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# Psychophysical Analysis of Complex Odor Mixtures

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*Abstract*: Odors in everyday life are usually complex and contain many components. This review describes current knowledge of how mixtures are perceived and the mechanisms that result in the suppression of many odors in mixtures. It discusses the limited capacity of humans to analyze mixtures and why only up to three odors can be identified perceptually in a mixture. Although this limit appears to be a disadvantage, the sense of smell seems to have evolved to provide a system that uses information processing techniques to detect and identify the most complex of odors within a second. Recent advances in gene technology which have resulted in the cloning of different types of receptors have provided new insights to odor reception and perception with mixtures and have the potential to open a new era in the development of fragrances.

**Keywords:** Neural mechanisms · Odor mixtures · Odor suppression · Olfaction · Psychophysics

## 1. Introduction

In everyday life the smells encountered are composed of dozens, even hundreds of odors; few arise from a single odorant. Fragrances from flowers and perfumes, aromas from bakeries, fruit and fish shops, unpleasant smells from piggeries, car exhausts and chemical factories, are almost always complex. Similarly, marine and terrestrial animals, and insects, communicate largely by a variety of smells. Reproduction, territory and prey seeking are all dependent on smells, many of which are complex. Importantly, regardless of the complexity of a smell, once it is encountered it can be detected and identified within a second. A key question is, 'How does this happen?' Understanding the underlying mechanisms has the potential to allow the design of fragrances to be based on how the sense of smell operates rather than on the lengthy training of perfumers to build up a working knowledge of what is and what is not perceived when odorants are mixed. The following review addresses this question. It aims to describe what has been learned from psychophysical and neurophysiological studies of the perception of simple and complex smells, and how this information is being used to investigate the relationship between the molecular structure of odorants, the coding of smells by the brain, and what we perceive.

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## 2. Characteristic Outcomes of Mixing Odorants

When two odorants are mixed there can be several outcomes. First, at low concentrations *i.e.* just above the levels that identification of each occurs, it is unusual for any effects to be observed, and both odorants can be identified and perceived at strengths that are not different to when they are sniffed alone [1]. Second, if the odorants are very similar in smell they may produce an additive effect where the perceived strength of the mixture is equal to the sum of the perceived strengths of the two odorants, and both are likely to be perceived. However, as the concentrations of both are increased, the perceived strength of the mixture reaches a plateau and the strengths of the two components will be reduced with any further increment in concentration [2]. Third, the most common outcome of mixing odorants is that the perceived strength of one or both odorants will be reduced. Reduction can be largely nonreciprocal or asymmetric as with mixtures of (–)-carvone (spearmint) and propionic acid (vinegar) [1], where the latter odorant was reduced in strength over a wide range of concentrations and often not identified, whilst the strength of the former remained constant. Interactions can also be approximately reciprocal or symmetric as with mixtures of benzaldehyde (almond) and eugenol (cloves) [1] where both were reduced in strength when mixed at moderate or high concentrations. Finally, mixing can lead to synergism where the perceived strength of a mixture is greater than the sum of the strengths of the unmixed components. Perceptual synergism, however, occurs rarely. Commonly reports of synergism can be accounted for by changes in the concentrations of components in the headspace of media in which they are mixed. Such changes can arise if the solubility of the odorants in the solvent is changed sufficiently by the addition of other ingredients or solvents. Predicting the perceptual strength of even the simplest of mixtures is a difficult task and has been a goal of a number of researchers for many years. Although good approximations have been made for two-component mixtures [2][3] the accuracy of predictions decreases rapidly with increasing numbers of components [4]. Obtaining satisfactory methods for predicting the strengths of complex mixtures is particularly relevant to odor pollution in the environment, since the siting of sewage plants, piggeries and chemical factories is dependent on predicting the perceptual strength of their odors to avoid pollution in residential areas.

To provide an understanding of the mechanisms that underlie mixing effects the following three sections describe the anatomy and physiology of the two best understood parts of the sense of smell, namely, the receptor neurons in the nose and the olfactory bulb, and the current view of how a smell is identified.

### 3. The Receptors

The receptors for odorants in mammals reside on cilia, which are hairlike structures that project from single receptor neurons into the nasal mucus (Fig. 1a and b). A large multigene family encodes 500–1000 types of receptors in humans [5], and each receptor is characterized by a seven-transmembrane protein structure similar to that for hormones and rhodopsin (Fig. 1c). Recent evidence suggests a receptor neuron may have only one type of receptor. Unfortunately, it is not known whether a receptor is designed to sense the total structure of an odorous molecule or a structural feature. Given that there are thousands of odorants and many have similar structures, or a feature of their structures is similar, it appears that substantial competition between odorants may occur for any one receptor type. In this regard, neurophysiological studies have demonstrated that individual receptor neurons can be activated by a range of odorants, not just one particular type of odorant [6–8]. However, different odorants have different affinities for a particular neuron as demonstrated by the very different concentrations required to activate a neuron. Accordingly, with a mixture of odorants competition may occur between agonists to activate a receptor neuron, or between agonists and antagonists and result in the blocking of a site by the latter and failure of the former to activate the neuron (Fig. 1d). Inability of an agonist to bind to a receptor site and activate a neuron constitutes one of the mechanisms that results in the reduction of the perceptual strength of an odorant or no perception. The reduced activation represents one mechanism of *odor suppression* which is the most common outcome of mixing odorants.

