Chemesthesis: The Third Part of Flavor Perception

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Flavor

- Taste
- Olfaction
- Chemesthesis

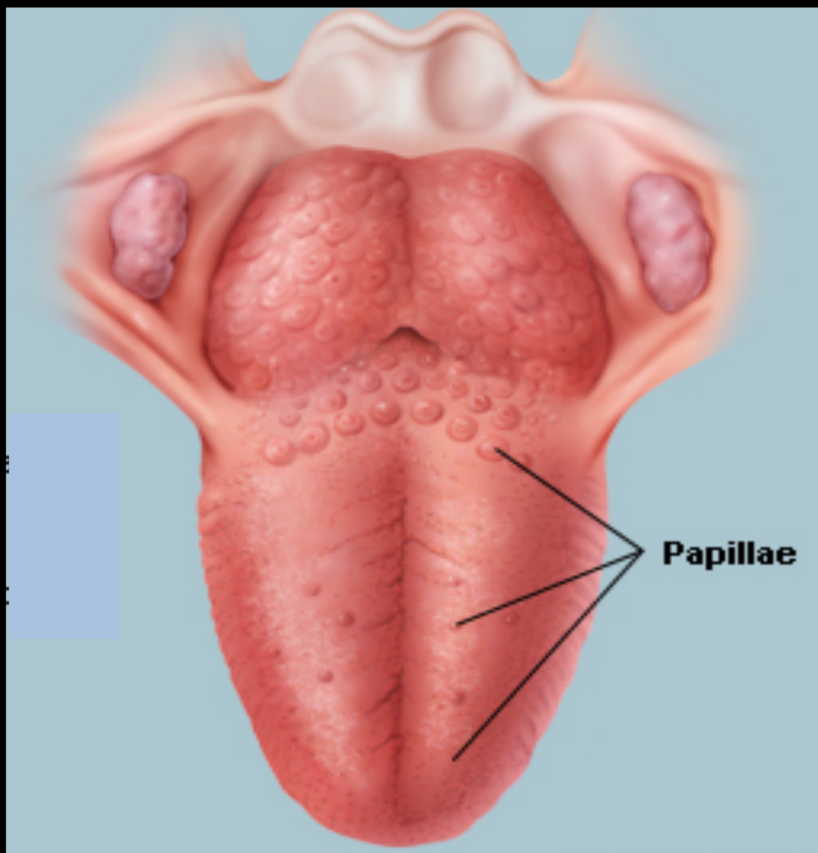
Taste

Taste is perceived by taste buds in the tongue.

Five distinct tastes are known:

- Sweet
- Sour
- Bitter
- Salty
- Umami

Compounds perceived by taste must be soluble in water/saliva



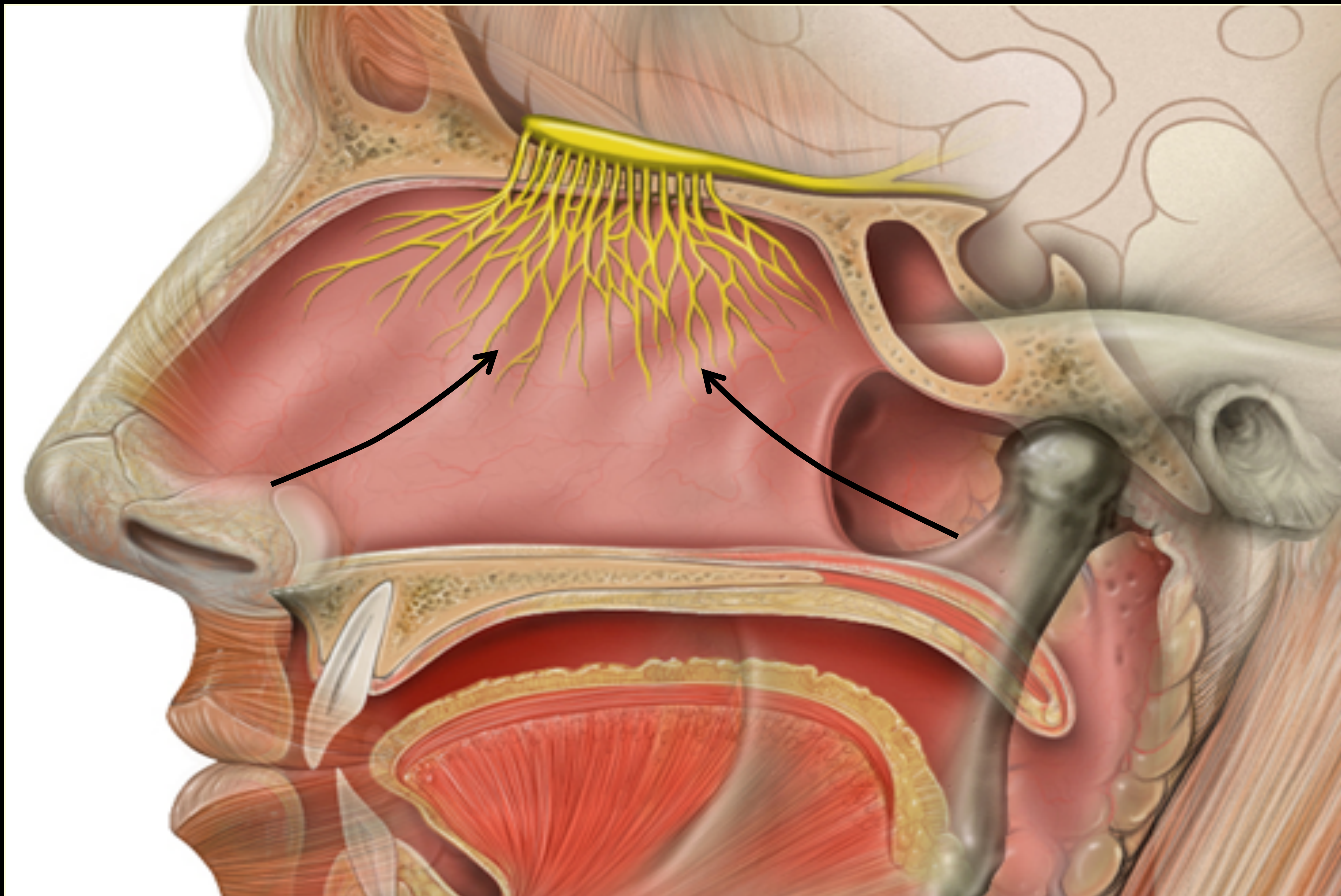
Taste buds for different sensations are spread all over the tongue rather than localized (Lawless & Heymann).

Olfaction

Olfaction (or smell) is perceived when volatile substances reach the olfactory epithelium in the nose.

This can occur either when inhaling (orthonasal olfaction) or exhaling (retronasal olfaction).

Nerves from the olfactory epithelium directly enter the brain.



Olfactory receptor genes form the largest known multigene family in the human genome (Niimura and Nei, 2003).

The ~900 human olfactory receptor genes are expressed as 300-500 receptor types.

A single odorant compound is sensed to varying degrees by multiple receptor types.

