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Perceptual Processing Strategy and Exposure Influence the Perception of Odor Mixtures

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Abstract

In flavor perception, both experience with the components of odor/taste mixtures and the cognitive strategy used to examine the interactions between the components influence the overall mixture perception. However, the effect of these factors on odor mixtures perception has never been studied. The present study aimed at evaluating whether 1) previous exposure to the odorants included in a mixture or 2) the synthetic or analytic strategy engaged during odorants mixture evaluation determines odor representation. Blending mixtures, in which subjects perceived a unique quality distinct from those of components, were chosen in order to induce a priori synthetic perception. In the first part, we checked whether the chosen mixtures presented blending properties for our subjects. In the second part, 3 groups of participants were either exposed to the odorants contributing to blending mixtures with a "pineapple" or a "red cordial" odor or nonexposed. In a following task, half of each group was assigned to a synthetic or an analytical task. The synthetic task consisted of rating how typical (i.e., representative) of the target odor name (pineapple or red cordial) were the mixtures and each of their components. The analytical task consisted of evaluating these stimuli on several scales labeled with the target odor name and odor descriptors of the components. Previous exposure to mixture components was found to decrease mixture typicality but only for the pineapple blending mixture. Likewise, subjects engaged in an analytical task rated both blending mixtures as less typical than did subjects engaged in a synthetic task. This study supports a conclusion that odor mixtures can be perceived either analytically or synthetically according to the cognitive strategy engaged.

Key words: blending mixture, odor, perceptual learning, perceptual processing strategy

Introduction

One speaks about analytical perception when it is possible to break up a mixture of several distinct qualities into its various components. Hearing is a prototype of analytical perception because of the capacity of humans to differentiate various concurrent sounds, such as instruments from an orchestra. By contrast, synthetic perception occurs when the mixture of qualities generates a single, distinct perception. Thus, vision is a synthetic perception, in that, when red and yellow are mixed, a new perception, orange, occurs.

In everyday experience, our sense of smell sometimes seems analytical and sometimes synthetic. Thus, at a restaurant, we are able to simultaneously and distinctly perceive the odor of food and that of the perfume of a companion; conversely, the odor of hazelnut contains 51 odorants, none of which smell like hazelnut. However, there is no scientific consensus regarding the extent to which taste and smell are synthetic or analytical senses. According to McBurney (1986), fusion of odors and tastes, or of multiple individual odor components, could occur as a function of cognitive strategy, without involving complete perceptual synthesis or analysis. On the basis of subjects' experience, Erickson and Covey (1980) and Erickson (1982) showed that naive subjects perceive mixtures of tastes as being more or less "unitary" than others. For example, mixtures of sweet and bitter tastes are more often perceived as binary, that is, subjects perceive both the sweet and the bitter taste, whereas mixtures of salt and acid tastes are more often perceived as a unit, that is, subjects perceive either the salt or the bitter taste. This issue has received attention in recent years in relation to the integration of odors and tastes in flavors. Schifferstein and Verlegh (1996) suggest that evaluating taste or odor intensities is primarily analytical, except when the stimulus components are perceptually similar, or congruent. Consistent with this, Frank et al. (1991) found that the ability of certain odors to enhance some tastes was significantly correlated with ratings of the perceived similarity of the odorant and tastant. In attempting to explain such effects, Frank et al. (1993), Van der Klaauw and Frank (1993), and Frank (2003) suggested that, given perceptual similarity between an odor and taste, the conceptual "boundaries" that the subject sets for a given complex stimulus will reflect the task requirements, which in turn may influence the extent to which the elements are combined. This explanation invokes the notion that synthesis of perceptually similar dimensions is determined by the attentional focus demanded in an assessment task, an effect that has been experimentally demonstrated (Prescott et al. 2004). However, there has been little evidence of this to date with odor mixtures (Solomon and Prescott 2003).