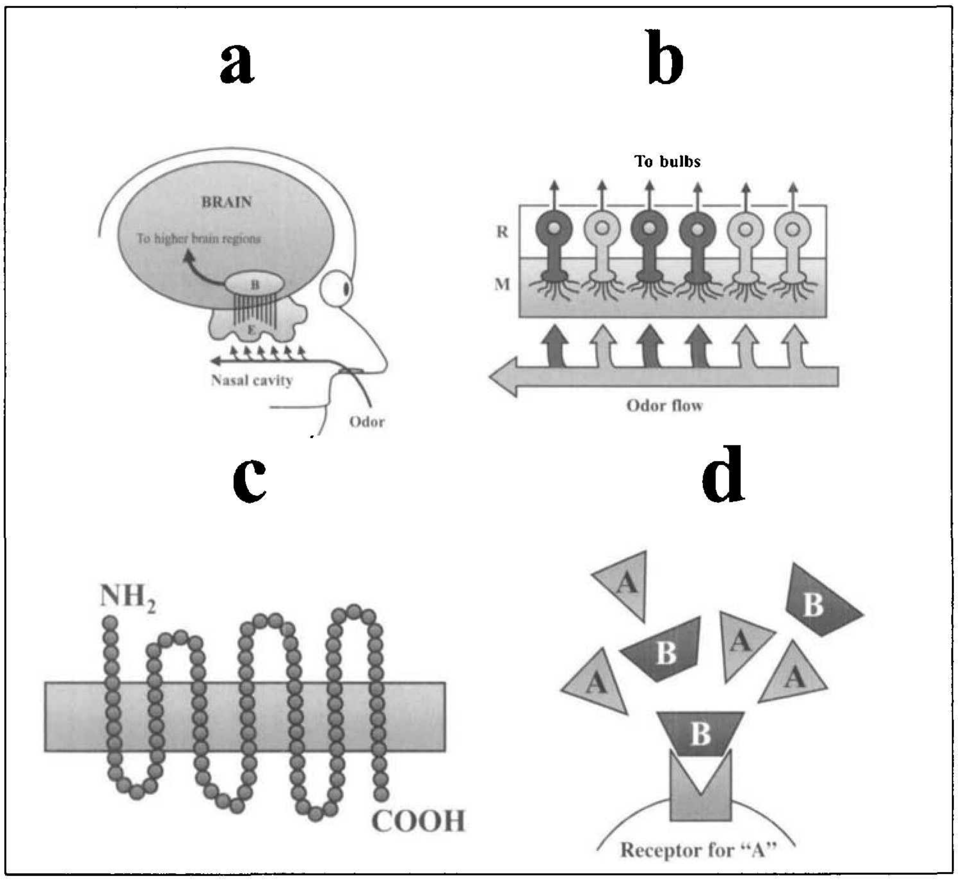


Fig. 1. Diagrammatic representation of a) the olfactory system showing the locations of the olfactory receptor epithelium (E) and the olfactory bulb (B); b) olfactory epithelium showing two odors (light and dark arrows) entering the aqueous mucus layer in which the cilia of their target receptor cells bathe; c) putative seven-transmembrane receptor protein in wall of cilia; d) competition of two odorants A (agonist) and B (antagonist) to occupy a receptor site for A.

### 4. The Olfactory Bulb

Gene technology has also revealed that neurons containing a specific receptor type are sited in only one of four zones in the nasal receptor area [9], and that the single nerve fibers from each of these neurons project into the olfactory bulb in the forebrain and converge and integrate at two glomeruli [10] (Fig. 2a).

The latter are small regions that receive incoming information from the nose and transfer it with or without modification to mitral cells in the bulb, which in turn send it to higher brain centers for identification and a motor response *e.g.* vocal description, or avoid if disliked. Typically in mammals the millions of receptor cells project to 1–2 thousand glomeruli. Neural connections between nearby glomeruli and between mitral cells permit the input from one odorant to inhibit and reduce or block input from another, providing a second form of *odor suppression.* This mechanism is known as lateral inhibition [11]. Beyond the bulb, little is known of how two odorants interact to interfere with perception.

### 5. The Spatial Code and Odor Identification

When an odorant is sniffed it produces a pattern of activated and inhibited receptor neurons [12] which is mirrored by simpler patterns in the olfactory bulb at the levels of glomeruli and mitral cells [13]. The pattern that characterizes an odorant is believed to provide the basis upon which the brain identifies an odor. The patterns in the nose and bulb at low concentrations contain fewer activated and inhibited cells than at high concentrations (Fig. 3a and b). At the lowest concentration an odorant can be identified: the receptor type(s) activated are those for which the odorant has a high affinity or best fit. Increasing the concentration results in the recruitment of more activated cells and more receptor types for which the odorant has increasingly

