

- Human:
  - 40 million receptor cells
- Rabbit:
  - 100 million receptor cells
- Dog:
  - 1 Billion!

PUTRID?


GARBAGE
FLAVOR
PUTRID
CAT CHOW
The HIGH SMELL
Cat Food
*©T.C.G., PRTD. IN U.S.A.



Are Some Aromas Innate?

Aroma & Epigenetic Programs

- Fruity means Vitamin C?
- Fires mean Food?
- Putrid means Death?
- Vanilla means Bonding?

Sense of Smell Principles

- Odorants bind to mucous, must be both fat and water soluble
- 1000 (450) olfactory receptors
- Aromas acquire significance thru food ingestion—forms food memory
  - Fat and sugar best form memories!
- Almost all aroma preference learned
- Once formed aromas resistant to extinction
- Bad aromas remembered better than good
  - Light up motor cortex!
- FLAVOR: Taste + Smell in Orbitofrontal Cortex

Function of Taste & Smell

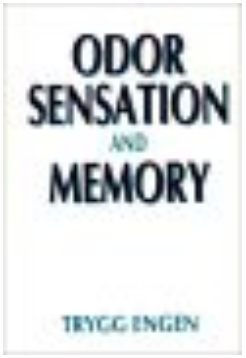
- Once bees taste nectar they memorize how they got there!

J Exp Biol. 2004 Dec;207 (Pt 25):4371-81.

Eat a Food, Memorize the Room!!!

Odor Memory

- Hedonic Perception in Right Hemisphere
- Odor Memory in Left Hemisphere



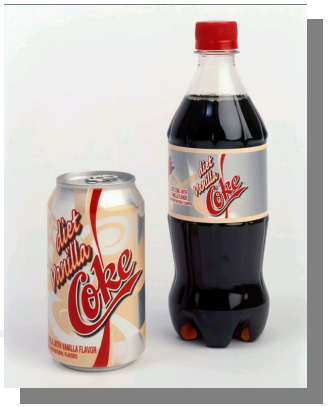
Dr. Linda Buck, Cell, 96:1 (99)

Why Do People like Spicy Food?

capsaicin & heat & acid

- Hot peppers were domesticated faster than any other plant (besides……???)
- Capsaicin excites vanilloid receptors for heat or hot taste (lots or receptors in mouth)
- PAIN induces (1) endorphin surge
- Releases (2) cannabinoids!

Vanilla Theory (SAW)



- Why do People like Vanilla Aroma?
- Here, perhaps is the answer:
  - Potent Antioxidant (Good for Tissues)
  - Stimulates Vanilloid Receptors (hot food)
  - Brain Never Tires of Vanilla aroma:
    - "…the OFC decreased after satiety to…banana aroma, but NOT in response to a vanilla odor"
    - No Sensory Specific Satiety!

Brain (2001), 124, 1720-33.

Vanilla ROCKS

Vanilla Coke

- Why is it so Popular?

Vanilla & Breast Milk

- Vanilla does not Habituate!!!!
- The Aroma of Breast Milk is Mostly Vanilla!

Equivalence!!!

=

Aromas & Brain Stimulation

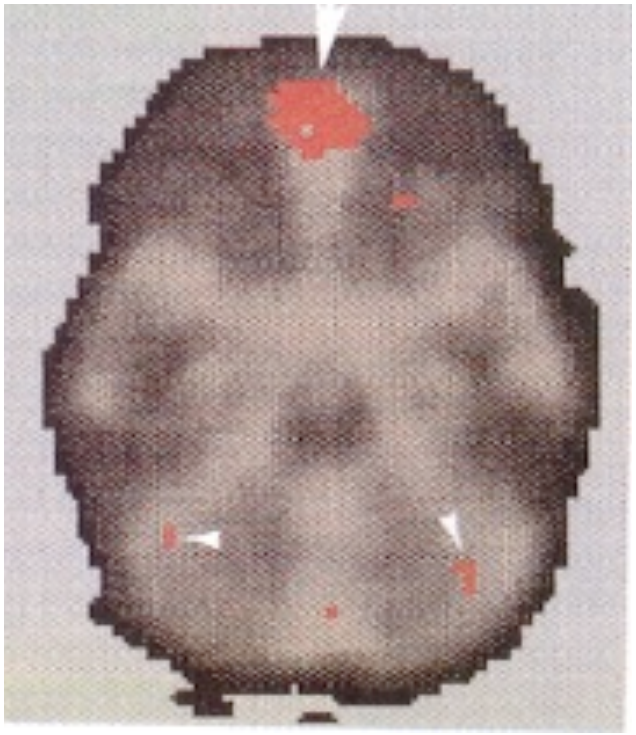
- Aromas: Orbitofrontal Cortex (Right)
  - Repeat Testing = ↓ activity
- Trigeminal Aromas: Widespread brain activation.
  - Repeat Testing = ↑ activity