There is evidence that prior experience with mixture components is another influence on overall mixture perception. Skramlik (1926, cited by McBurney 1986) observed that a tonality made up of 2 notes and perceived in an apparently unique way can be broken up after sufficient training—a typical example of perceptual learning. Similar examples exist in the perception of different volatile odors in wine, following training. Conversely, whether an odor/taste combination is seen as congruent—and hence likely to form a synthetic whole—is dependent upon familiarity or experience with the components as a combination (Stevenson et al. 1995). The degree to which subjects are naive to odor mixtures and their components may, therefore, also be a determinant of synthesis. To date, however, the most consistent finding has been that individuals cannot consistently identify more than 3 odors in a mixture (Laing and Francis 1989; Laing et al. 2002) and that training (Livermore and Laing 1996), adaptation (Laing and Glemarec 1992), or odor type (Livermore and Laing 1998) has little or no impact on this limitation. Similarly, Solomon and Prescott (2003) showed that the perception of binary odor mixtures was not affected either by training and experience of the panellists or by the task required. At least 1 recent study does, however, suggest a role for prior experience with odor mixture components. Mandairon et al. (2006) showed that prior exposure to the odor components of a binary mixture makes it possible for rats to discriminate this mixture from its components. Surprisingly, the improvement in discrimination was not specific to the odors used during the phase of exposure, and it was suggested that the olfactory system treats the binary mixture of similar odorous compounds in a synthetic way before the phase of exposure and in an analytical way after exposure.

The aim of the present study was to investigate the relative influence of both perceptual processing strategy and preexposure to individual odor mixture components on the perception of mixtures. We decided to work with blending mixtures in order to induce, a priori, olfactory synthetic perception (Thomas-Danguin et al. 2007). Therefore, it was necessary in part 1 of our study to assess whether the chosen mixtures produced a unique quality distinct from any of their components (i.e., blending). In part 2, several groups of subjects, exposed or nonexposed to mixture components, were involved in synthetic or analytical tasks and their mixture perception was compared. Our hypothesis is that subjects exposed to the components of the mixture and engaged in an analytical strategy would perceive the mixtures as less typical of the target odor than the other subjects. Indeed, after an exposure to the components, we predict that the quality of each component would be perceptually memorized and thus would emerge from the mixture, leading to a decrease of the perception of the target odor. Likewise, subjects engaged in an analytical strategy would be focused on the different facets of the mixture and thus perceive less the global odor (target odor).

Materials and methods

Subjects

Participants were 120 volunteers (93 women and 27 men; mean = 31.3 years, standard deviation = 12.8 years) recruited at James Cook University campus. The subjects were not informed of the aim of the experiment. They were awarded credit points toward their psychology course or entered into a draw to win 1 of the 20 A$25 vouchers.

Odorants

Three odor-blending mixtures of differing chemical complexity and their individual components were used in the study: a binary mixture (ethyl isobutyrate + ethylmaltol) giving rise to a pineapple odor; a ternary mixture (ethyl isobutyrate + ethylmaltol + allyl-α-ionone) giving rise to a pineapple odor; and a mixture of 6 compounds (beta-ionone + damascenone + frambinone + ethyl acetate + isoamyl acetate + vanilline) giving rise to a red cordial (Grenadine) odor. Additionally, allyl caproate was used as a single odorant giving rise to a pineapple odor.

All stimuli were tested in the first part of the experiment (part 1) in order to verify the blending mixture properties. Only the pineapple ternary mixture and red cordial mixture were used in the second part of the experiment (part 2) dealing with the effect of preexposure and perceptual processing strategy on mixture perception.

Odorants and mixtures were presented on strips of paper placed in 15-ml brown bottles. A specific quantity of each odor was poured on 2 strips of paper (50 μl/strip and 2 strips/bottle), except for frambinone (100 μl/strip and 2 strips/bottle) and ethyl isobutyrate (50 μl/strip and 1 strip/bottle), the quantities of which were selected to match the moderate intensity of the other stimuli. The strips in the bottles were changed after every 10 subjects.