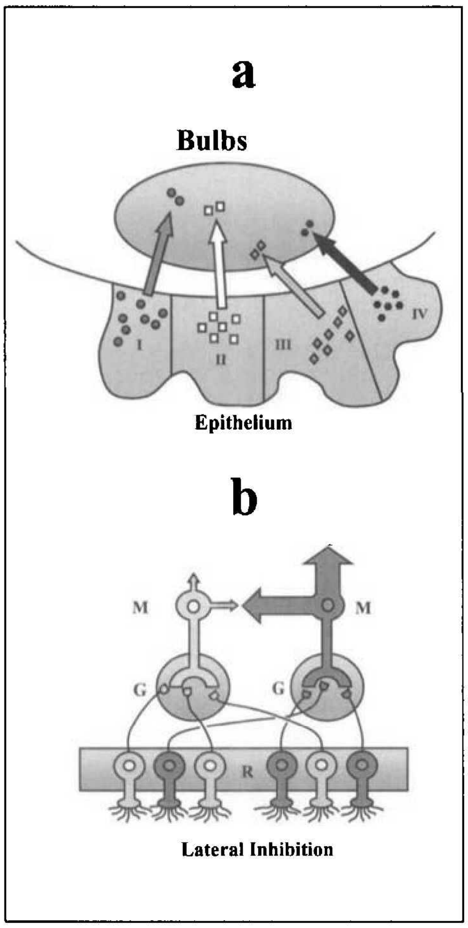


Fig. 2. Neural connections between the olfactory receptor epithelium and the bulb showing a) the four receptor zones in the epithelium, with receptor cells that contain a specific type of receptor projecting to two glomeruli in the bulb; b) the greater activation of receptor cells by a strong odor produces greater neural input to the right hand glomerulus (G) and mitral cell (M), which suppresses activation of the left hand mitral cell by a weaker odor. The size of the vertical dark and light arrows indicate the strength of the neural signal passing (vertical arrows) to other brain centers, whilst the horizontal arrows reflect the amount of suppression of the input from each odor resulting from lateral inhibition.

lower affinity [14]. Increases in the number of receptor types is also accompanied by an increase in the number of glomeruli and mitral cells that are activated. Since a glomerulus contains input predominantly from a population of receptor cells that contain the same receptor type, the increased number of glomeruli provides a pattern that represents the range of receptor types activated by the odorant. The patterns, therefore, increase in complexity as regards the number of receptor types activated as the concentration increases. Such changes in the types of receptors activated are likely to be the cause of changes in odor qualities that occur at different concentrations. For example, low concentrations of pentanal have dry-fruity or nutty odors, whilst high concentrations smell acrid and pungent [15]. The identity of an odorant, therefore, appears to be based on the activation of a combination of receptor types which recently was described as the *combinatorial receptor code of odor identity* [16].

A very important question is whether an odorant can be identified from only one receptor type being activated. Recent data suggest that more than one is required. Thus, aliphatic carbonyl odorants having a C7-carbonyl chain that included the ester, ketone, aldehyde and acid, were found to activate common mitral cells in the dorsomedial region of the olfactory bulb [17]. However, since these odorants have their own distinct smell they must activate at least one other receptor type that is unique to the aldehyde or ester *etc.* The major structural feature that differentiates these odorants is their functional group. The data showed that differentia-

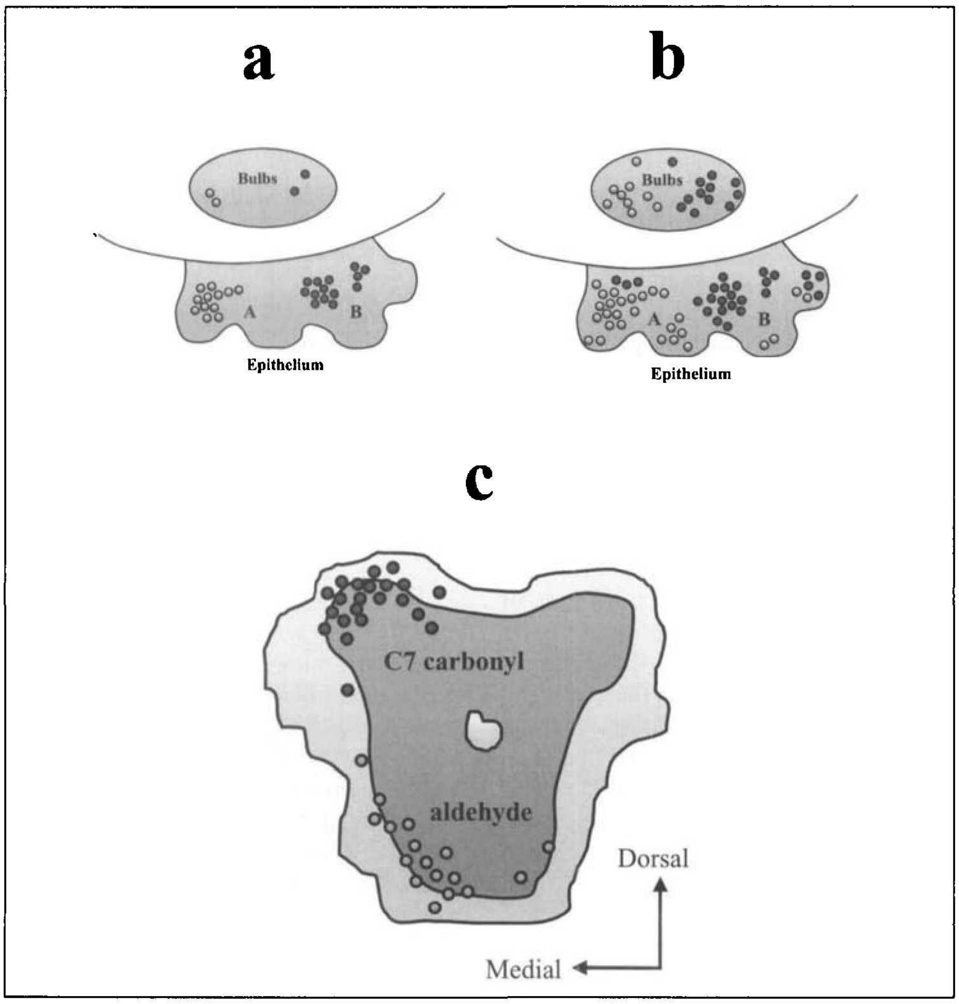


Fig. 3. Patterns of activated receptor cells in the epithelium and glomeruli in the olfactory bulb to a) low and b) high concentrations of odors A and B; c) spatial coding of C7 aliphatic carbonyl odorants showing that two major locations in the olfactory bulb are involved for the aldehyde. The diagram represents a thin slice of the three-dimensional spatial map.

