What Is Odor? How Brains Make Smell Sensations

Contents

Abstract

Brain transforms perceptual properties into patterns and motions of geometric-algebra vectors, making microscopic surface textures whose spatial and temporal properties are sensory experiences.

Keywords

amygdala-hippocampal complex, base note, entorhinal complex, forebrain, glomerulus, middle note, mitral cell, odor, odor hedonics, odorant, olfactory bulb, olfactory cleft, olfactory nerve, pyriform cortex, retronasal area, rhinencephalon, shape-pattern theory, stereochemical theory, top note, tufted cell, vibration theory

1. Anatomy

Odor receptors send to olfactory-bulb glomeruli, which send to cortical regions.

1.1. Receptors

Upper-nasal-passage olfactory-cleft sensory cells have cilia with receptors that chemically bind molecular weight 30 to 350 air-borne hydrophobic molecules. Odorant molecules have different chemical groups, shapes, sizes, and vibration states, so odor receptors have 30 functionally different types.

1.2. Glomeruli

Olfactory-nerve, mitral-cell, and tufted-cell axons converge on spheres {glomeruli} in lateral or medial olfactory bulb, above and behind nose in forebrain rhinencephalon. Glomeruli receive from many olfactory receptors.

1.3. Cortex

Olfactory-bulb signals go to pyriform cortex and entorhinal complex to detect odors.

Olfactory-bulb signals go to limbic-system amygdala-hippocampal complex to measure smell associations and emotions.

2. Physiology

Odor receptors are specific for odor-molecule charge, size, shape, vibration, and chemical group.

2.1. Charge

Receptor sites can have electric charges that attract oppositely charged molecules. Different sites have different electric fields. Molecules with negative charge have pungent smell, and molecules with positive charge have putrid smell [Moncrieff, 1970].

2.2. Shape

Molecule shape can be chain, oblong, or spherical. Molecule edges can be sharp, medium, or smooth. Molecule shape helps determine odorant type {shape-pattern theory}.

Molecule geometry correlates with odorant type {stereochemical theory} [Amoore, 1970] [Moncrieff, 1970]. Concave (and small) receptor sites are for camphorous smell. Concave (and large) sites are for musky smell. V-shaped sites are for minty smell. Trough-shaped sites are for ethereal smell. Concave-and-trough-shaped sites are for floral smell.

Chiral-molecule right-handed and left-handed forms, like spearmint and caraway, smell different [Amoore, 1970] [Amoore et al., 1964].

2.3. Size

Odor receptors hold molecules between 35 and 350 molecular weight. Sizes can be small and compact, small and linear, large and compact, and large and linear.

Molecule size correlates with odor type [Amoore, 1970] [Moncrieff, 1970]. Small (and concave) receptor sites are for camphorous smell. Large (and concave) sites are for musky smell.

2.4. Vibrations

Smell molecules and receptors have different vibration and rotation states. Perhaps, molecules with similar vibration frequency have similar smell {vibration theory} [Turin, 1996].

2.5. Chemical-binding sites

Odor-receptor chemical sites are for alcohols, aldehydes, amines, aryls, carboxylic acids, esters, ethers, halogens, ketones, cysteines, thiols, sulfides, or terpenes. Sites can be for small, medium, or large molecules [Firestein, 2001] [Laurent et al., 2001]:

- Alcohols that are small, such as methanol and ethanol, smell alcoholy, biting, and hanging.
- Alcohols that are medium-chain, such as butanol and octanol, smell sweet and fruity.
- Alcohols that are cyclic, such as menthol, smell cool and minty.
- Alcohols that are monoterpenoids, such as geraniol and linalool, smell flowery and fresh.
- Alcohols that are monophenols, such as phenol and guaiacol, smell burnt and smoky.
- Alcohols that are polyphenols, such as cresol, smell tarry and oily.
- Aldehydes that are small, such as diacetyl aldehyde, smell buttery.
- Aldehydes that are short-chain, such as isovaleraldehyde, smell malty.
- Aldehydes that are alkene aldehydes, such as hexenal, smell grassy and herby.
- Amines that are alkyl and aryl monoamines, such as trimethylamine and phenethylamine, smell fishy.
- Amines that are alkyl multi-amines, such as putrescine, smell spermous.
- Amines that are heterocyclic amines, such as pyrroline, smell spermous.
- Amines that are heterocyclic aromatic, such as alkyl pyrazines, smell nutty, earthy, and green peppery.
- Amines that are heterocyclic aromatic, such as 2-acetyl-tetrahydro-pyridine, smell roasted, fermented, and popcorny.
- Aryls that are benzene alkyls, such as benzene, toluene, and xylenes, smell aromatic.
- Aryls that are monophenols, such as phenol and guaiacol, smell burnt and smoky.
- Aryls that are polyphenols, such as cresol, smell tarry and oily.
- Aryls that are polycyclic aromatic hydrocarbons, such as anthracene and pyrene, smell burnt and smoky.
- Aryls that are polycyclic in small concave sites, such as camphor, smell camphorous and resinous.
- Aryls that are aryl monoamines, such as phenethylamine, smell fishy.
- Carboxylic acids that are small, such as acetic acid, smell acrid, vinegary and pungent.
- Carboxylic acids that are medium-short polar chains, such as butyric acid (butanoic acid), smell putrid, sweaty and rancid.
- Carboxylic acids that are medium-length polar chains, such as caprylic acid (octanoic acid), smell goaty and hircine.
- Carboxylic acids that are carboxylic-acid thiols, such as dithiolane-4-carboxylic acid, smell asparagusy and bitter.
- Esters that are non-polar chains, such as methyl butyrate, smell sweet and fruity.
- Ethers that are linear in concave and trough-shaped sites, such as ethyl methyl ether, smell fragrant, ethereal, floral and flowery.

- Ethers that are cyclic, such as dioxacyclopentane, smell earthy, moldy and potatoey.
- Halogens, such as fluorine, chlorine, and bromine, smell pharmaceutical, medicinal, pungent, and unpleasant.
- Ketones that are heterocyclic, such as furanone and lactones, smell savory and spicy.
- Ketones that are alkane ring ketones, such as steroid ketones, smell urinous.
- Ketones that are macrocyclic in large concave sites, such as muscone (methylcyclopentade-canone), smell musky and ambrosial.
- Ketones that are alkenes with one ring, such as ionones, damascones, and damascenones, smell tobaccoy.
- Ketones that are cyclic alkene ketones in V-shaped sites, such as terpenoids and R-(–)-carvone (2-methyl-5-(1-methylethenyl)-2-cyclohexenone), smell minty, spearminty, and pepperminty.
- Sulfur compounds that are cysteines, such as gamma-glutamylcysteines and cysteine sulfoxides, smell alliaceous and garlicy.
- Sulfur compounds that are carboxylic-acid thiols, such as dithiolane-4-carboxylic acid, smell asparagusy and bitter.
- Sulfur compounds that are small thiols, such as methyl mercaptan (methanethiol), smell foul, sulfurous, and rotten.
- Sulfur compounds that are sulfides, such as methyl sulfides, smell cabbage-like and rotten at high concentrations.
- Terpenes that are cyclic alkene ketones in V-shaped sites, such as terpenoids and R-(–)-carvone (2-methyl-5-(1-methylethenyl)-2-cyclohexenone), smell minty and pepperminty.
- Terpenes that are monoterpenoid alcohols, such as geraniol and linalool, smell flowery and fresh.
- Terpenes that are isoprenes and monoterpenes, such as isoterpene, smell rubbery.
- Terpenes that are sesquiterpenes and triterpenes, such as humulene, smell woody.

Some sites are for both alcohol and terpene, alcohol and aryl, amine and aryl, carboxylic acid and thiol, or ketone and terpene.

Some sites are for carbon chains and rings: alkyls, alkenes, single rings, multiple rings, single heterocyclic rings, multiple heterocyclic rings, single aromatic rings, and multiple aromatic rings.

After seven or eight molecules bind to cilia odorant receptors, olfactory receptors signal once. People need 40 signals to perceive odorant.

2.6. Brain

Glomeruli test for only one odorant.

Cortical smell neurons excite and inhibit each other to form intensity ratios that distinguish odorant relative concentrations and combinations (odors).