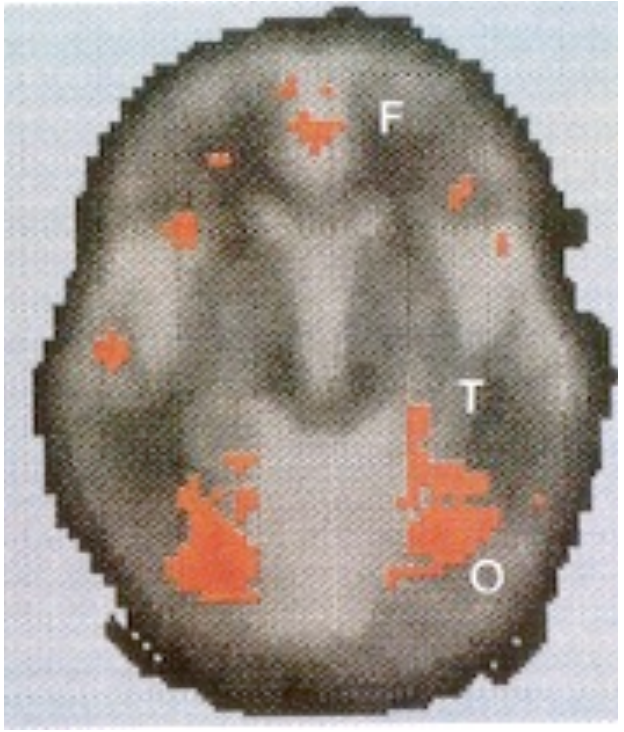
∴ Aroma + Trigeminal Aromas = 6X Activation

Yousem, Radiology, 204: 833 (97)