tion of the acid and aldehyde in the bulb may be characterized by the aldehyde having a second major site of activation located in the ventral olfactory bulb (Fig. 3c), whereas sites for the acid were only found in the dorsomedial region [18]. Identification of an aliphatic carbonyl odorant, therefore, requires at least two receptor types to be activated. Similarly, discrimination and identification of different aliphatic aldehydes must depend on activation of an 'aldehyde' receptor and a receptor that can differentiate different lengths of hydrocarbon chains.

### 6. Perceptual Analysis of Odor Mixtures

A question that remained unanswered for many years concerns the number of odorants a human can discriminate and identify in a mixture. Resolution was important because such knowledge should indicate the maximum number of impact components that influence a human's acceptance of a food or fragrance and the number of potential problem odorants in plumes from sewage plants or factories. Currently, no method for estimating the contribution of an odorant to the acceptance or non-acceptance of a product or environmental pollutant includes the effect of perceptual odor interactions. In particular, no consideration is given to the effect of suppression that occurs perceptually between odorants, which, as will be described shortly, commonly results in the loss of identity of most of the odorants in mixtures containing more than five or six components.

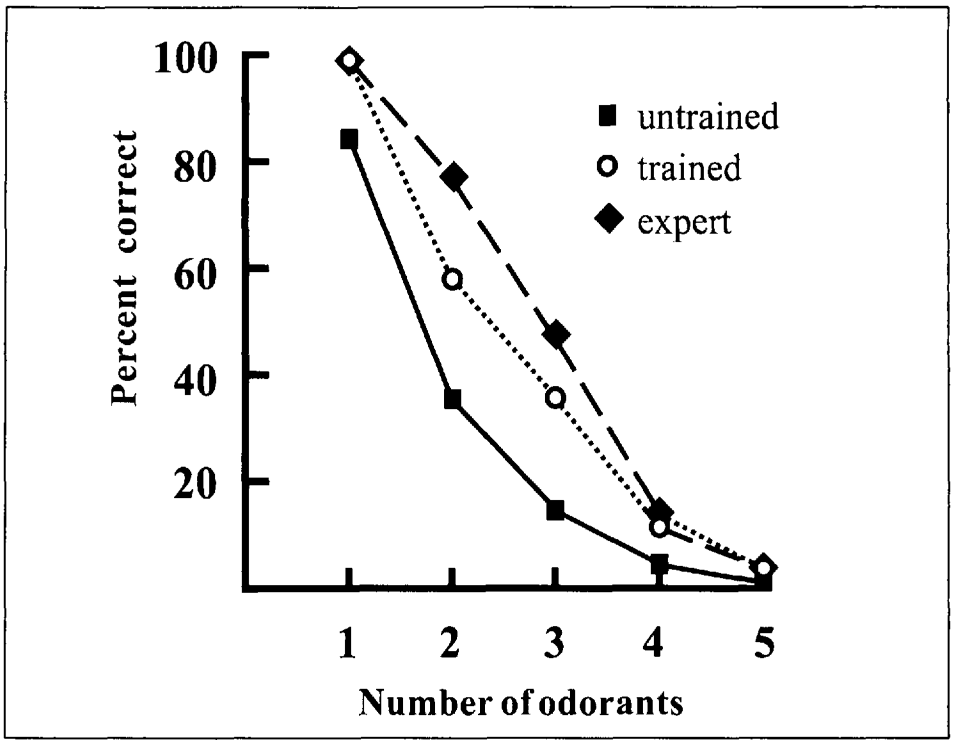


Fig. 4. Percent correct responses of humans when identifying the components in mixtures containing up to five odorants. Untrained subjects were day visitors to the institute; trained subjects were given three weeks of daily training; experts were perfumers and flavorists.

#### 6.1. *Limited Capacity of Humans to Analyze Odor Mixtures*

Over a decade ago it was reported that humans untrained in identifying odorants could identify up to three odorants in mixtures that contained five components [19]. During the ensuing years it was demonstrated that regardless of the method [20], training or experience [21], and type of odorant [22], the limit of three was rarely exceeded (Fig. 4). Since these experiments demonstrated that the limitation did not appear to be due to cognitive influences that might bias the participants to respond in a particular way, it was concluded that the most likeliest reason was that the limitation arose from physiological mechanisms. The following sections describe the three mechanisms that have been proposed to limit perception of odors.