Experimental procedure

In order to study both the effect of preexposure to the mixture components and the effect of the cognitive task on the perception of odor-blending mixtures, each subject was assigned to 1 of 6 groups (20 subjects per group; Table 1) depending on the content of the preexposure and on the task. Thus, each group differed by the odorants they were exposed to (pineapple odorants, red cordial odorants, or nonexposed) and by the task required during the measurement phase (analytic or synthetic). Two control groups received no prior exposure to odorants but were required to assess the mixtures and their components using the differing tasks.

The experiment was undertaken in 2 phases: the first phase consisted of 2 sessions of preexposure to the odorants of the target mixture (pineapple or red cordial odorants) and the second phase consisted of 1 session of rating tasks, in which subjects undertook either a synthetic or an analytical assessment task.

Preexposure phase

The preexposure phase consisted of 2 half-hour sessions, in which subjects were preexposed to the odorants of their respective target mixture (pineapple odorants or red cordial odorants). The aim of these sessions was to preexpose each group (except the 2 control groups who did not undergo the 2 preexposure sessions) to the components of their target mixture, without engaging them in a specific cognitive process (synthetic or analytic). To provide a rationale for these sessions, subjects were told that they were participating in an aromatherapy study in which they had to smell odors and then evaluate their feelings on different scales. Thus, subjects had to smell each component of their target mixture, presented in the same order for every subjects, and evaluate, for each odorant, their well-being using the Differential Emotion Scale (Lang et al. 1997) and the Self-Assessment Manikin (Morris 1995). The 2 preexposure sessions were conducted on successive days.

Task phase

The aim of this phase was to study the effect of the perceptual processing strategy on the perception of odor-blending mixtures. Every subject performed this phase of the experiment (subjects previously exposed to pineapple odorants, subjects previously exposed to red cordial odorants, and subjects not previously exposed), which consisted of 1 session. The session was divided into 2 parts. During the first part, subjects evaluated the target mixture and its odorants using a synthetic or analytical process, according to their group. During the second part, subjects evaluated the other mixture and its odorants (e.g., pineapple mixture and its odorants if they were exposed to red cordial odorants).

Synthetic task. For the synthetic task, subjects were instructed to sniff each bottle and to evaluate the typicality of each odor on a 10-cm linear scale for the target term (end point anchors: poor example–good example). For example, for odorants and mixture related to the pineapple odor, they evaluated the typicality of each odorant and the pineapple mixture for the label "pineapple." By typicality, we wanted subjects to compare and to rate how well each stimulus match the example they thought the odor was of their concept of the target odor (pineapple or red cordial).

Analytical task. For the analytical task, subjects were instructed to sniff each bottle and to evaluate, on 10-cm linear scales (end point anchors: poor example–good example), the odorants in terms of the typicality of several labels corresponding to the description of each odorant in the mixture, before rating the typicality of the target term (pineapple or red cordial). The terms evaluated by the subjects in each mixture are presented in Table 2.

In both tasks, subjects previously exposed to pineapple odorants first evaluated the pineapple mixture and its odorants, followed by the red cordial mixture and its odorants

Table 1 Exposed odorants corresponding to each group during the preexposure phase, and stimuli evaluated during each part of the task phase

Task	Synthetic task			Analytic task		
Groups	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Preexposure	Pineapple odorants	Red cordial odorants	Control group (no exposure)	Pineapple odorants	Red cordial odorants	Control group (no exposure)
Test (part 1)	Pineapple mixture + components	Red cordial mixture + components	Pineapple or red cordial mixture + components	Pineapple mixture + components	Red cordial mixture + components	Pineapple or red cordial mixture + components
Test (part 2)	Red cordial mixture + components	Pineapple mixture + components	Pineapple or red cordial mixture + components	Red cordial mixture + components	Pineapple mixture + components	Pineapple or red cordial mixture + components

(and vice versa if they were exposed to red cordial odorants). In each case, the first sample was the mixture, followed by its components in a random order for each subject. For the control groups, half of each group started with the pineapple mixture and its odorants, whereas the other half started with the red cordial mixture and its odorants (see Table 1).