Aroma Only

Trigeminal+Aroma





Methylsalicylate

Rosemary

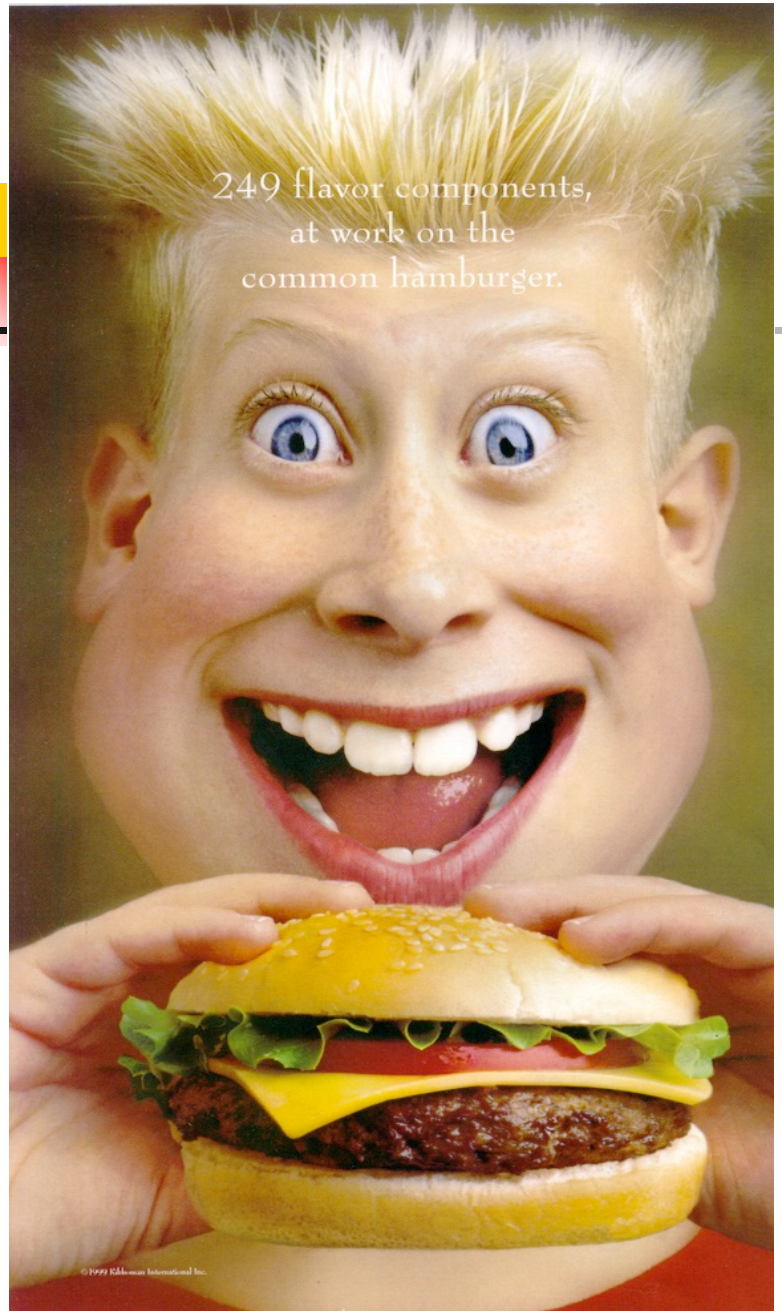
Food Palatability Theories

- SuperNormal Stimulus
  - Wilson
- Sensory Specific Satiety
  - Rolls
- Taste Aversion Learning
- Dynamic Contrast
  - Hyde & Witherly
- Food Pleasure Equation
  - Witherly & Capaldi

Super Normal Stimulus (SS)

1. Increased attention to stimuli that are scarce and essential
2. SS stimulus: exaggerated consummatory response
3. SS is innate and resistant to extinction

E.O. Wilson "Consilience", 1998

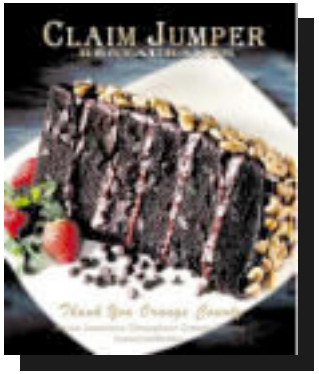


249 flavor components at work
On the common hamburger

Typical Reaction to a SuperNormal Stimulus

Super Normal Stimulus

Exaggerated Response to Significant Stimuli in the Environment



The "Claim Jumper Effect"

E.O. Wilson

Six Dollar Burger!

- They actually received an award for this!

And now they Have a double Meat version

Over 900 Calories!!! Yikes!!!

SuperNormal Stimulus

Double Whopper!

- 1150 Calories!!!

SuperNormal Stimulus

Sensory Specific Satiety*

Huge Importance to the Food Industry!

No One Knows!

*Variety Effect

Sensory Specific Satiety (SSS)

- Change in hedonics, not intensity, through exposure to sensory stimuli
- Repeated tastings reduce food pleasantness
- Sensory Specific (Taste, Aroma, Visual, Texture)