##### 6.1.1 *Odor Suppression at the Receptors*

First, as described above (Section 2) odor suppression can occur when two odorants compete for receptor sites regardless of whether they are both agonists, or an agonist and an antagonist. In the former case both odorants may be perceived as weaker than when unmixed, or one may have a greater affinity for the receptor and be more successful at activating the neuron. As a result the less successful odorant will be perceived to be substantially weaker than the other, or not be perceived. A similar result could occur with an agonist and antagonist, with the agonist being least successful. *Loss of the identity of an odorant*, therefore, can occur early in the processing of an odorous stimulus. Indeed this may have occurred with the binary mixture of (+)-limonene (citrus) and propionic acid where, at a particular set of concentrations, the acid was not perceived even though it was close to moderate strength before mixing [23]. Importantly, increasing the number of components in a mixture increases the likelihood of competition for receptor sites and the chance an odorant will not be perceived. In this regard, it was predicted and demonstrated that this intense competition would result in no odorant being identified in mixtures containing about a dozen equal strength (when unmixed) components [24]. Whether the massive loss of information on identity was primarily due to peripheral interactions remains to be demonstrated, but it is clear from neurophysiological studies [25][26] that significant suppression of an odor(s) can occur at this early stage of processing.

##### 6.1.2. *Odor Suppression at the Olfactory Bulb*

Another established mechanism for odor suppression which occurs in the olfactory bulb is lateral inhibition between glomeruli or mitral cells [27] (Fig. 2b). This mechanism is not based on competition between odorants for receptor sites, but is dependent on an imbalance in neural (electrical) input to different glomeruli or mitral cells. The greater the input to one glomerulus the greater is the chance that this input will inhibit the weaker input of a neighbor from passing to mitral cells and to other brain centers for identification. A similar imbalance of neural inputs between mitral cells provides another mechanism for suppressing the weaker input of one of the odorants. In addition to increasing the difference between the inputs of two odorants, these two bulbar mechanisms provide a means for fine tuning incoming information by eliminating olfactory 'noise' arising from small numbers of receptor cells activated by impurities in an odor mixture or cells for which an odorant has a low affinity for the receptor type. Neurophysiological studies with rats [23] and bees [28] have confirmed that substantial reduction in the amount of input available for passage from the bulb to other olfactory centers occurs even with binary and ternary mixtures.

### 6.1.3. *Odor Suppression and the Spatial Code*

When the perceived strength of an odor is reduced but the odor remains identifiable, the spatial pattern at the periphery or in the bulb that characterizes the odorant will be changed. The most obvious difference will be a reduction in the *number* of receptor cells that are activated or glomeruli that receive input [23][28]. A second less obvious change will be in the *types* of receptors activated (Fig. 5). Changes in both of these were the basis of the prediction that no odorant would be identifiable in mixtures containing about a dozen odorants [24]. In essence the prediction was that the patterns would be reduced to such an extent that the brain would not be able to identify each odorant.

However, another aspect of the changes concerns how much information needs to remain in a pattern to allow identification, and conversely, how much remains when identification is not achieved. This question was investigated using a procedure that defined the several odor qualities an odorant can possess [29]. For example, the major qualities of ethyl glycidate are strawberry, fragrant and eucalyptus, and it is commonly described as 'like strawberry', whilst guaicol is 'burnt-smoky' with lesser qualities of medicinal and chemical. In binary mixtures with methyl salicylate (wintergreen) or anisole (chemical) the major results were the loss of the 'strawberry' or 'burnt-smoky' qualities, but surprisingly the odorants remained identifiable. Clearly sufficient information about other quality characteristics of ethyl glycidate or guaicol remained in the patterns to allow identification. In contrast, the main qualities of methyl salicylate remained when this odorant could not be identified in a quaternary mixture. In this instance it was postulated that although the major qualities of the salicylate were identified, their perceived intensity ratios were not the same as normally associated with the odorant. The authors accounted for the two sets of results by proposing that identification of an odor occurs in a similar manner to facial recognition. For example, as shown in Fig. 6, the presence of only some of the facial features (Fig. 6a), or features that are out of proportion (size ratios are different) (Fig. 6b), makes it difficult to recognize a face. In analogy with the facial recognition model [30], the olfactory model was named the Configurational Hypothesis of Olfaction.

## 7. Perception of Complex Odors

The limited ability of humans to identify only about three odorants in a mix-

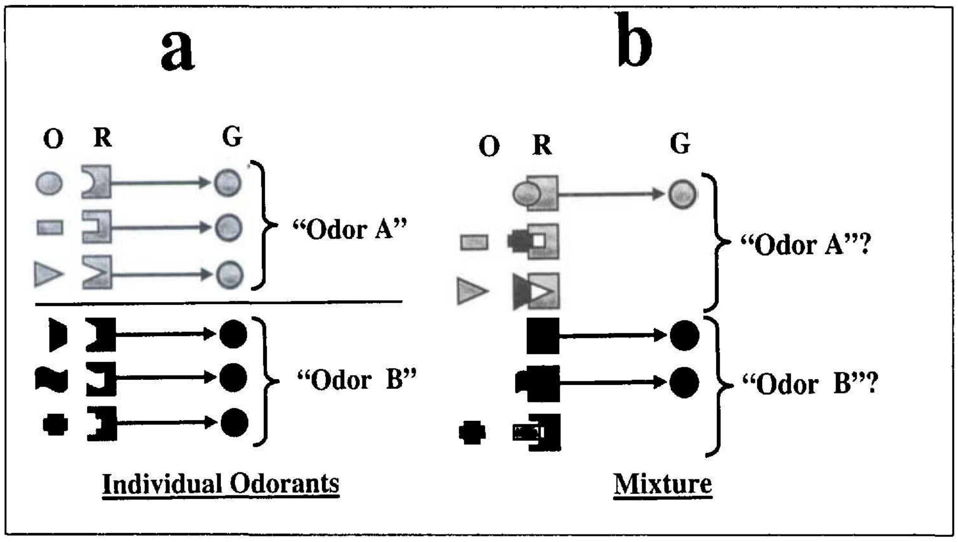


Fig. 5. Activated glomerular patterns for a) odors A and B. Each activates a unique set of receptor types; b) a mixture of A and B showing a reduced number of activated glomeruli and receptor types because of blocking of receptor sites by each odor. O, R and G signify odors, receptor types and glomeruli, respectively.

