Tạp chí Khoa học và Công nghệ ***49*** *(1) (2011) 73-82*

TASTE-ODOR INTERACTIONS AND PERCEPTUAL SEPARABILITY

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Received 12 April 2010

ABSTRACT

Taste-odor interactions are usually studied by asking assessors to estimate the taste intensity of tastants alone or in mixture with odor compounds. We propose another method to study taste-odor interactions based on the selective attention paradigm proposed by Garner (1974). This paradigm is based on the following principle: If two dimensions are separable (i.e., no interaction occurs), the performance at a categorization task based on one dimension is not affected by variations on the other dimension. Two pairs of perceptual dimensions were studied with stimuli varying in: sucrose/vanillin concentrations and citric acid/lemon aroma concentrations. For both pairs of dimensions, results showed that performance at the categorization task on one dimension were consistently lower when the level of the irrelevant dimension varied than when it remained constant. This gave evidence of an interaction for these two pairs of dimensions. This experiment shows the potential of such a paradigm for taste-odor interactions studies.

Keywords. taste-odor interaction, separability.

1. INTRODUCTION

Taste-odor interaction consists in a modification in perceived taste intensity in presence of an odor and vice versa. Many studies have investigated this effect over the past 30 years [25, 33]. The conventional way to study taste-odor interactions is to estimate the taste intensity of solutions of tastant alone or in mixture with odor compounds. When appropriate scales are provided to eliminate the dumping effect [6, 34], a discrepancy in rating is considered as a sign of interaction. The same paradigm was implemented recently to explore more complex interaction schemes involving taste, odor, and texture [32, 35]. Even with more sophisticated

experimental procedures such as "dynataste" [13, 4, 16] where a solution is continuously delivered, allowing to vary either tastant or odorant compound concentrations over the session, evaluations are still based on intensity rating. While this classical approach of taste-odor interaction has been proved useful, its main limit is that even when several scales are used, the observed increase in intensity rating might be due to a response bias difficult to dissociate from a real perceptual effect.

In this paper, we propose an alternative task to study taste-odor interactions that eliminates the dumping effect problem related to intensity rating. This task is based on the selective attention paradigm proposed by Garner (1974), in which assessors are asked to categorize the stimuli rather than to judge their intensity. In this context, taste (e.g. sweet) and odor (e.g. strawberry) are seen as two perceptual dimensions and a perceptual interaction is defined as the inability for subjects to make judgements regarding one dimension (e.g., taste) while ignoring the level of the other dimension (e.g., odor). In Garner (1974) terms, an interaction between a taste and an odor will occur if the taste and the odor are not "separable". If two dimensions are separable, classificatory judgments made on the attended dimension should not be disturbed by variations on the irrelevant one. For instance, shape and color are separable dimensions (one can identify shape and ignore color at the same time), whereas pitch and loudness are integral dimensions (the loudness of a pure tone changes along with its frequency). Garner proposed an operational definition of separability based on speeded classifications. The basic principle of Garner's selective-attention paradigm is generally implemented with four stimuli obtained as a factorial combination of two levels of the two studied dimensions. In the shape – color example, the four stimuli could be: a red circle, a green circle, a red square, and a green square. Assessors are presented with a set of these stimuli and their task is to identify, as quickly as possible, the shape of the stimuli. In a first experimental condition, the *control condition*, the stimuli differ only by their shape; the irrelevant dimension for shape judgement, color, remains constant. Assessors receive two separate series of stimuli: a series of red circles and red squares and, later on, a series of green circles and green squares. In a second experimental condition, the *orthogonal condition* or *filtering condition*, the irrelevant dimension, color, varies as well as the relevant one, shape; the stimuli differ by both their shape and their color. Assessors receive series of the four stimuli: red circles, green circles, red squares, and green squares randomly presented. Finally, in the third experimental condition, the *correlated condition,* the relevant and the irrelevant dimensions co-vary. Assessors are presented with a series of red squares and green circles and, later on, a series of green squares and red circles. The reverse situation is also tested: Assessors perform color judgments on series of stimuli where the shape is either the same (control condition) or varies (filtering and correlated conditions). Garner states that if the performance is equivalent over the three experimental conditions and for both classification tasks, then the two dimensions are separable. By contrast, if the dimensions are not separable (i.e., integral) the filtering condition should lead to interference and thus, impair performance, whereas in the correlated condition, a facilitation is expected. It is worth noticing that the situation is not to be systematically symmetrical. For instance, in vowel and tone identification, tone can be attended to selectively whatever the pronounced vowel, whereas tone differences interfere with vowel identification. The Garner interference paradigm was used in psychophysics to study a wide variety of interactions: auditory perception of pitch and loudness [12], pitch and timbre [15], timbre dimensions [5], linguistic and perceptual dimensions of speech [3, 14], face perception of gender and expression [17], emotion and identity [2], emotional expression and gaze [11]. It was also used to study interactions between cross-modal dimensions such as auditory and visual dimensions [20, 23], and olfactory and visual dimensions [7].