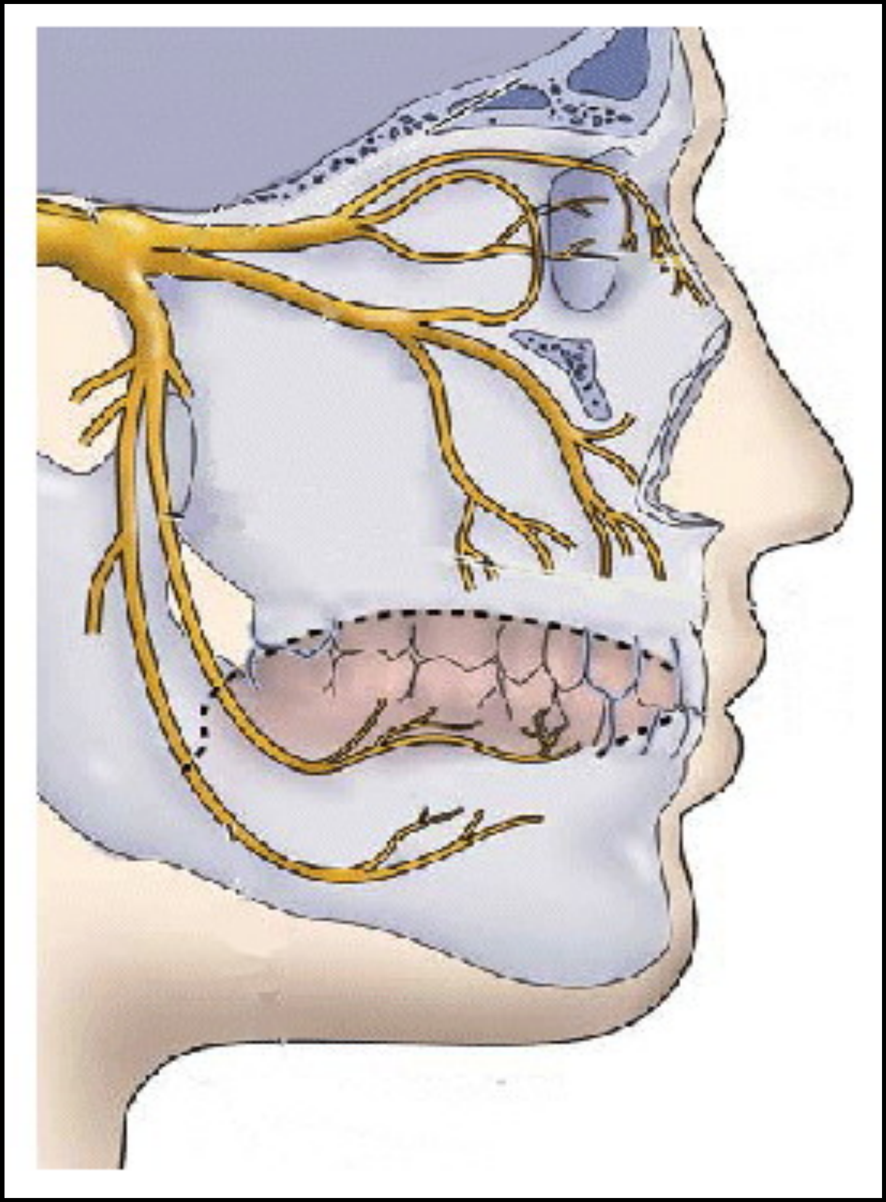
Olfaction results in thousands of different sensations that can be recognized by the brain once they have been experienced.

Chemesthesis

Chemesthesis is the result of perceptions made by the trigeminal nerve, which wraps around the nose and throat.

The trigeminal nerve is a tactile sensor.

The Trigeminal Nerve



Chemesthesis

Chemesthesis perceptions include mainly physical factors, such as:

- Hot
- Cold
- Smoothness
- Astringency
- Tingling of CO_2

Chemesthesis

The sensations of hot and cold can be triggered not only by the physical phenomena, but also by certain chemicals.

- The Hot sensation is also turned on by capsaicin (the hot pepper compound), pepperine (from black pepper), or gingerine (from ginger).
- The Cold sensation is also produced by menthol and some similar substances.

There are four heat activated channels

TRPV1	≥ 42ºC
TRPV2	≥ 52ºC
TRPV3	≥ 33ºC
TRPV4	~ 27ºC – 42ºC

There are two cold-activated channels

TRPM8	≤ 25ºC
TRPA1	≤ 17ºC

Dhaka et al. *Annu. Rev. Neurosci.* 2006.

Astringency results from several quite different compound classes:

- Ethanol and some other solvents
- Multivalent metal ions (most famously Al^{3+} in alum)
- Tannins and polyphenols
- Inorganic and organic acids

The astringency of ethanol and alum [i.e. multivalent metal ions] appears to be a result of physical drying of the mouth. Both require a significant amount of hydration and compete for it with oral tissues. As a result they remove water (Haslam et al., 1988).

Polyphenol Astringency

Polyphenol astringency is generally recognized as the result of interactions between proline-rich proteins (PRPs) in saliva and dietary polyphenols.

The PRPs and polyphenols combine to form colloidal particles, and this removes the lubricity provided by the PRPs in solution.

Bate-Smith, 1973; Gawel, 1997

Acid astringency results because saliva normally contains polyphenols as well as proline-rich proteins. At normal saliva pH (6.5-7.0) the protein-polyphenol interaction is weak and little or no astringency is felt. When acids are ingested, the saliva mixture drops in pH. Interaction is maximal near pH 4 and astringency results.

Siebert et al. *Food Qual. & Pref.* 2011

It was of interest to investigate relationships among chemesthetic sensations.

It occurred that some of these might be in opposition. For example, it is known that in cultures in which very hot foods are consumed, it is customary to chew on leaves that contain menthol-like substances to offset the heat.

And smoothness might be simply the lack of astringency.

Experimental Approach

Select chemicals that elicit chemesthetic responses and carry out preliminary experiments to select appropriate test concentrations.

Prepare combinations of these at various concentrations according to a statistical experiment design.

Have a sensory panel rate the intensities of a number of sensations.

Carry out Principal Components Analysis on the data to determine the number of phenomena represented and their relationships.

Test Substance Concentrations Used

- Alum (0.2, 0.6 and 1.0 g/L)
- (-)-Menthol (1, 3.5 and 6 mg/L)
- Capsaicin (0.5, 0.75 and 1 mg/L)
- Ethanol (0.52, 2.6 and 20.8 g/L)

Sensory Panel

Six subjects between 21 and 28 years old with normal smell and taste and without oral injuries, lesions or tongue piercings who refrained from eating, chewing gum or drinking flavored beverages for one hour before the experiment.

The sensory technique used was basically Descriptive Analysis. After experiencing the range of samples to be used, panelists suggested terms and agreed on seven.

Sensations Rated

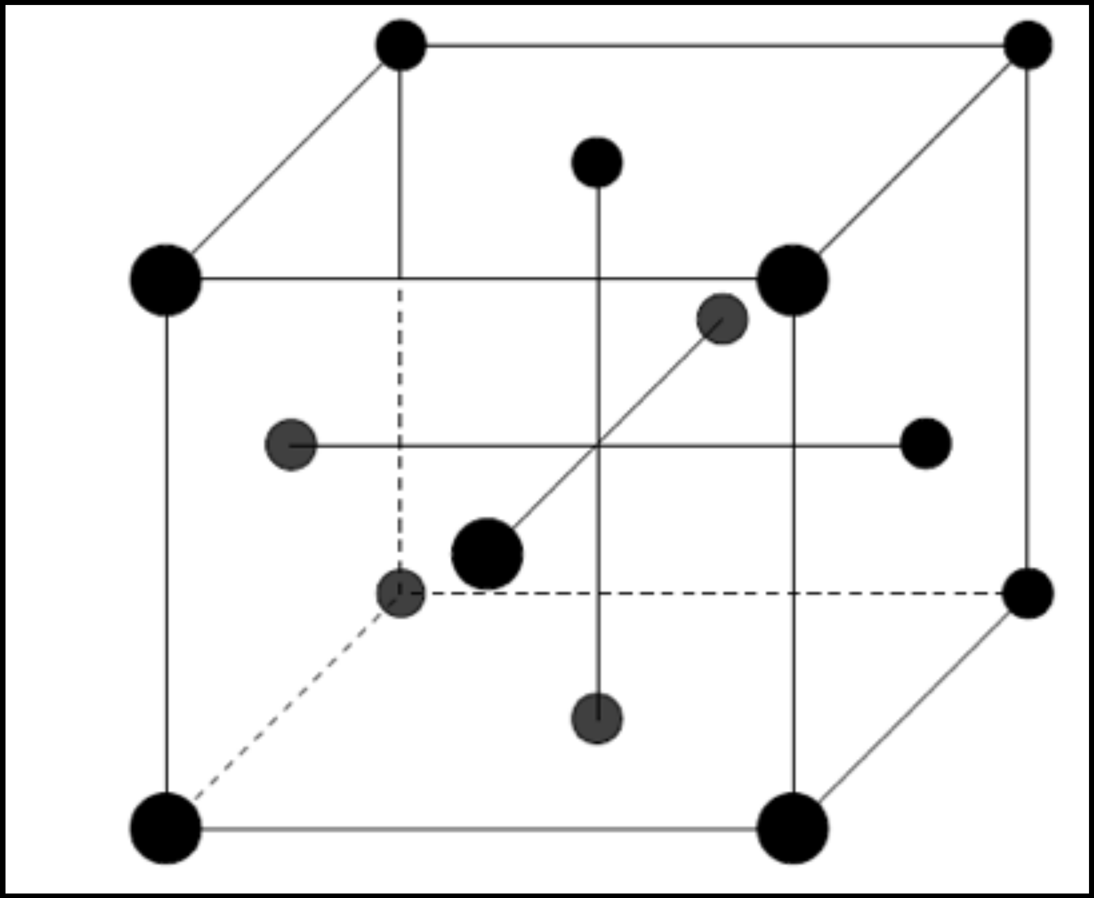
- ‘astringency’
- ‘sourness’
- ‘coolness’
- ‘burning’
- ‘sweetness’
- ‘smoothness’
- ‘alcoholic’