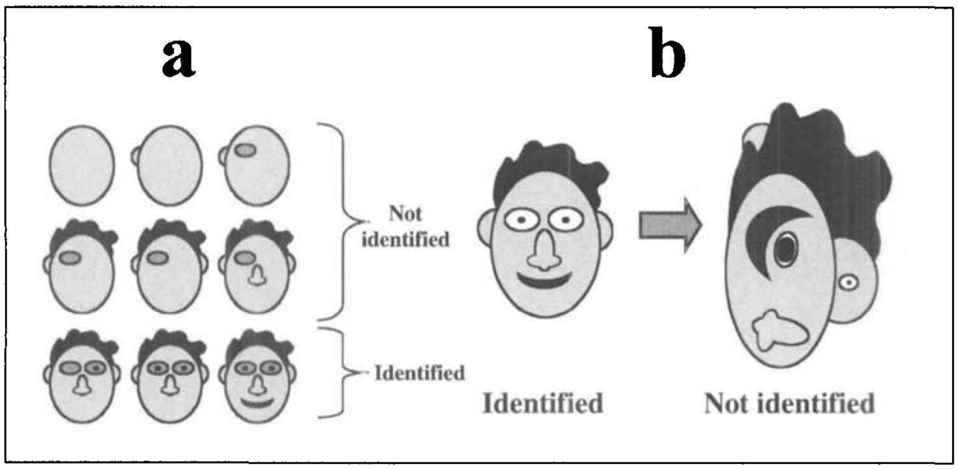


Fig. 6. Identifying faces: a) a minimum number of features must be present for identification to occur; b) features not in their normal proportions result in non-identification.

ture and the speed of identification of commonly encountered complex mixtures as single entities regardless of the number of components present, suggests that the olfactory system uses a rapid system involving pattern recognition to identify complex odorants. Perhaps the best example of how the system may operate is in the identification of the odor of chocolate. The latter is complex and is composed of many odorants, none of which smell like chocolate *i.e.* there is no molecule which alone smells like chocolate. Thus, when a human experiences the smell of chocolate for the first time, there is no special receptor that responds. Indeed the pattern of activated cells will be the combined remains of input from the many odorants present in the mixture, none of which may be individually identified *e.g.* as simplified in Fig. 5b. Accordingly, to establish the identity of chocolate, the pattern of responding receptor or bulbar cells needs to be associated with the word 'chocolate' for the person to identify this smell in the future (Fig. 7).

This hypothesis was tested by investigating the capacity of humans to identify the components of mixtures that were composed of only complex odorants [31]. The odorants included smoky, strawberry, lavender, kerosene, rose, honey, cheese and chocolate. It was proposed that the neural representations of each of these complex odors are stored and processed in olfactory memory as unique and single entities rather than as patterns of the dozens or even hundreds of individual chemical components that the complex odorants contain. Thus, if the odorants are perceived as single entities, a maximum of about three complex odorants should be identified in mixtures. However, if the large number of inputs from the many individual chemicals present are the basis of coding, none of the complex odorants should be recognized. The results were clear-cut with a maximum of three complex odorants being identified, demonstrating that complex odorants are processed as single entities. This interpretation was supported by image analysis of the olfactory bulbs of rats which showed that single chemical odors *e.g.* the citrus odor of limonene [23], or fruity odor of amyl acetate [32], contain similar numbers of activated glomeruli as the complex odor of rats nest which contains hundreds of odors from urine, feces and body odor. In other words, the pattern of responding glomeruli was no more complex in terms of the number activated than the number activated by a single chemical odorant. The major difference between the two patterns, however, would be in the number of receptor types represented in the patterns. The single chemical odorant would be expected to stimulate a relatively small number of receptor types, the number depending on the affinity it had for different receptors. In contrast, the many single components of a complex odor would have activated a variety of receptor types. It is envisaged that part of the information stored in memory which is used to identify a single or complex odorant would be the receptor types stimulated. Identification of simple or complex odors, therefore, proceeds *via* similar mechanisms that involve recognition of the unique neural pattern of each.

## 8. Role of Temporal Processing of Odors in Mixture Analysis

Perception of odorants in mixtures is also influenced by a second olfactory processing mechanism, namely, temporal processing. The existence of this mechanism was based on the finding that odorants can differ by hundreds of milliseconds in the times they take to activate receptor cells [33]. Accordingly, it was proposed that if the time differences between the odorants at the periphery were maintained during the whole odor processing procedure, odorants in mixtures may be perceived at slightly different times [34]. In other words, odorants in mixtures may be perceived in series. Importantly, it was proposed that the first odorant perceived would have a number of advantages. For example, a 'faster' odorant may be more successful in competing for receptor sites and activating