Data analysis

All statistical analyses were conducted using SAS 8.2 (SAS Institute Inc., Cary, NC) release. Analyses of variance were performed with the general linear model procedure.

Results

Part 1: verification of the blending mixture properties

This part had for its aim to check that our mixtures (pineapple binary and ternary mixtures and red cordial mixture) have blending properties or, in other words, that the mixtures were perceived as significantly more typical of their target term than the components. The way to check this without the bias of a preexposure or a particular task is to analyze the data coming from the group who did not undergo any previous exposure to the components and who performed the simplest task (i.e., synthetic task). Thus, statistical analysis was conducted only with the synthetic control group (group 3 on Table 1) who did not undergo the preexposure sessions and performed a synthetic task (rating on one scale labeled with the target odor name). One-way analyses of variance (ANOVAs) (stimuli) followed by Newman–Keuls post hoc tests were performed for each mixture type to determine if the mixtures were more typical of the prototypical odor than the individual components. There were significant differences between stimuli for the pineapple ($F_{(5,714)}$ = 69.6; $P <$ 0.0001) and red cordial ($F_{(5,832)}$ = 82.3; $P <$ 0.0001) mixtures, each mixture being significantly different from their respective components in the extent to which they typified pineapple or red cordial odor.

Figure 1 shows that, as expected, the mixtures were perceived significantly more typical of either pineapple or red cordial than their components. These results demonstrate that the 3 mixtures constitute odor-blending mixtures for these subjects, as they did for subjects in a previous study (Thomas-Danguin et al. 2007).

Table 2 Terms evaluated by the subjects during the analytical task according to the mixture

Pineapple	Red cordial
Strawberry (ethyl isobutyrate)	Vanilla (vanilline)
Caramel (ethylmaltol)	Raspberry (frambinone)
Violet (allyl-α-ionone)	Camphor (damascenone)
Pineapple (mixture)	Violet (beta-ionone)
	Banana (isoamyl acetate)
	Solvent, ether (ethyl acetate)
	Red cordial (mixture)

The odorant corresponding to the term is indicated in parentheses.

Part 2: effect of preexposure and perceptual processing strategy

For this part, our target mixtures were the pineapple ternary mixture and the red cordial mixture. Subsequent analyses examined the impact of the task (analytic vs. synthetic) and type of preexposure (to components of target mixture, to components of another mixture, or nonexposure) on the perception of the mixtures. Thus, 2-way ANOVAs with factors "Exposure" and "Task" and interaction, followed by

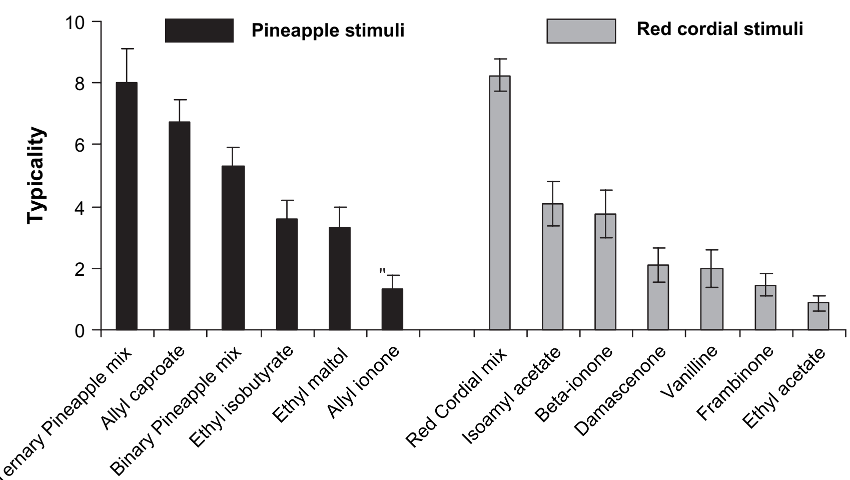

Figure 1 Mean typicality ratings of the term pineapple for odorants and mixtures related to pineapple odor and mean typicality ratings of the term red cordial for odorants and mixtures related to red cordial odor.