The intensities of the seven attributes were rated on 10 cm unstructured linear scales anchored at the extremities with the descriptions ‘weak’ and ‘strong’.

Samples (15 mL) were served at room temperature in balanced randomized order. Panelists were instructed to rinse their mouths with a sample for 10 sec, rate the attributes and expectorate.

Panelists cleared their palettes with water and unsalted crackers and waited at least 1 min between samples.

The experiment design is basically a central composite, face-centered design.



Face-centered central, composite design for 3 factors

The experiment design was basically a central composite, face-centered design with 4 factors and 37 conditions.

The progressions for menthol and capasaicin were linear while those for alum and ethanol were essentially logarithmic.

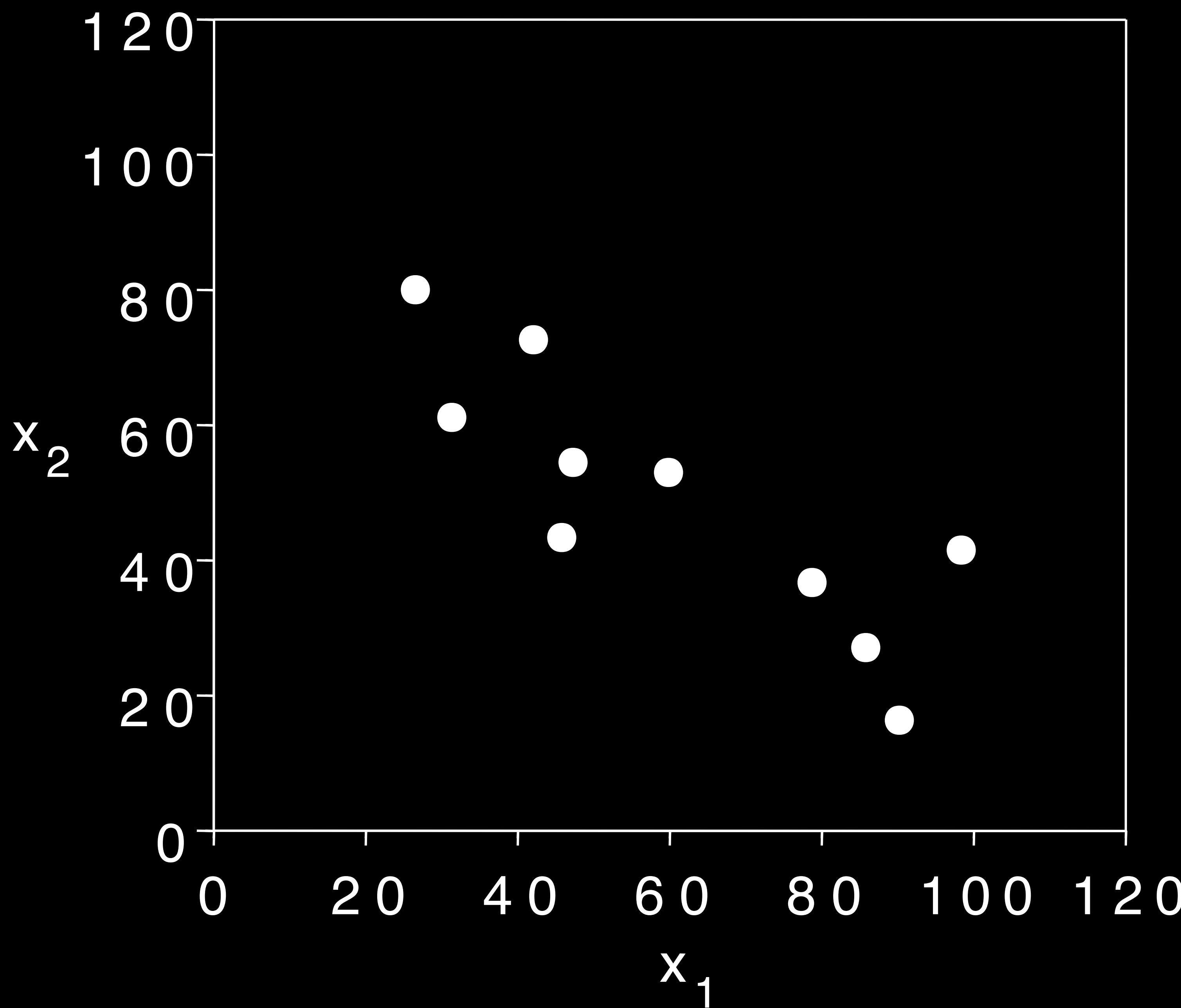
Principal Components Analysis

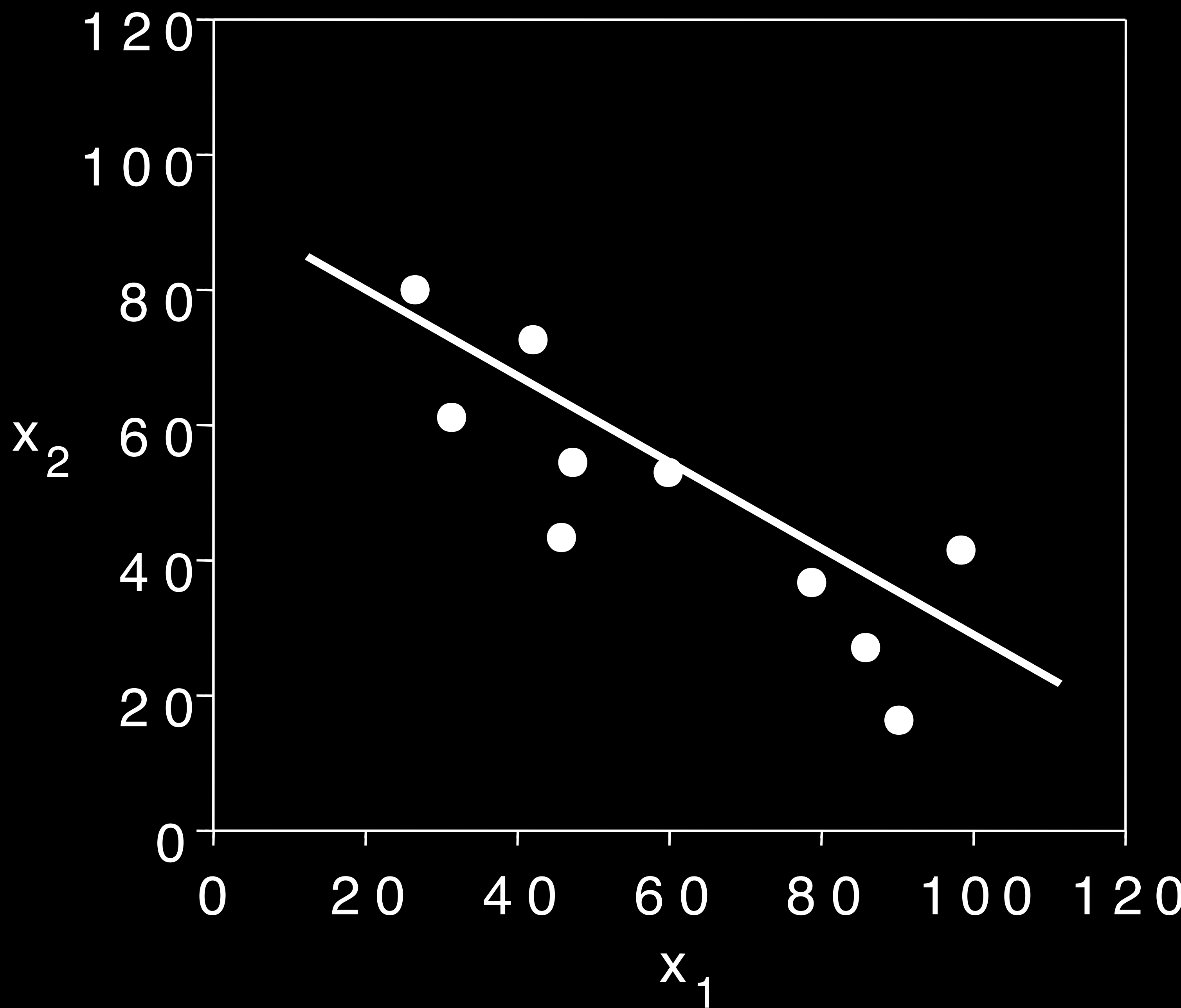
PCA is primarily a variance explaining technique.

It constructs vectors that attempt to explain the variance in a data set.

Principal Components Analysis - 2D Example

sample	x_1	x_2
1	27	81.5
2	32	63
3	42.5	74
4	47.5	56.5
5	46	45.5
6	60	55
7	79	39
8	86.5	29
9	99	43
10	91	18


120
100
80
60
40
20
0
x_2
0
20
40
60
80
100
120
x_1



120
100
80
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20
0
x2
0
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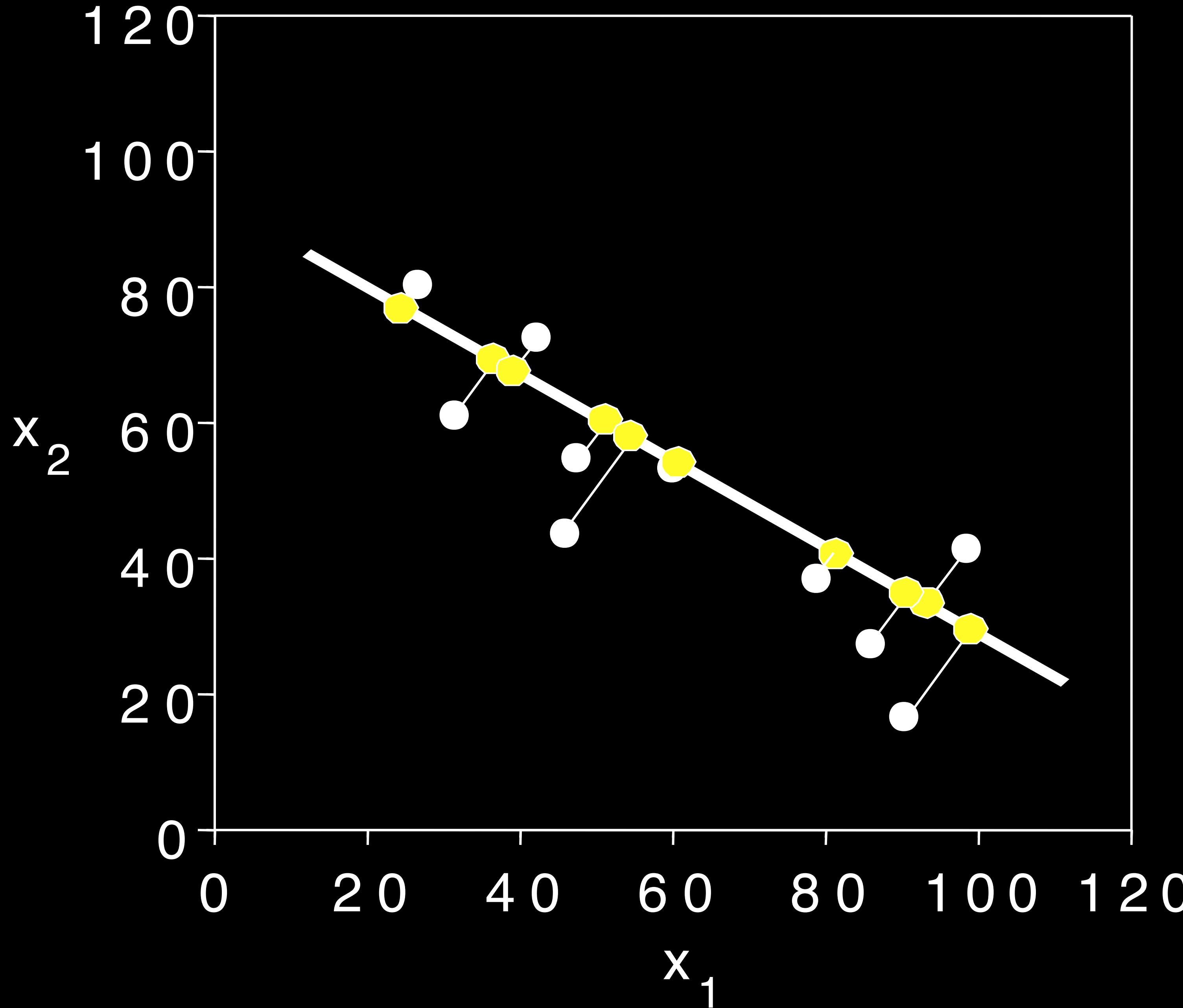
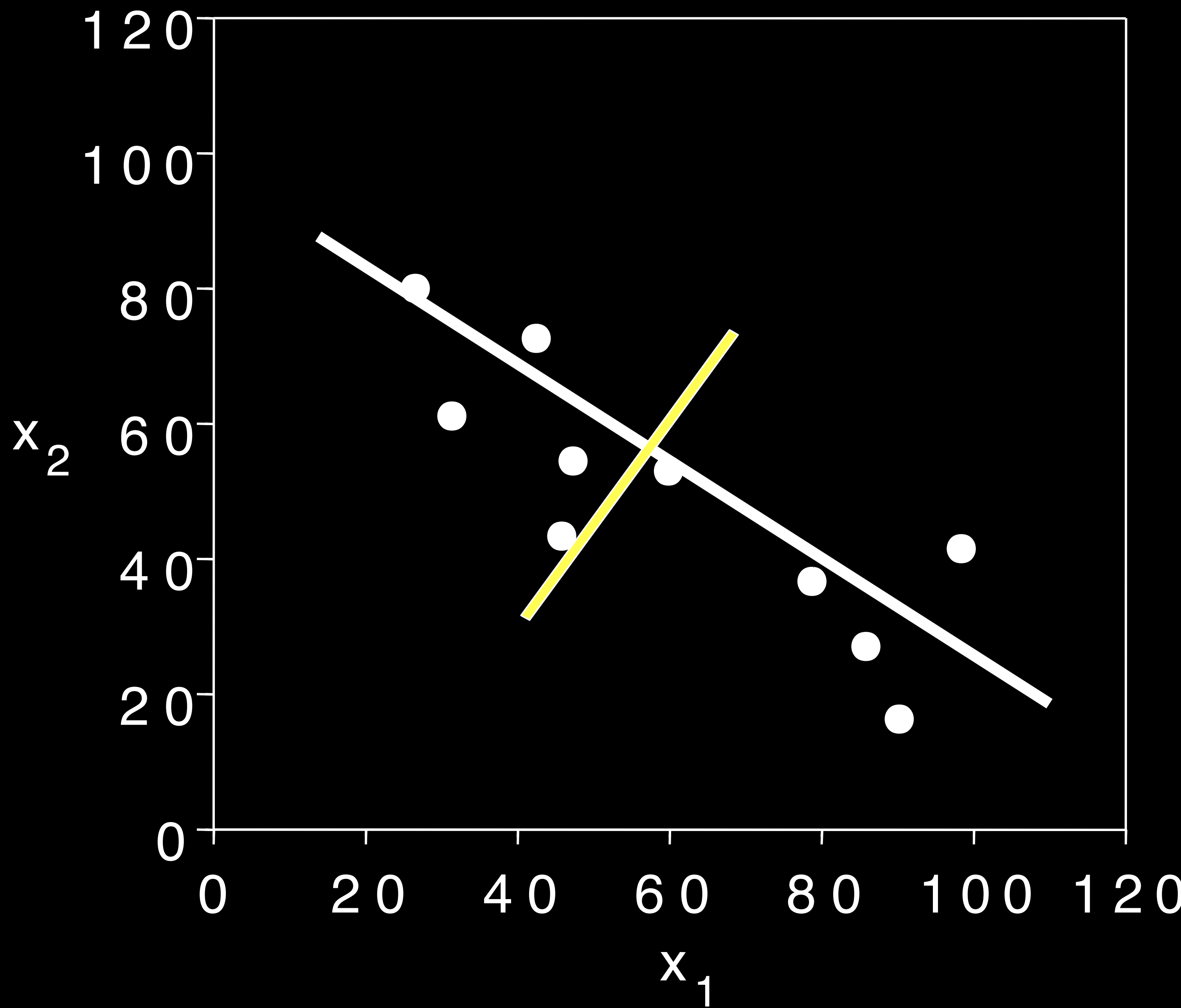
40
60
80
100
120
x1