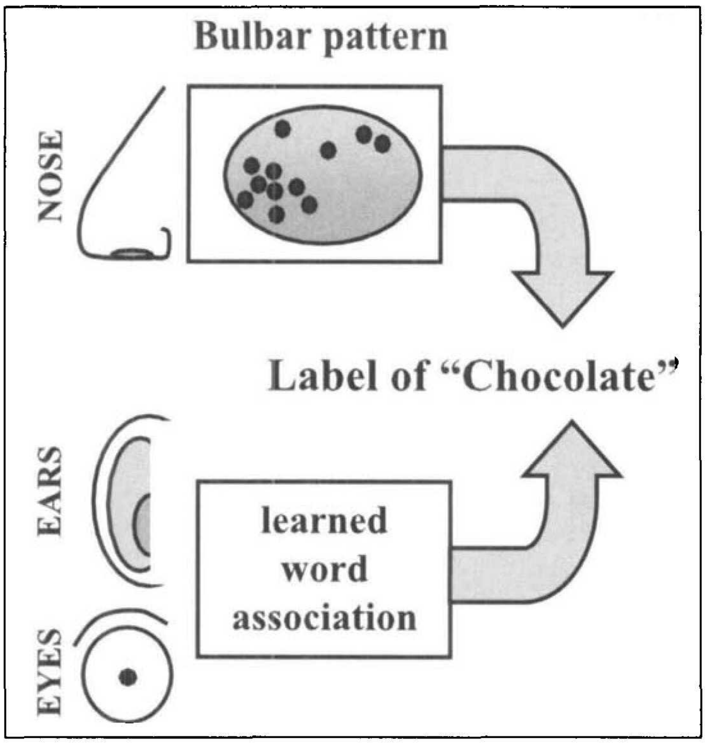


Fig. 7. The process of learning that the spatial response pattern of the complex odor of chocolate is associated with the word 'chocolate'. Visual sighting of a chocolate bar could aid this process.

glomeruli and cells in the bulb which could inhibit later input from a 'slower' odorant. In brief, it was predicted that the 'faster' odorant would be the first identified in a mixture, the 'slower' odorant would incur the greater suppression of intensity, and the number of receptor and bulbar cells and glomeruli in spatial arrays activated by the latter odorant would be reduced, making its identification more difficult. Using a specially designed instrument (olfactometer) to deliver odorants to the nose as mixtures or in series separated by times as small as 200 ms, it was demonstrated that odorants in binary mixtures are perceived in series, with concentration and the type of odorant being the determining factors [35]. The slower odorant was also the one that incurred the greatest suppression as predicted. More recently, in studies on temporal processing with ternary mixtures, it was found that humans could not indicate which odorant was perceived first and in doing so revealed another mechanism that limits the ability of humans to analyze mixtures [36]. The mechanism involves working memory.

## 9. Working Memory and Mixture Analysis

Although not fully understood, working memory is defined as the 'system responsible for the temporary storage and manipulation of information, forming an important link between perception and controlled action' [37]. Thus, when an odorant is identified it is envisaged that the process involves matching of its unique neural pattern with the same in long-term memory, linking the correctly matched pattern with its description in semantic memory, and finally transfer of this information into a vocal or motor response *e.g.* written response, that indicates the identity of the odorant. The process is rapid, occurring within a second, and the information is largely discarded following the response as the brain readies itself for the next task. In the task of identifying the first odor perceived in a ternary mixture, it was found that this could not be achieved [36]. This was in contrast to the successful conduct of this task with binary mixtures. Since it was the inclusion of a third odorant that appeared to prevent specifying the 'fastest' odorant, it was proposed that the problem may lie in the time taken to process and identify the first and second 'fastest' odorants in working memory [36]. If processing of these two odorants was still in progress when neural input from the third odorant entered the working memory process, it is possible that the storage and processing capacity of working memory was insufficient to cope with this new information, became overloaded and loss of order information occurred. To test this proposal the third odorant was delivered to the nose at 0, 300, 600 and 900 ms later than the mixture of the other two odorants. This study showed that for the two groups of odorants investigated, the third odorant needed to be delivered at between 600 and 900 ms after the binary mixture of the others for order of perception to be determined (Fig. 8). However, even under these more favorable conditions, it was very difficult to identify all the odorants present, with few subjects completing the task successfully. Limitations in the capacity of olfactory working memory to process more than two odorants within 600–900 ms, therefore, appears to be the ultimate limiting factor in the discrimination and identification of odorants in multi-component mixtures.

## 10. Summary of Mechanisms Underlying the Perceptual Analysis of Odor Mixtures

The limited capacity of humans to identify the components of mixtures is due to at least three mechanisms. The first involves changes to the characteristic neural patterns of odorants arising from competition for receptor sites and cells in the nose, and inhibition in the bulb and other olfactory centers. This results in a reduction of information in the neural patterns about the identity of individual odorants making it difficult for the