The objective of the present work is to test the feasibility of adapting Garner's selective-attention paradigm to study taste-odor interactions. Two pairs of taste – odor dimensions were chosen based on previous work: sucrose – vanilla and citric acid – lemon, both being expected to lead to perceptual interaction [33].

When implemented with visual or auditory stimuli, performance measurements are based on reaction times (RT). But, with chemical stimuli, RTs are difficult to measure because of the difficulty of monitoring stimulus onset. Moreover, RTs are appropriate to evaluate performance when the categorization task leads to only a few mistakes. This is easily achieved with natural categories such as shape or color but not with odor or taste intensity levels. The categorization of even two intensity levels of the same aromatic compound is expected to lead to some mistakes. Garner (1974) stated "*Errors in performance constitute, of course, a common alternative to the measurement of time"* (p. 123). This received support in the theoretical framework of categorization RT [18]. According to this framework, a perceptual category includes stimuli that share common characteristics. These stimuli can be represented on a perceptual map as a region of space separated from the adjacent category by a boundary. Stimuli close to the boundary are less typical of the category; they are ambiguous and lead to a larger number of mistakes in categorization judgments. Maddox et al. (1998) demonstrated that the closer to the boundary a stimulus is, the longer the reaction time to make a decision regarding its category membership. Thus, both reaction times and classification accuracy reflect the difficulty level of categorization tasks. Thus, in the present experiment performance measurements are based on error rates not on RT and, more specifically, on d' values computed from Hit and False Alarm rates.

In the original Garner paradigm, the correlated condition is expected to facilitate speeded classification with integral dimensions but not with separable dimensions. However, as highlighted by Ashby and Townsend (1986), signal detection theory predicts an increase in d' value in the correlated condition compare to the control condition even with separable dimensions. As enhanced performance in correlated condition is predicted for both separable and integral dimensions, we did not implement this experimental condition.

2. MATERIAL AND METHODS

2.1. Assessors

Fifty-three assessors (32 females and 20 males), students at the *Université de Bourgogne*, took part in the experiment. They were randomly assigned to one of the two groups. A group of 28 assessors worked with the sucrose/vanillin stimuli and a group of 25 assessors with the citric acid/lemon aroma stimuli. The unbalanced number of assessors was due to defections through the experiment. Assessors were paid for their participation.

2.2. Products

Two pairs of stimuli were tested: sucrose/vanillin and citric acid/lemon aroma (IFF, France). For each pair, four solutions were prepared as a factorial combination of two concentrations of each tastant/odorant (table 1). Solutions were prepared in mineral Evian bottled water. Five mL of solution were presented in small disposable tumblers and served at room temperature. Assessors were instructed to sip and swallow the whole sample.

Table 1. Constitution of the two sets of stimuli

SET 1	Sucrose	
Vanillin	Level 1 (42.5 g/l)	Level 2 (60 g/l)
Level 1 (50 ppm)	S1V1	S2V1
Level 2 (800 ppm)	S1V2	S2V2
SET 2	Citric acid	
Lemon aroma	Level 1 (0.8 g/l)	Level 2 (1.2 g/l)
Level 1 (50 ppm)	C1L1	C2L1
Level 2 (600 ppm)	C1L2	C2L2

2.3. Procedure

The experiment had a familiarization phase and a test phase. During the familiarization phase, assessors had to learn the taste and odor intensity levels. For instance, they learned the intensities elicited by vanillin solutions of 50 ppm and 800 ppm, as “low” and “high” vanilla intensity respectively. During the test phase, assessors had to categorize the stimuli according either to their taste or to their aroma. Thus, when categorizing according to vanilla aroma, they had to decide for each stimulus, whether it belonged to the “low” or “high” intensity level, as previously learned.