3. Perceptual properties

People can distinguish 30 primary odorants:

- alliaceous and garlicy: cysteine sulfur compounds
- aromatic: benzene alkyls
- asparagusy, bitter: carboxylic-acid thiols
- biting, hanging, alcoholy: small alcohols
- burnt, smoky: monophenols and polycyclic aromatic hydrocarbons
- buttery: small aldehydes
- camphorous, resinous: polycyclic aryls
- cool and minty: cyclic alcohols
- earthy, moldy, potatoey: cyclic ethers
- fishy: alkyl and aryl monoamines
- flowery, fresh: monoterpenoid alcohols
- foul, rotten, sulfurous: small thiol sulfur compounds
- fragrant, floral, flowery, ethereal: linear ethers
- fruity, sweet: medium-chain alcohols and non-polar chain esters
- goaty, hircine: medium-length polar chain carboxylic acids
- grassy, herby: alkene aldehydes
- malty: short-chain aldehydes
- minty, spearminty, pepperminty: cyclic alkene ketones
- musky, ambrosial: macrocyclic ketones
- nutty, earthy, green peppery: heterocyclic aromatic amines
- pharmaceutical, medicinal, pungent, unpleasant: halogens
- pungent, acrid, vinegary: small carboxylic acids
- putrid, sweaty, rancid, nauseating: medium-short polar chain carboxylic acids
- roasted, fermented, popcorny: heterocyclic aromatic amines
- rubber: monoterpenes (isoprenes)
- cabbage-like, rotten: methyl sulfides
- savory, spicy: heterocyclic ketones
- spermous: alkyl multi-amines and heterocyclic amines
- tarry, oily: polyphenols
- tobacco: alkenes-with-one-ring ketones
- urinous: steroid ketones
- woody: triterpenes (sesquiterpenes)

Odorants mix to make odor, and people can distinguish 10,000 different odors.

Smell always refers to object that makes smell, not to an accidental or abstract property nor to a concept about smell.

3.1. Categories

Smells are animal, vegetable, or mineral. For example, caprylic acid and carboxylic acids are animal. Ethers are vegetable. Halogens are mineral.

Smells can range through sweet/flowery/fruity, mild/vegetably, mild/animaly, mild/mineraly, strong/vegetably, strong/animaly, putrid/animaly, and sharp/mineraly.

The smell-category sequence correlates with molecule reactivity:

- Ether -C-O-C-
- Alcohol -CH_2OH
- Ester -COO-
- Aryl =CHC=
- Terpene =CC_2
- Ketone -COC-
- Aldehyde -CHO
- Acid -COOH
- Amine -CH_2NH_2
- Sulfhydryl -CH_2SH
- Halogens Br_2

3.2. Temporal order

Brain detects aldehydes (malty, grassy, buttery) first {top note}.

Brain detects ethers (florals) second {middle note}.

Brain detects sesquiterpenes (woody, such as cedar and sandalwood), polycyclic aryl ketones (lingering musky, such as musk, vetiver, ambergris, and civet), and non-polar aryl compounds (sweet spicy, such as vanilla) later {base note}.

3.3. Similarities

Similar chemical types make similar smells. Similar chemical origins make similar smells.

3.3.1. Chemical types

Alcohols are similar: biting, fruity, sweet.

Aldehydes are similar: malty, grassy (herby).

Amines are similar: spermous, fishy, nutty, roasted.

Aryls are similar: aromatic, burnt (smoky), camphorous (resinous), tarry (oily).

Carboxylic acids are similar: pungent (acrid, vinegary), putrid (sweaty, rancid), goaty (hircine).

Ethers are similar: fragrant, floral, fruity and sweet.

Ketones are similar: minty, spicy, savory, tobacco, musky (ambrosial), urinous.

Sulfur compounds are similar: asparagusy, cabbage-like, alliaceous (garlicy), foul, rotten.

Terpenes are similar: minty, flowery (fresh), rubbery, woody.

3.3.2. Chemical-type pairs

Alcohols and aryl ketones are similar: biting, fruity, minty, musky.

Alcohols and esters are similar: fruity, sweet.

Aldehydes and alkene ketones are similar: malty, grassy, tobacco.