120
100
80
60
40
20
0
x2
0
20
40
60
80
100
120
x1

sample	x_1	x_2	PC1
1	27.0	81.5	-25.6
2	32.0	63.0	-10.8
3	42.5	74.0	-8.7
4	47.5	56.5	5.6
5	46.0	45.5	10.8
6	60.0	55.0	16.6
7	79.0	39.0	41.4
8	86.5	29.0	53.3
9	99.0	43.0	55.3
10	91.0	18.0	63.4



120
100
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40
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x_2
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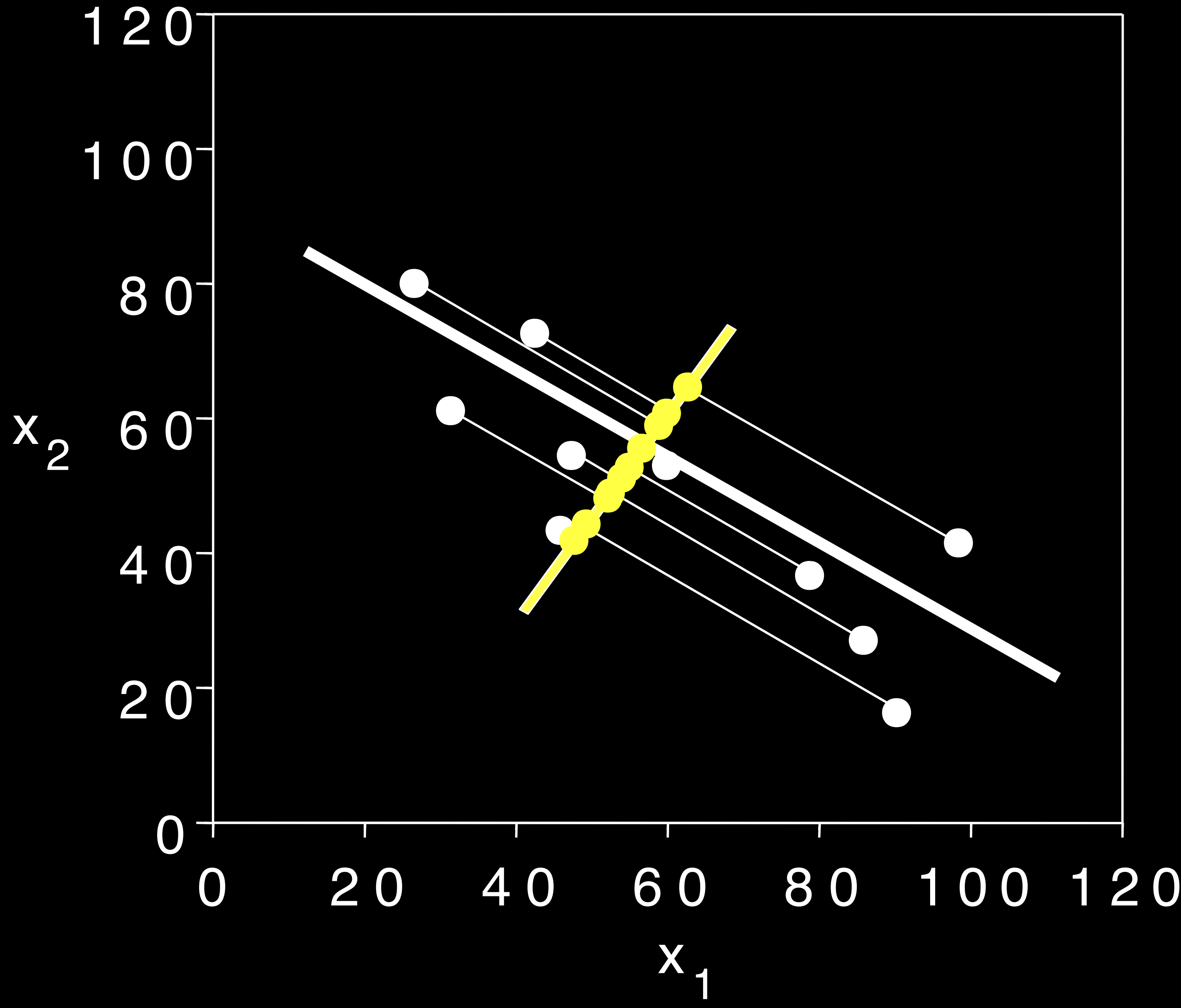
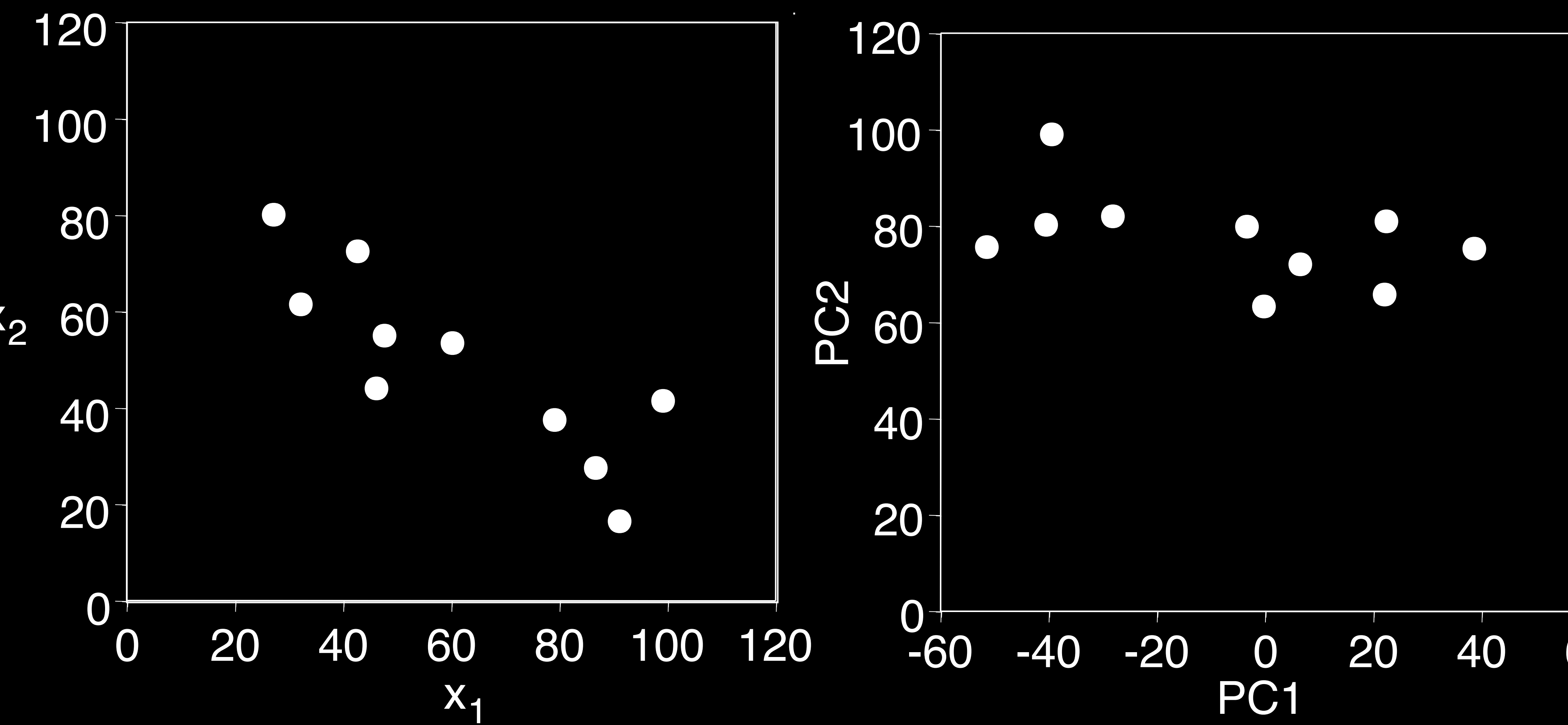
80
100
120
x_1