Newman–Keuls tests, were performed on the typicality rating of the target terms (pineapple or red cordial) for both mixtures.

There was a significant effect of Exposure for the pineapple ternary mixture ($F_{(2,114)}$ = 3.1; P = 0.047) but not for the red cordial mixture ($F_{(2,114)}$ = 1.5; P = 0.23). Figure 2 (left-hand panel) shows that subjects previously exposed to the components of the pineapple ternary mixture evaluated the mixture as less typical of the target term (pineapple) than subjects either previously exposed to other odorants or not previously exposed. However, there is no significant impact of the exposure on the perception of the red cordial mixture (Figure 2, right-hand panel).

A significant effect of the Task was observed for both the pineapple ternary mixture ($F_{(1,114)}$ = 19.9; P < 0.0001) and the red cordial mixture ($F_{(1,114)}$ = 9.7; P = 0.002). Figure 3 shows that for both mixtures, subjects engaged in a synthetic task rated the mixtures as significantly more typical of their target term (pineapple or red cordial) than subjects engaged in an analytical task. However, no significant interactions between Exposure and Task were observed for either mixture ($F_{(2,114)}$ = 1.2; P = 0.31 for pineapple mixture; $F_{(2,114)}$ = 1.6; P = 0.20 for red cordial mixture) showing that these effects are independent.

Discussion

Our results confirmed that blending occurred in the binary, ternary, and more complex mixtures used here. It was previously observed that a mixture could give rise to a target odor significantly more typical in the mixture as compared with its separate components (Thomas-Danguin et al. 2007). These recent data provided new evidence for a synthetic process in the perception of odor mixtures by humans (Jinks and Laing 2001) and animals (Wiltrout et al. 2003; Kay et al. 2005; Coureaud et al. 2007). As a consequence, such blending mixtures appear to be good models with which to study the effect of perceptual processing strategy and previous exposure on the perception of odor mixtures.

One aim of this experiment was thus to test the hypothesis that prior exposure to the components of a mixture or to other odorants affect the perception of odor-blending mixtures.

It has been argued that, in chemosensory perception, combining components (e.g., odor/taste) that are likely to form a synthetic whole could rely on familiarity, or experience with the components as a combination (Stevenson et al. 1995). Similarly, the degree to which subjects are naive to odor mixtures and their components may, therefore, also be a determinant of the synthetic process in odor mixture perception. Our results showed that only for the pineapple ternary mixture, which consisted of 3 separate odorants, was there an impact of a previous exposure to the components on the perception of the mixture's typicality. Subjects previously exposed to the components of this mixture evaluated the mixture as less typical of the pineapple odor as compared with subjects exposed to other odorants or nonexposed. However, when exposed to other odorants not included in the mixture, subjects were more likely to perceive the mixture as a whole. Thus, only a previous exposure to the components of the mixture influences the perception of the new odor induced by this mixture. One possible explanation for this finding is that perception of the components of a mixture is enhanced by prior exposure—that is, perceptual learning takes place. As a consequence, the perception of the unique quality of the overall odor mixture is attenuated. In that case, perceptual learning may attenuate the synthetic process. However, when exposed to odorants not included in the mixture, the synthetic process is not altered—thus confirming the impact of odor-specific perceptual learning. This is inconsistent with the finding of Mandairon et al. (2006) of an improvement in discrimination that was not necessarily specific to the odors used during the exposure phase.