Aldehydes and ethers are similar: malty, grassy, earthy.

Aldehydes and terpenes are similar: malty, grassy, rubbery, woody.

Amines and steroid ketones are similar: spermous, fishy, nutty, roasted, urinous.

Amines and carboxylic acids are similar: spermous, fishy, nutty, roasted, pungent, putrid, goaty.

Polycyclic aryls and halogens are similar: camphorous, pharmaceutical.

Carboxylic acids and steroid ketones are similar: pungent, putrid, goaty, urinous.

Alkene ketones and terpenes are similar: tobacco, rubbery, woody.

Polycyclic aryl ketones and ethers are similar: minty, camphorous, musky, fragrant, flowery, fruity.

3.3.3. Chemical origin

Vegetable smells are similar: alcohols, aldehydes, ethers, aryl and alkene ketones, sulfur compounds, terpenes.

Animal smells are similar: carboxylic acids, amines, polycyclic aryl ketones, steroid ketones.

3.4. Opposites

Carboxylic acids (sour, putrid, animal) and esters (sweet, fruity, vegetable) are opposites.

Carboxylic acids (sour, putrid, animal) and alcohols (sweet, fruity, vegetable) are opposites.

Amines (animal) and aldehydes (vegetable) are opposites.

Amines (animal) and terpenes (vegetable) are opposites.

3.5. Mixing

Odorants mix to make odors. Smells blend in concordances and discordances, like music harmonics. Odors are not independent, so smell is a synthetic sense, with some analysis.

Smells can interfere with each other. Perhaps, smells can cancel other smells, not just mask them, so smells have opposites. (Neutral smell has no smell.)

3.6. Odor hedonics

Odors have pleasantness, familiarity, and intensity {odor hedonics}, which define how much people like them.

Smells range from pleasant to unpleasant.

Smells range from familiar to unfamiliar.

Smells range from weak to strong, depending on concentration and type.

3.7. Sharpness-sweetness

Smells range from dull, sweet, and smooth to harsh, sour, and sharp. For example, musk, ether, ester, flowery, fruity, and musky are dull, sweet, and smooth. Vinegar and acid are sharp, sour, and harsh.

3.8. Temperature

Smells range from cool to hot. For example, menthol is cool, and perfume is hot.

3.9. Source location

Olfactory bulb preserves odor-receptor spatial relations. Smell cortex can detect smell location in space. Smell can detect several sources from one location. Smells from different sources can interfere.

4. Relations to other senses

Taste and retronasal-area smell combine to make flavor.

Touch locates smells in inner upper nose. Smell uses tactile three-dimensional space to locate smells in space.

Smells can have temperature.

Smells can be painful.

Smells feel like touches on fluids.

Perhaps smell sensations are elaborations of taste sensations, because cells evolved first in water and only later in air. For example, carboxylic-acid smells have contraction, no fluid, and one point, like sour acid tastes. Amine smells have no diffusion or contraction, no fluid, and many points, like bitter basic tastes. Ether smells have diffusion, spreading fluid, and are smooth and rounded with no points, like sweet tastes. Alcohol smells have no diffusion or contraction, inflowing fluid, and several sharp points, like salt tastes.

5. Smell sensations

Smell detects odor-chemical concentration, charge, size, shape, vibration, and chemical group.

Smell perceives relatively small, medium, or large chemicals in air:

- Steroids: non-polar [animal fluids].
- Aryls and polycyclic aryls: non-polar [mineral aromatic].
- Terpenes (triterpenes, monoterpenes, and monoterpene alcohols): non-polar [vegetable aromatic].
- Ethers (linear): very slightly polar [vegetable flowery].
- Ethers (cyclic): very slightly polar [vegetable earthy].
- Esters: slightly polar [vegetable fruity].
- Amines (monoamines, alkyl amines, alkyl multiamines, heterocyclic amines, and heterocyclic aryl amines): somewhat polar [animal cooked/cells].
- Ketones (alkene, aryl, and heterocyclic): middling polar [vegetable spicy].
- Aldehydes: middling polar [vegetable earthy].
- Sulfur compounds (alkyl sulfides, thiols, carboxylic-acid thiols): above middling polar [vegetable rotten/bitter].
- Phenols (monophenols and polyphenols): polar [mineral petroleumy].
- Alcohols (linear and cyclic): polar [vegetable cool/alcoholic].
- Halogens: strongly polar [mineral medicinal].
- Carboxylic acids: ionic [animal secretions].