In each group (sucrose/vanilla and citric acid/lemon) half of the assessors started with the taste categorization and the other half with the aroma categorization. As the procedure was exactly the same for the two groups of assessors, in what follows we only detail the familiarization and the test phase for the sucrose/vanilla group.

2.3.1. Familiarization phase

During the familiarization phase, assessors had to learn the two intensity levels of each stimulus. They first tasted two sucrose solutions S1 and S2 corresponding to the high and low concentration levels to be used in the test. Then, they received a series of 20 samples (10 S1 and 10 S2 concentrations) in random order and were asked to categorize the intensity level of each of them as high or low. For each assessor, the process was repeated until he/she achieved 15 correct categorizations out of 20, up to three times. Only assessors who reached this performance level participated in the test phase. The same learning procedure was implemented to learn the aroma intensity levels of the two vanilla concentrations V1 and V2.

2.3.2 Test phase

In the test phase, assessors were asked to make categorization judgements according to intensity level of the target attribute, on three series of sucrose-vanillin solutions. For sweetness judgements, the three series were arranged as follows: one series of 15 S1V1 and 15 S2V1 solutions, one series of 15 S1V2 and 15 S2V2 solutions and finally one series with 15 samples

of each of the four solutions (S1V1, S1V2, S2V1, S2V2). The first two series corresponded to the control condition (sucrose concentration varied and vanillin concentration remained constant) and the third series to the filtering condition (both sucrose and vanillin concentrations varied). The presentation order of samples was chosen at random but was the same for every assessor.

For vanilla assessments, the same procedure was followed, except that in the control condition, the concentration of vanillin varied and the concentration of sucrose remained constant.

3. RESULTS

3.1. Discrimination capacities

To evaluate assessors' ability to discriminate the two taste and odor intensity levels, *d*' values were computed using raw data from the two experimental conditions. Whenever frequencies of 0 or 1 were observed, they were converted to 1/(2N) and 1-1/(2N) respectively, with N the number of stimuli [19]. This leads to a maximum d' value of 4.25.

Taste intensities were relatively easy to discriminate as shown by *d*' values ranging from 1.5 to 4.1 for sweetness and from 1.7 to 3.8 for acidity. Odor intensities were much more difficult to discriminate: d' values did not exceed 2.7 for lemon and 2.8 for vanilla. Only results from assessors who were able to discriminate the two odor intensities (i.e., with d' values significantly higher than 0 at a 10 % confidence level) were considered for subsequent analyses. This led us to consider only 21 assessors for the sucrose/vanillin stimuli and 13 for the citric acid/lemon stimuli.

3.2. Control vs. Filtering conditions

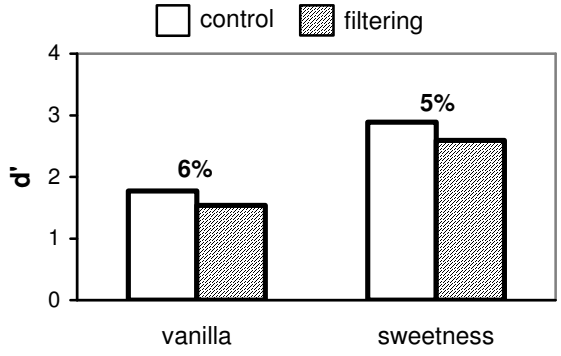

Figure 1. Results of the sucrose / vanillin solutions. Mean d' values for sweetness and vanilla aroma judgements in both experimental conditions

Individual *d*' values were computed for taste and odor judgements in each experimental condition. Mean *d*' values for the sucrose / vanillin stimuli (Fig. 1) are lower in the filtering condition than in the control condition. One-tailed paired t-tests show that the difference is significant at 5% level for sweetness categorization and the same trend was observed ($p = 0.06$)

for the vanilla categorization. Lower *d'* in the filtering condition means that assessors had more difficulty categorizing intensity levels when the irrelevant dimension varied than in the control condition where the irrelevant dimension remained constant. This indicates that even if assessors were asked to focus on sweetness, they were not able to completely ignore the vanilla aroma and vice versa.