120
100
80
60
40
20
0
x2
0
20
40
60
80
100
120
x1

sample	x_1	x_2	PC1	PC2
1	27.0	81.5	-25.6	81.9
2	32.0	63.0	-10.8	69.8
3	42.5	74.0	-8.7	84.9
4	47.5	56.5	5.6	73.6
5	46.0	45.5	10.8	63.8
6	60.0	55.0	16.6	79.7
7	79.0	39.0	41.4	77.8
8	86.5	29.0	53.3	74.0
9	99.0	43.0	55.3	92.7
10	91.0	18.0	63.4	67.7



x2
x1
0
20
40
60
80
100
120
PC2
PC1
-60
-40
-20

The same approach can be extended to situations with many dimensions (the maximum number of PCs is the smaller of the number of factors or the number of samples).

In this study seven characteristics were rated so the data has 7 dimensions and as many as 7 PCs could be extracted.

Because each new PC is constrained to be orthogonal (at right angles in multidimensional space) to all previously extracted PCs, each PC is completely uncorrelated with all the other PCs.

That means they each represent something entirely different.

PCA Information Content

Often the first few PC's (and sometimes just two or three) are enough to account for the majority of the variance and the rest is mainly error (noise).

Variance

The variance accounted for by a PC is called its "eigenvalue".

The total variance is equal to the number of PCs extracted.

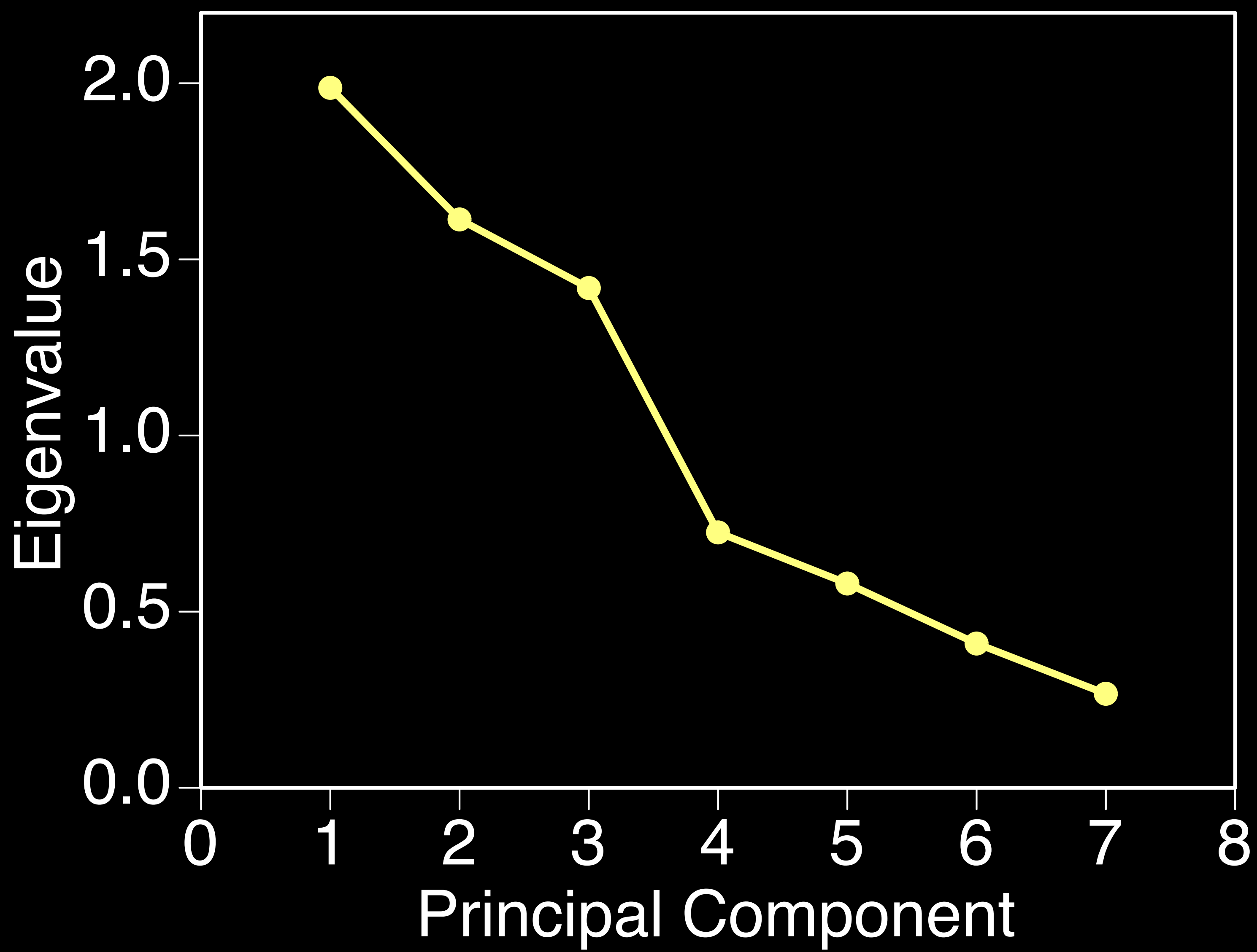
The variance explained by a PC (eigenvalue) always decreases as more PC's are extracted.