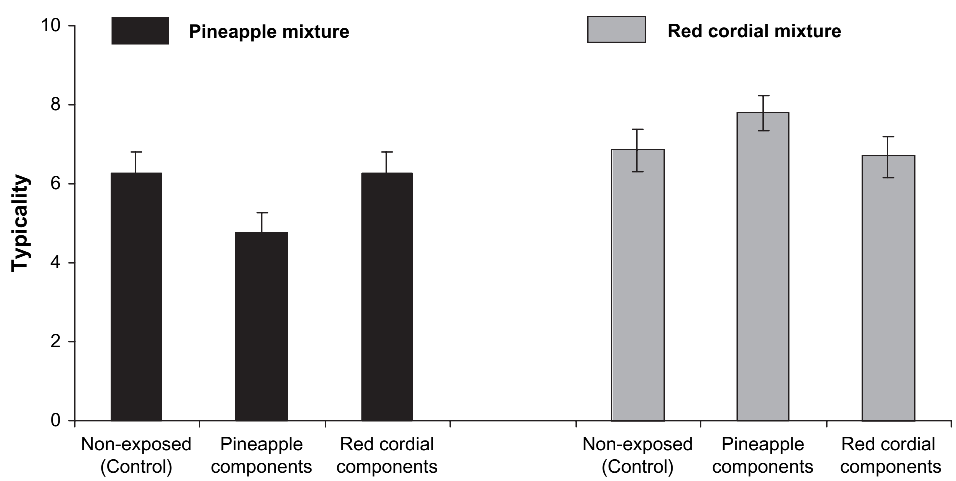

Figure 2 Mean typicality ratings as a function of type of preexposure (pineapple components, red cordial components, or nonexposure) of the pineapple mixture for the term pineapple (left-hand panel) and of the red cordial mixture for the term red cordial (right-hand panel).

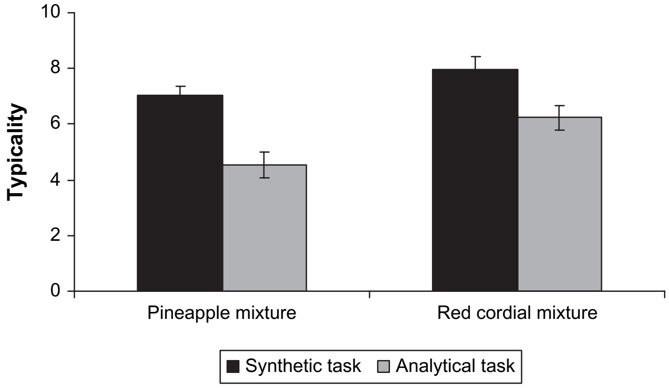

Figure 3 Mean typicality ratings of the pineapple mixture for the term pineapple and of the red cordial mixture for the term red cordial according to the task.

In contrast, no effect of exposure was observed for the red cordial mixture. The obvious difference between red cordial mixture and pineapple mixture is their respective chemical complexity and hence the number of constituents to which the subjects were exposed (6 components for the red cordial mixture compared with 3 components for the pineapple mixture). Laing et al. (2001) and Laing and Jinks (1999) provided evidence to indicate that subjects' failure to discriminate more than 3 components in an odor mixture (Laing and Francis 1989) was memory based, with the capacity of working memory being the limiting factor. The complexity of the red cordial mixture may have exceeded this capacity, leading to only the global odor of the mixture being evident. It can be, therefore, argued that blending mixtures including 3 or fewer components are more likely to undergo an analytic process because of the capacity of humans to identify individual odors in these mixtures. This could explain the decrease in typicality only for the pineapple ternary mixture. Conversely, mixtures including more than 3 components are more likely to undergo a synthetic process, which could account for the absence of effect of perceptual learning on the red cordial mixture. Rabin and Cain (1984) showed that odors that were identified more accurately during the acquisition phase of a memory task were also more accurately recognized during the recognition stage. Whether the addition of such explicit learning or recognition of the odor components during exposure would have also influenced the outcome here remains to be determined.