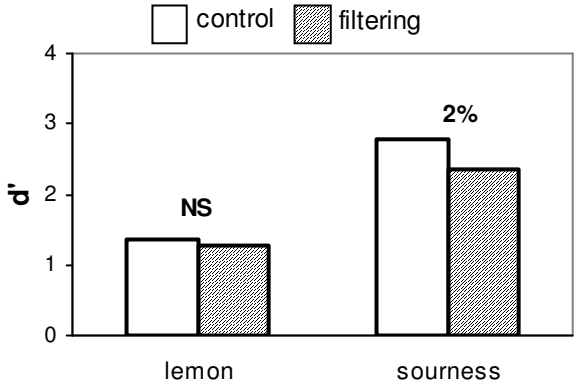

Figure 2. Results of the citric acid / lemon aroma solutions. Mean d' values for acidity and lemon aroma judgements in both experimental conditions

Figure 2 shows the results for the citric acid / lemon stimuli. Mean *d*' values are also lower in the filtering condition than in the control condition, but the difference is significant (5% level) for the acidity categorization only. The evidence of an interaction between acidity and lemon odor is thus not as clear as the one observed for the sweet and vanilla dimensions. A closer examination of the lemon categorization results shows that only three assessors exhibit higher d' values in the filtering than in the control condition. Two of them show a very large increase (+1.5 and +2.5). These two assessors also have a 100% hits or a 0% false alarm in the filtering condition.

4. DISCUSSION

The aim of the present study was to evaluate whether Garner's selective-attention paradigm can be implemented to study taste-odor interactions. Substituting d' for the classical reaction-time measurements, we found that assessors were not able to focus their attention selectively on either the odor or taste dimension of a sweet / vanilla. And the same was true to a lesser extent for an acidic / lemon solution. For both solutions, we observed an interference between odor and taste. That is, the categorization task based on the odor dimension was affected by variations on the taste dimension and *vice versa*. This result confirms recent work showing that odor and taste might be integrated dimensions [25] rather than separate or additive dimensions as was first proposed by Murphy, Cain and Barthoshuck (1977) or Murphy and Cain (1980). According to Stevenson and his collaborators [28, 30, 31] the integration between smell and taste might result from a perceptual learning of the association between taste and odor. Consistent with this interpretation, White and Prescott (2007) showed that an odor can prime the cognitive system to expect a particular type of taste based on past flavor experiences.

The question that naturally emerged from this result is that if taste-odor integration is the result of a perceptual learning, is this process reversible? If we encode flavor as a whole in our everyday life, are we able, with some training, to split out taste and odor and evaluate them in an independent way? Such questions are highly relevant for sensory scientists using descriptive analysis. This approach is aimed at describing the perceptions elicited by one or several product(s) as the sum of several quantified attributes (i.e., perceptual dimensions). According to Frank (2002) "when subjects are asked to attend to multiple stimulus attributes, the instructions encourage them to disentangle the concepts for each of the attributes and this constricts the conceptual boundaries of the attributes and minimizes dimensional interactions" (p. 142). For example, providing only a sweetness scale to evaluate a sucrose-vanilla mixture might lead to a broader interpretation of the sweetness concept, including sensations such as fruitiness for instance. By contrast, providing both a sweetness and a fruitiness scale might lead to a narrower sweetness concept, as excluding fruitiness sensation from sweetness is now implicitly stated. An implication of this interpretation is that taste and odor dimensions might be separable by individuals trained to focus their attention on these components but not by untrained consumers. Such effects of training however are not always found. Indeed, Stevenson (2001) and Stevenson and Case (2003) found no difference in the ability of trained and untrained participants to separate an odorant-sucrose mixture into its components. Further work is needed to tackle this issue and Garner's selective-attention paradigm might prove to be a useful tool to compare the ability of trained and untrained assessors to separate odor and taste dimensions as it is not sensitive to the dumping effect demonstrated by Clark and Lawless (1994).