Orbitofrontal Cortex

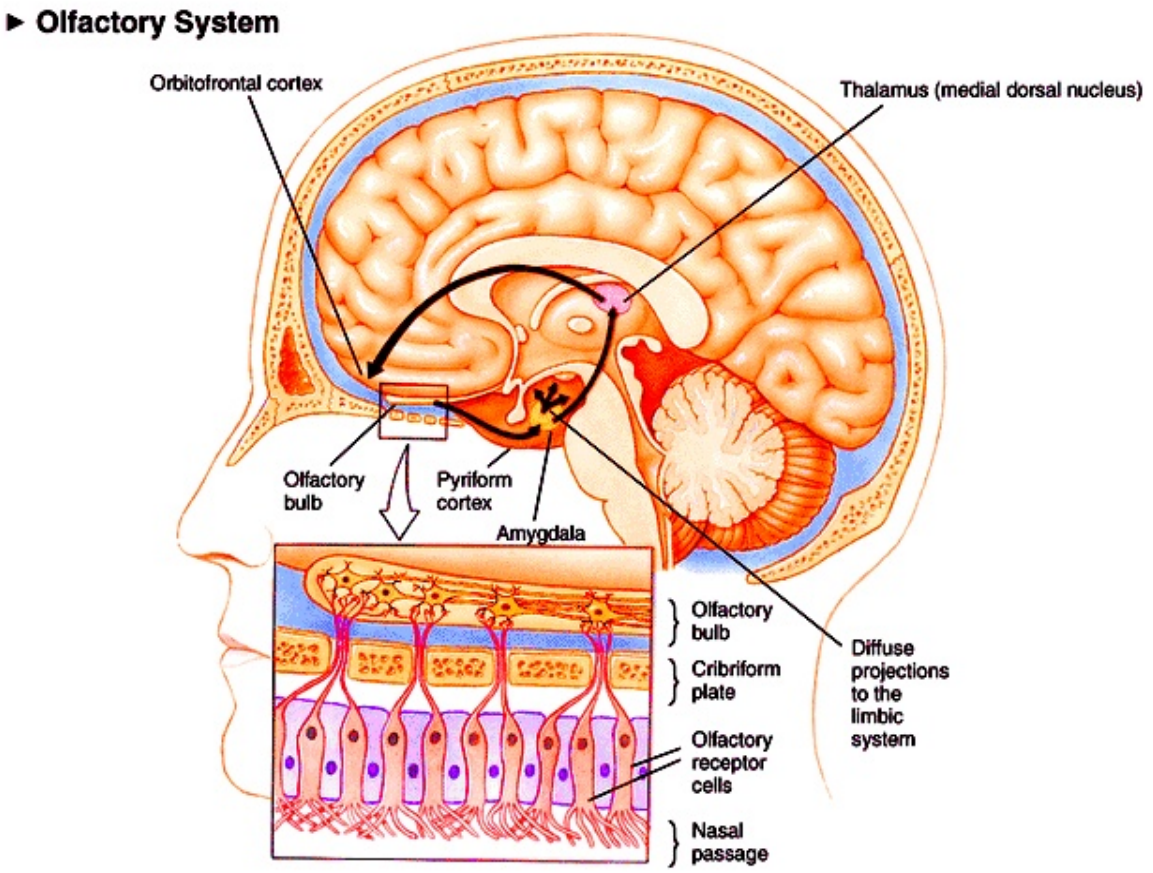
- Some aromas **resistant** to extinction!
- Non-Trigeminal aromas:
  - Vanilla
  - Baked or fried potato
  - Popcorn

Vanilla outsells Chocolate Ice cream two to one!

SSS Physiology

Orbitofrontal Cortex

Pleasure Center



Dynamic Contrast Theory

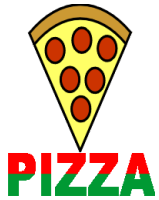
- "Foods with sensory properties that change rapidly or have major sensory contrasts are ones that are preferred—Hyde & Witherly"
- Most rewarding and reinforcing stimuli are those that change *rapidly*
  - *Robinson & Berridge 2003*

Dynamic Contrast Theory

- Chocolate:
  - Goes from solid to liquid at body temperature. Allows hedonic solutes to be released. Few fats can do this!
- Popcorn:
  - Melts down extremely fast in the mouth releasing flavor and hedonic solutes without causing much satiety.

High Dynamic Contrast Foods

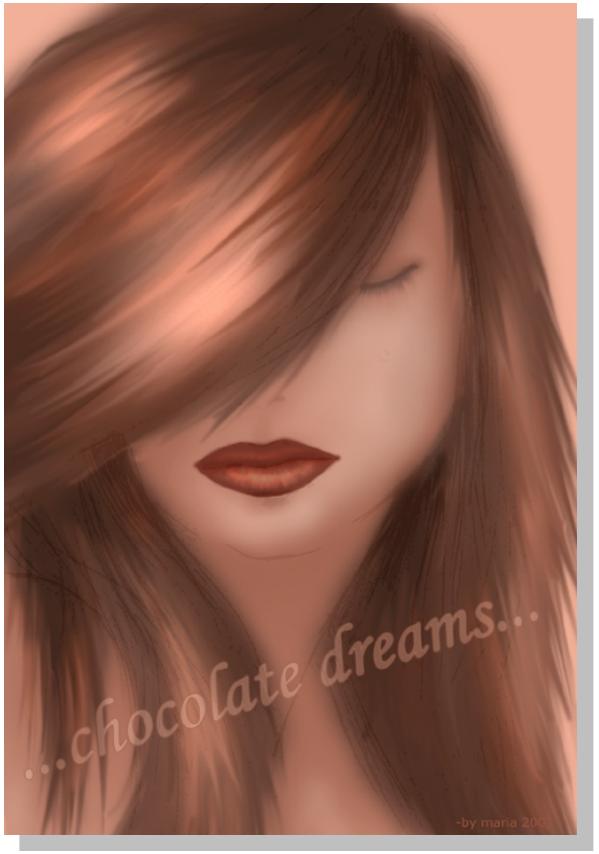
- Ice Cream Number One
- Potato Chips
- Pizza
- Popcorn
- Carbonated Soft Drinks
- Chocolate



Chocolate Pleasure

It Melts!