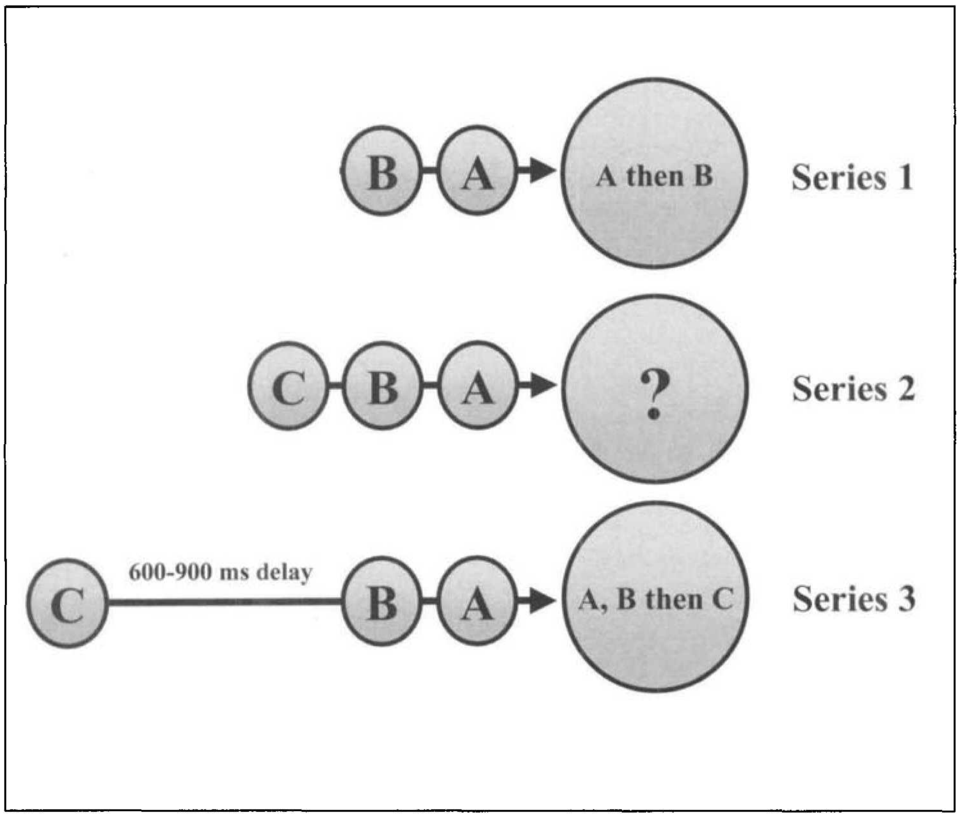


Fig. 8. Temporal processing of odor mixtures. Series 1 represents the perception of a binary mixture of A and B where odorant A is perceived before odorant B. Series 2 represents perception of a ternary mixture of odorants A, B and C and shows that humans could not indicate the order of perception of the three odorants. Series 3 shows that if the presentation of odorant C is delayed by 600–900 ms it is possible to determine the order of perception.

brain to recognize the patterns. The second mechanism, temporal processing, favors identification of the first processed odorant, giving it the opportunity to act as an antagonist towards the other odorants at the periphery and be an inhibitor of neural activity of the other odorants in the bulb. However, the ultimate factor limiting the analysis of odor mixtures to the identification of about three odors is working memory, which does not appear to have the capacity to process more than this number of odorants at the rate they normally enter the nose during a sniffing episode.

The three mechanisms all limit identification of mixture components. But is this as disadvantageous as it seems? Depending on your view, the answer could be yes or no. Certainly the limitation is a disadvantage for the modern chemist whose analytical tools allow large numbers of odorants to be separated and identified from natural and synthetic sources. However, the three mechanisms make it difficult for the chemist to identify the impact odorants in fragrances, food aromas, air pollution and animal communication when all the components are mixed. The other view, however, is that Nature has developed these mechanisms to maximize the rapid identification of complex odors which are the most common odors encountered in everyday life not only by humans, but by all vertebrates and invertebrates. The mechanisms of competition and inhibition reduce the amount of information used by the sense of smell to identify complex odorants and provide the rapid processes needed for indicating whether a predator is near or dangerous gases are present, and fleeing is the appropriate response, or for the rapid assessment of the safety and acceptability of foods before they enter the mouth and during their mastication.

### 11. Molecular Structure and the Odor of Mixtures – New Opportunities

The existence of many different types of odor receptors and the ability of an odorant to activate a number of receptor types suggest that the different odor qualities of a molecule are produced by activation of several receptor types [16]. Accordingly, it should be possible to suppress a specific quality of an odorant by use of an antagonist for the relevant receptor type. This opens up a new avenue of research for the fragrance chemist. The traditional role of the chemist in the development of fragrances has been to synthesize single odorants that are used by the perfumer in complex mixtures. Based on a knowledge of the relationship between the structural characteristics of molecules and odor qualities, the chemist has aimed to enhance particular qualities by optimizing the dimensions and physicochemical properties of a molecule. The emphasis, therefore, has been on the production of a *single* odorant with a single or several odor qualities that will enhance these in a complex fragrance or flavor. However, as described above, when odorants are mixed a number of factors are encountered which determine whether an odorant will be perceived or one or some of its odor qualities lost. None of these possibilities is currently incorporated into strategies for developing new fragrances or flavors.

Thus, it is suggested here that, instead of limiting their approach to synthesizing a molecule which possesses a particular desirable odor quality such as rose-like, in conjunction with the perfumer who selects the ingredients of a perfume, the chemist should design molecules which will block the lesser but undesirable odor qualities of the rose odorant or of other molecules used by the perfumer. In essence, the task of the fragrance chemist can be much more like that of the pharmacological chemist, *synthesizing new fragrance molecules and antagonists* that can be manipulated by the perfumer when creating a perfume. The perfumer would then have two different types of molecules available for creating new products or improving older ones. Indeed being able to suppress undesirable odor qualities with the use of specific molecules could allow the reassessment of molecules previously found to be unsuitable for use. Clearly, developments in gene technology, neurophysiology and psychophysics have created new opportunities for the fragrance chemist and perfumer to apply their skills and knowledge, opening a new era in fragrance development.

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