A related issue is the measure of the degree of integration of two perceptual dimensions. Separability and integrality may be viewed as the two extremities of a continuum. The degree of integration may depend on the nature of the stimuli. Indeed, previous work showed that odors do not all have the same effect on taste perception; some increase taste intensity, others decrease it and others have no effect. Thus, Garner's paradigm is potentially more informative than the intensity-rating approach because the discrepancy between control and filtering conditions provides an indication on the integrality level of the perceptual dimensions. This might help us to better understand the nature of interactions regarding both the nature of the perceptual dimensions and the expertise of the subjects. It might be especially relevant when these issues are studied through cross-cultural experiments as the comparison of rating scores across cultures is a delicate issue related to difficulties in translating labels and differences in the use of scales. A categorization task would probably overcome most of these difficulties.

However, Garner's paradigm is not exempt from experimental difficulties when implemented with chemical stimuli. Assessors' sensitivities are quite variable for chemical senses. Thus, categorizing the same pair of stimuli can be a very difficult task for some assessors and easy for others. This inter-individual variability leads to the exclusion of a number of assessors: those who did not perceive the difference between the two levels and those who made virtually no mistakes. To overcome this problem, the difficulty of the task could be adapted to individual sensitivity by adapting the concentration of the two stimuli to each assessor. Obviously, this is time consuming. But, as the categorization task requires a learning step prior to the test, concentrations might be adjusted through an adaptive scheme implemented at this step.

Separability vs. integrality was proven to be an operational concept to account for relationships between perceptual dimensions in visual and auditory fields. The present study indicates that it could also be effective with chemico-sensory dimensions relevant for food perception. However, integrality demonstrated with Garner's selective-attention paradigm, is a

global effect that may encompass perceptual as well as decisional components. Ashby and Towensend (1986) proposed a theoretical framework accounting for several varieties of perceptual independence: The Generalized Recognition Theory (GRT), a multi-dimensional generalization of signal detection theory. GRT assumes that independence (or interaction) may hold at a perceptual or a decisional level, in the same way as responses to A-not A tests rely on both detectability (d') related to the perceptual difference between the stimuli, and to a criterion related to the decision process. Thus, GRT is undoubtedly a powerful approach to explore in depth interaction processes and their origins. The experimental approach is based on an identification task, typically with nine stimuli obtained as a factorial combination of three levels of the two studied dimensions. Results are summarized in a confusion matrix analyzed through a MDS approach. Although Rosett, Klein and Ennis (1997) did implement this approach with food model stimuli (solutions varying in saltiness and thickness), it is still a very difficult and time-consuming task for the subjects – especially with chemical stimuli, as it requires to learn to identify the nine stimuli. It probably also requires a longer pre-test phase to choose levels of stimuli on both dimensions to avoid floor and ceiling effects. Thus, Garner's selective-attention paradigm might be relevant to study interactions as a first step, allowing us to determine whether the two dimensions are separable or integral. If the dimensions are demonstrated to be integral, the GRT approach may lead to a deeper understanding of underlying processes.

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TÓM TẮT

TƯƠNG TÁC MÙI VỊ VÀ SỰ PHÂN CHIA CẢM GIÁC

Tương tác mùi vị thường được nghiên cứu bằng cách yêu cầu cảm quan viên ước lượng cường độ vị của các chất tạo vị trong dung dịch đơn hoặc trong hỗn hợp với các hợp chất tạo mùi. Chúng tôi đề xuất một phương pháp khác để nghiên cứu các tương tác mùi vị dựa trên học thuyết về sự chú ý có lựa chọn (selective attention paradigm) của Garner (1974). Học thuyết này dựa trên nguyên tắc sau đây: nếu hai chiều cảm nhận là độc lập nhau (nghĩa là không có tương tác), năng lực phân nhóm trên một chiều sẽ không bị ảnh hưởng bởi sự dao động trên chiều còn lại. Hai tổ hợp gồm hai chiều cảm nhận được khảo sát với các tác nhân kích thích dao động ở các mức khác nhau của: nồng độ đường/vani và nồng độ acid citric/mùi chanh. Đối với cả hai tổ hợp, kết quả cho thấy năng lực phân nhóm trên một chiều trong trường hợp chiều còn lại thay đổi ở các mức khác nhau luôn luôn thấp hơn so với trường hợp chiều còn lại không đổi. Kết quả này cho thấy có sự tương tác giữa hai chiều cảm nhận. Thí nghiệm này cho thấy tiềm năng ứng dụng của học thuyết sự chú ý có lựa chọn trong nghiên cứu tương tác mùi vị.

Từ khóa: tương tác mùi vị, sự phân chia cảm giác.