Salt-Fat-Sugar!



Chocoholic Quiz

- **What is your favorite way to consume chocolate?**
- a. By nibbling a bit now and then throughout the day.
- b. By swallowing whole chunks at a time.
- c. By intravenous injection.
- d. I dive into a 100 gallon vat and slurp.

Vanilla Ice Cream is # 1 Favorite

- Ice Cream Melts. Changing Temperature in the oral Cavity is very rewarding
- Why? Brain does not habituate to vanilla aroma!

The CHANGE of oral temperature is arousing!

High energy density!

Oreos

- >350 Billion Sold…WHY?
- Lots of Dynamic Contrast:
  - Sweet and Salty
  - Dark and Light
  - Creamy and Crunchy
  - Smooth and Ridges
  - Vanilla aroma and Chocolate
  - High in Salt, Fat and Sugar

Popcorn

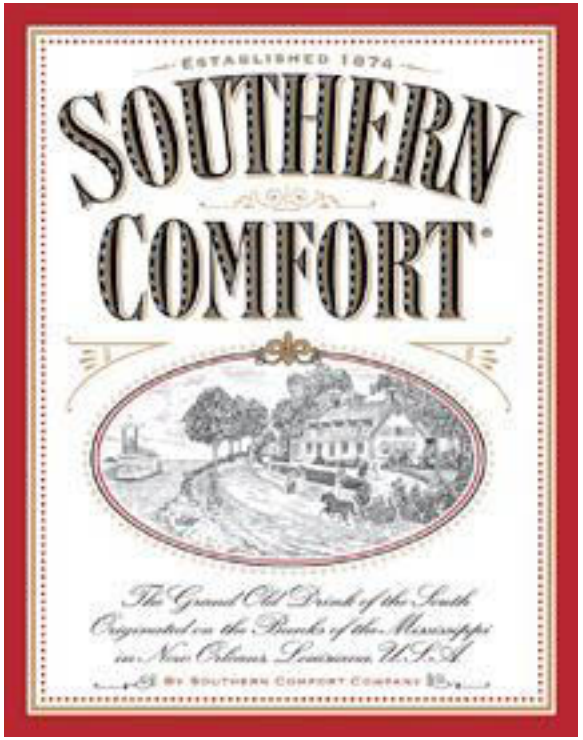
- Very Popular Snack Food
- Popcorn has a unique feature:
  - Quickest food meltdown in mouth known
- Popcorn also has an aroma profile that does not extinguish quickly (like vanilla)
- Eating enjoyment without a lot of calories that inhibit pleasure

Also allows unlimited addition of flavors!

Taste Aversions!

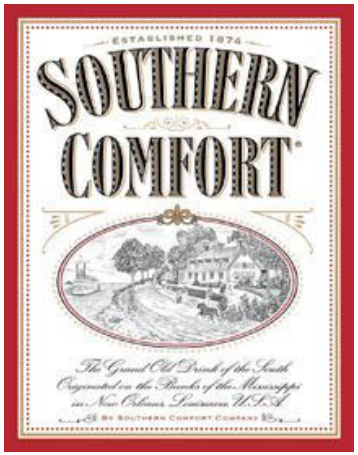
Taste Aversions

- AKA "Garcia Effect"
- "Southern Comfort Effect"



Taste Aversion Learning

- A single pairing with a food with GI malaise or upset stomach can form a permanent food aversion to that food
  - Sensory Specific (Texture)
  - Difficult to extinguish
  - Protects the body from toxic food
- Southern Comfort Phenomenon
  - Sweet drinks often cause GI upset and then taste aversions!



Pain/Pleasure

- "Essential" role in human life
- Poorly Understood
- Most primitive part of nervous system (Limbic)
- Always linked to reinforcement

Bull. Acad. Natl. Med., 183:1111 (99)

Pleasure Two Components

- Pleasantness is defined as the degree of favorable feelings a subject can experience.
- Arousal is defined as the degree of excitement (general activation) or [thrillingness] the subject feels under these circumstances”
  - Orosensation
  - Fat Taste?
  - Snap / crackle / pop

Food Pleasure Equation 1

- The Food Pleasure Equation:

$$F.P. = f(\text{Sensation}) + (\text{Calories})$$

See book: "Why We Eat, What we Eat", ED Capaldi

Food Pleasure Equation 2

FP= Sensory + Caloric Content

- Gustation
  - Salt, MSG, 5'Nuc.
  - Sweet
  - Fat Taste
- Olfaction
  - Aroma
  - Trigeminal
- Dynamic Contrast
  - Temperature change
  - Snap, crackle & pop
- Protein
  - Casomorphins
- Carbohydrates
  - Neurons like glucose
  - Fat cells like sucrose
- Fat
  - Essential fatty acids
    - Linoleic
    - linolenic

Pleasure Hypothesis

- Food Pleasure = function of amount eaten (Dopamine, Opioids?)