Either of two approaches is often used to determine the number of significant components in a data set used for PCA:

Eigenvalue > 1 (i.e. better than average explaining power)

A ‘knuckle’ in a plot of eigenvalue vs. PC no. (called a Scree plot)

Scree plot from PCA of Sensory Data



So the seven attributes rated contained information on only three fundamental perceptions.

The relationships between the original observations and the PCs are represented by the PC loadings.

The factor loadings indicate the strength and directional relationships between factors and PCs (akin to correlations).

Factors with relatively high loadings on the same PC with the same arithmetic sign contribute to the same phenomenon.

Factors with relatively high loadings on the same PC with opposite arithmetic signs are in opposition.

PC Loadings

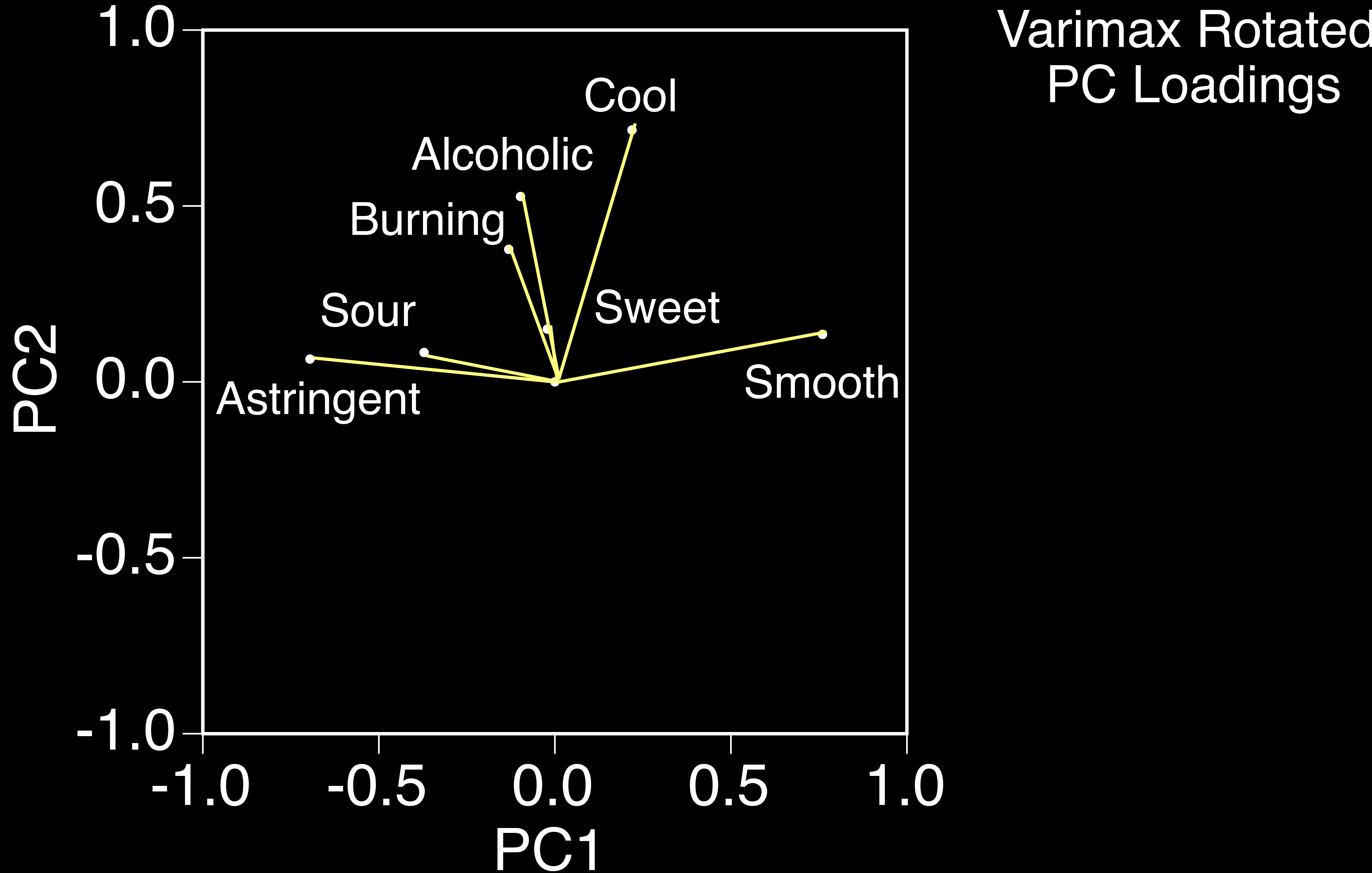
	PC 1	PC 2	PC 3
Astringent	0.652	0.234	-0.155
Sour	0.542	0.172	0.376
Cool	-0.379	0.640	0.105
Burning	-0.206	0.398	-0.539
Smooth	-0.687	-0.057	0.349
Sweet	0.158	0.151	0.389
Alcoholic	0.029	0.535	0.150

The exact configuration of the factor structure is not unique - without violating basic assumptions a factor solution can be transformed by rotation into many other factor solutions.

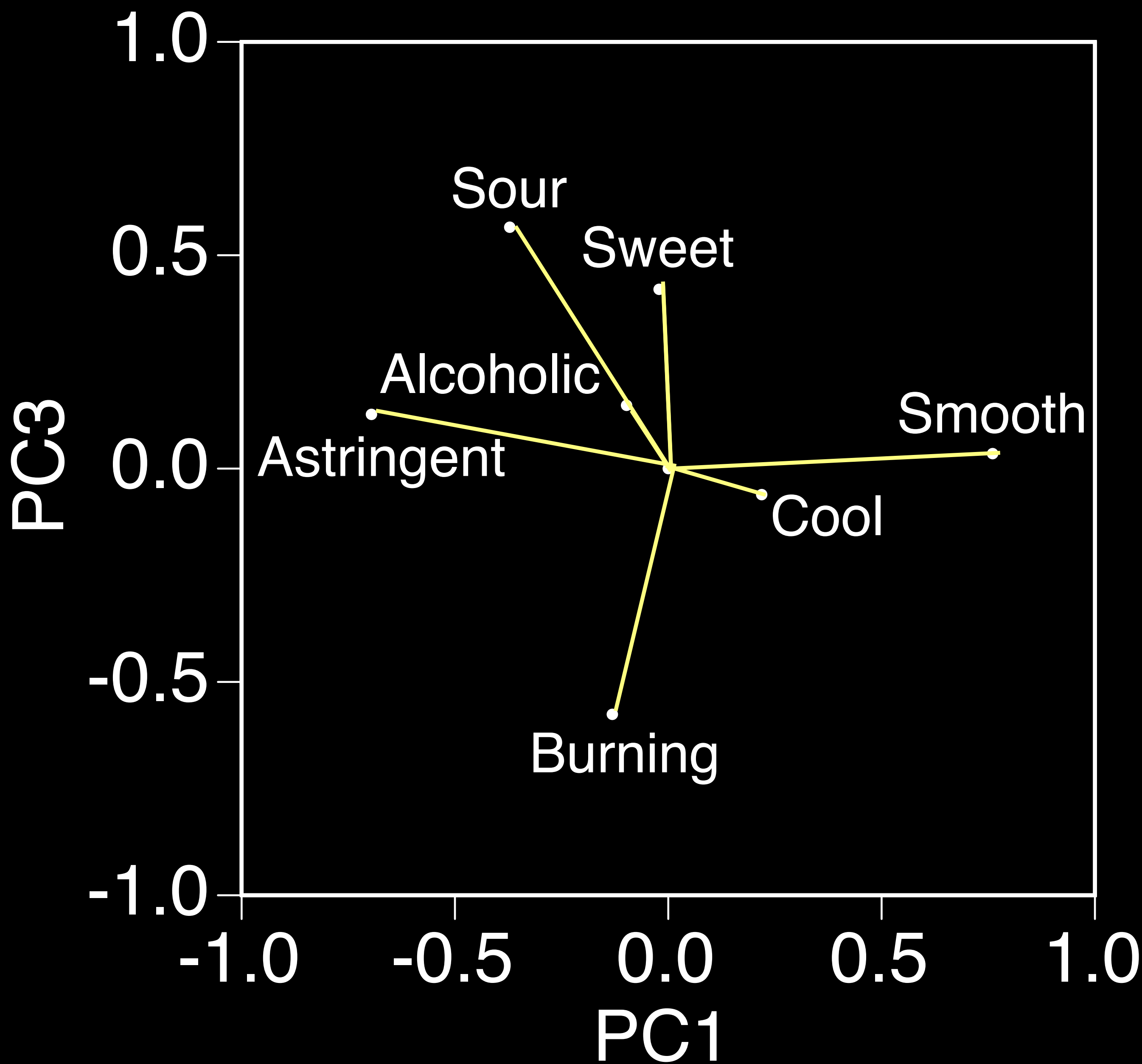
After rotation, each factor is often characterized by a single variable that is conceptually much simpler.