Another aim of this experiment was to test the hypothesis that perceptual processing strategy affects the perception of odor-blending mixtures. It has been previously demonstrated in studies of odor–taste integration that synthesis of perceptually similar dimensions is determined by the attentional focus demanded in an assessment task (Prescott et al. 2004), but this has not previously been shown for odor mixtures. Our results showed an impact of the perceptual processing strategy on the perception of odor-blending mixtures, independent of prior exposure. For pineapple and red cordial mixtures, subjects engaged in a synthetic strategy rated both mixtures as significantly more typical of their target term than subjects engaged in an analytical strategy. These results suggest that performance of an analytical task, in which the different mixture components were emphasized, led the subjects to perceive the global odor (the target odor) as less distinct. By contrast, subjects who performed a synthetic task were not asked to analyze the mixture and thus mainly perceived the global odor that corresponded to the target term.

One potential explanation for the synthetic group reporting higher typicality is because they "dump" typicality of the component parts into the main category (i.e., the target terms, pineapple or red cordial). In previous research (see, e.g., Clark and Lawless 1994), halo dumping was hypothesized as an explanation for enhanced ratings for a single quality (e.g., sweetness) of an odor/taste mixture in which ratings were restricted to this quality out of other obvious and related qualities such as "fruitiness." However, it is unlikely that a "dumping" effect would have occurred in our case, as subjects in the synthetic group judged a set of distinct odor components for similarity to a prototype quality in memory. In other words, rating of sensory qualities per se was not invoked. Moreover, a dumping of other perceived qualities (e.g., qualities of the components) onto the main category in terms of typicality should have weakened this typicality, rather than have enhanced it. Thus, if subjects perceive another quality (e.g., violet) in, for example, the pineapple mixture, they would presumably decrease their ratings of typicality of the pineapple note, resulting in a reduction of the difference between the analytical and the synthetic groups.

Another possible explanation for our findings is that they result from a response bias in the analytical task due to the fact that subjects would not rate typicality high for the target because they have already marked typicality high for components. However, because no relationship between the ratings for the target term and the other terms was apparent, it is also unlikely that this kind of response bias occurred.

A related question is whether the exposure to the components was a source of the analytical strategies employed. It is possible that exposure to components produces recognition of the components in the mixture and, as a consequence, subjects evaluate the mixtures more analytically. However, this would act to both produce a task by exposure interaction, which was not seen, and to weaken the difference between the effects of the synthetic and analytical strategies. Clearly, these differences were still present, independent of prior exposure.

These results support a view that our perception of odor mixtures is not strictly or immutably either synthetic or analytic but can be influenced by the cognitive process engaged (Livermore and Laing 1996; Solomon and Prescott 2003). In other words, the olfactory system can function either configurally (the mixture is qualitatively perceived as different from its components) or elementally (components are recognizable) depending on the task required. The fact that we observed an effect of the task for both mixtures and an effect of the exposure only for the simplest model shows that both effects do not require the same memory resources. The analytical task does not necessarily need a correct identification of the components of a mixture; rather it directs the subject to focus on different qualities of the mixture instead of focusing on the main odor. Moreover, during the analytical task, the terms on which subjects had to focus were already given, which facilitated the focus of the subjects. This experiment thus provides evidence that information about individual components of a mixture is not completely lost in the olfactory system and that their influence can be demonstrated via their ''reactivation'' in an analytical cognitive strategy. Thus, as suggested by Rescorla et al. (1985), the simultaneous occurrence of several stimuli (pineapple odor and red cordial odor previously experienced as complex mixtures through everyday life) leads to the formation of separated memory representations corresponding to each component of the mixture, in addition to the formation of a mixture-unique configural representation resulting from their joint activation. Thus, through an appropriate task, subjects are able to perceive either the global odor of the mixture or, at least partially, some of its components.

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