You need (X) Amt
Of Pleasure per Day!

ENERGY: Brain's Number One Priority

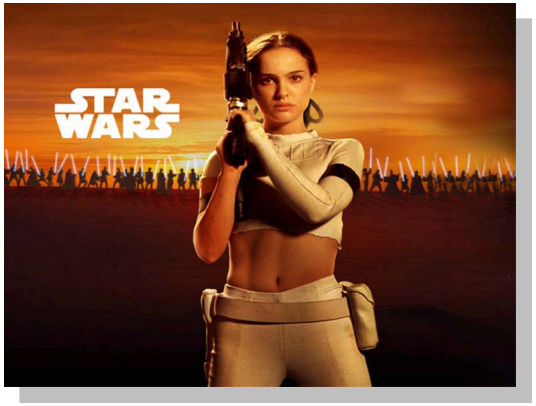
Flavor Processing

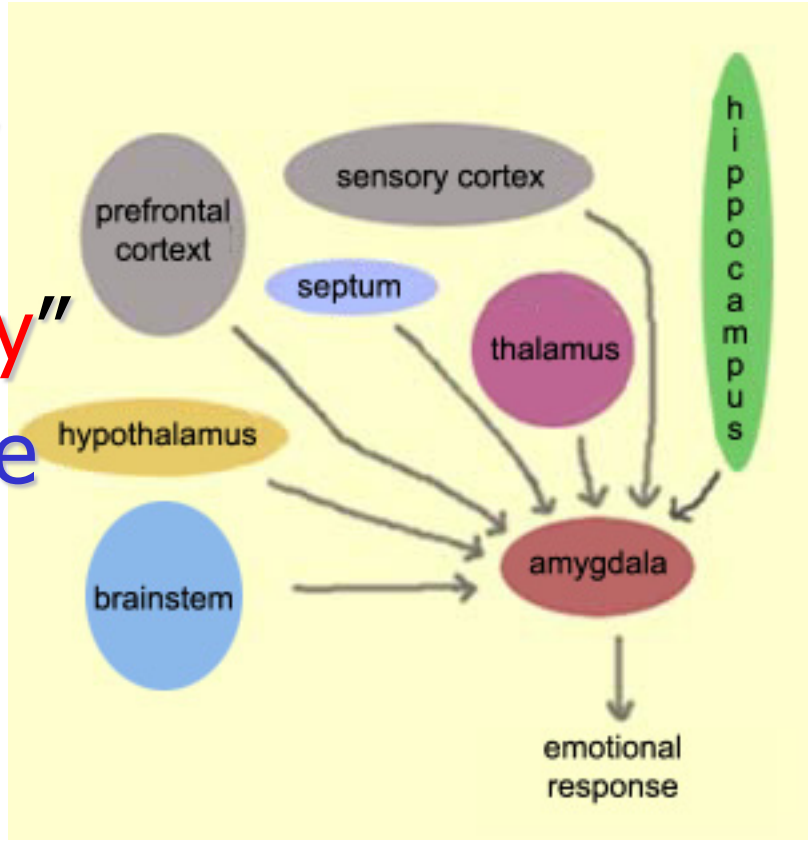
- Flavor Processing involves cortical gustatory area plus amygdaloid and basal forebrain nuclei
- Flavor = Taste + Smell (Vision)

Small et al., **Neuroreport** 8:3913, (1997)

Amygdala & Memory

- Receives sensory input from taste, smell, sight, sound and texture
- Creates a "Food Memory"
- Searches for significance





Clear Pepsi?

Is this a good Idea?

Best Food Ingredients for Memory

- Sugar in food foster food memories (Gold)
  - Glucose sensing neurons linkage serotonin and opioids Blum)
- Fat in food excellent in forming food memories & food selection
  - Brain lights up when fat ingested

Final Comments

- Taste and Smell are "Primary Pleasures"
- Taste and Smell are Idioscyncrastic
- Taste is More Complex
- Food can be manipulated:
  - More pleasurable
  - More addicting
  - Increased craving

Thank for Listening!

- Company seminars on Food Pleasure are available soon!

Steven Witherly, PhD

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