Varimax Rotated PC Loadings

	PC 1	PC 2	PC 3
Astringent	-0.696	0.065	0.127
Sour	-0.372	0.084	0.566
Cool	0.219	0.716	-0.061
Burning	-0.131	0.377	-0.576
Smooth	0.760	0.135	0.035
Sweet	-0.021	0.150	0.420
Alcoholic	-0.098	0.527	0.148


Varimax Rotated
PC Loadings
Cool
Alcoholic
Burning
Sour
Sweet
Smooth
Astringent
PC2
PC1
1.0
0.5
0.0
-0.5
-1.0
-1.0
-0.5
0.0
0.5
1.0

Varimax Rotated
PC Loadings



Conclusions

Principal Components Analysis showed that in this data set there were three main sensations.

Smoothness was in opposition to astringency.

Surprisingly, coolness and burning were not in opposition.

Sourness was opposed to burning.

It is possible that with more stimuli more sensations would be found.

The brain integrates 5 tastes, thousands of olfactory sensations and a modest number of chemesthetic sensations and produces a small number of dominant impressions.

Experience plays a large role in flavor recognition or association.

Acknowledgements

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IN SILICO VERITAS

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Astringency and smoothness appear to be largely opposite sides of the same coin. A lack of astringency leads to smoothness (Siebert & Xu, unpublished).

Several different classes of compounds produce astringency, notably polyphenols & tannins, acids, ethanol and some other solvents, and multivalent metal ions like Al^{3+} (this is why alum [mixed aluminum sulfate salts] is astringent).

Polyphenol Astringency

Polyphenol astringency is generally recognized as the result of interactions between proline-rich proteins (PRPs) in saliva and dietary polyphenols.

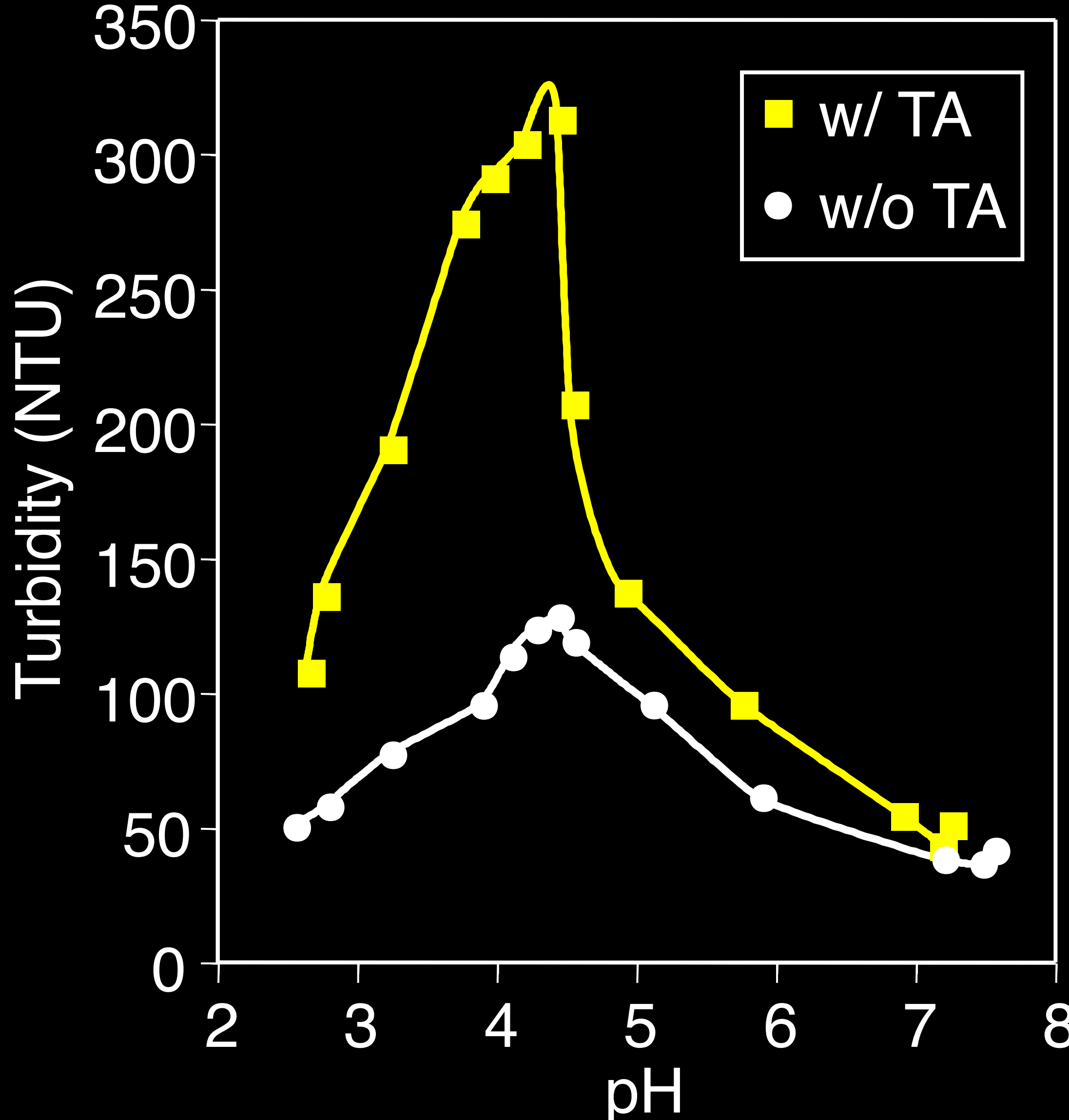
The PRPs and polyphenols combine to form colloidal particles and this removes the lubricity provided by the PRPs in solution.

Bate-Smith, 1973; Gawel, 1997

This is very similar to the mechanism of haze formation in beer, where proline-rich proteins (derived from barley hordein) are bridged together by polyphenols to form insoluble particles that scatter light.

And adding tannic acid to saliva also results in light scattering.

Effect of pH Adjustment of Saliva (●) and Saliva + Tannic Acid (■) on Light Scattering



Siebert & Chassy, *Food Qual. & Pref. 15: 13-18*, 2004.

Polyphenols are normally present in saliva and the level is affected by dietary habits. At saliva pH (6.5-7.0) they do not interact much with salivary PRPs. When acid is ingested, the saliva pH drops to the point that stronger PRP–polyphenol interaction occurs, removing the lubrication of the PRPs and astringency results.

(Siebert, Maekawa & Lynn, *Food Qual. & Pref. 22*: 157-164, 2011)

In typical flavor perception the brain combines the taste, olfaction, chemesthetic, and vision sensations to produce a few prominent perceptions.