6. Smell descriptors

Smells can be noxious and sharp/strong:

- cabbage-like, rotten: methyl sulfides
- foul, rotten, sulfurous: small thiol sulfur compounds
- goaty, hircine: medium-length polar chain carboxylic acids
- pharmaceutical, medicinal, pungent, unpleasant: halogens
- pungent, acrid, vinegary: small carboxylic acids
- putrid, sweaty, rancid, nauseating: medium-short polar chain carboxylic acids

Smells can be noxious and dull:

- fishy: alkyl and aryl monoamines
- spermous: alkyl multi-amines and heterocyclic amines
- urinous: steroid ketones

Smells can be medium and sharp:

- burnt, smoky: monophenols and polycyclic aromatic hydrocarbons
- rubber: monoterpenes (isoprenes)
- tarry, oily: polyphenols

Smells can be medium and dull:

- alliaceous and garlicy: cysteine sulfur compounds
- asparagusy, bitter: carboxylic-acid thiols
- buttery: small aldehydes
- earthy, moldy, potatoey: cyclic ethers
- grassy, herby: alkene aldehydes
- malty: short-chain aldehydes
- musky, ambrosial: macrocyclic ketones
- nutty, earthy, green peppery: heterocyclic aromatic amines
- roasted, fermented, popcorny: heterocyclic aromatic amines
- tobacco: alkenes-with-one-ring ketones
- woody: triterpenes (sesquiterpenes)

Smells can be pleasant and sharp:

- aromatic: benzene alkyls
- biting, hanging, alcoholy: small alcohols
- camphorous, resinous: polycyclic aryls
- cool and minty: cyclic alcohols
- minty, spearminty, pepperminty: cyclic alkene ketones
- savory, spicy: heterocyclic ketones

Smells can be pleasant and dull:

- flowery, fresh: monoterpenoid alcohols
- fragrant, floral, flowery, ethereal: linear ethers
- fruity, sweet: medium-chain alcohols and non-polar chain esters

Smells can smell like minerals, vegetables, or animals.

Smells can be sweet. For example, musk, ether, ester, flowery, fruity, and musky are dull, sweet, and smooth.

Smells can be acidic. For example, vinegar and acid are sharp, sour, and harsh.

Smells can be sweaty. For example, carboxylic acids are sweaty or goaty.

Smells can have harshness and be sharp. For example, vinegar and acid are sharp, sour, and harsh. Sharp smells can have one point or many points.

Smells can have dullness and be smooth. For example, musk, ether, ester, flowery, fruity, and musky are dull, sweet, and smooth. Smooth smells feel rounded with no points.

Smell sensations have hot, warm, neutral, cool, and cold temperature. For example, menthol is cool, and perfume is hot.

Smells can feel light and diffuse, medium, or heavy and dense. Smells can feel airy, medium, or with no air. Air can be inflowing, outflowing, or diffuse.

Smell sensations have intensity, pleasantness, and familiarity. Smells can feel attractive or repulsive.

7. Spatiotemporal properties and patterns

Smell perceptual-property spatiotemporal patterns are three-dimensional patterns.

Three-dimensional patterns can have zero, one, or more points, for smoothness or sharpness.

Three-dimensional patterns can contract, expand, diffuse, or slide. Perhaps, contractions are for sharpness, expansions are for sweetness, diffusions are for mild), and translations are for other.

Three-dimensional patterns can have distribution/evenness, for mildness-smoothness.

Three-dimensional patterns can have density, for heaviness-lightness.

Three-dimensional patterns can have diffusion, for fluidity.

Three-dimensional patterns can have radial motions, for attraction-repulsion.

Three-dimensional patterns can have curvature, for temperature.

8. Machines

Machines can simulate odor sensations using a microscopic-surface-texture array with elements with nine asymmetric positions, each with two states, making 2^9 = 512 possibilities. More elements represent higher intensities.

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