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BASIC PSYCHOLOGICAL PROCESSES IN FOOD TASTING SITUATIONS: ANALYSIS IN NOVICE TASTERS

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Basic Psychological Processes in Food Tasting Situations: Analysis in Novice Tasters

Procesos Psicológicos Básicos en Situaciones de Cata Alimentaria: Análisis en Catadores Noveles

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TESIS DOCTORAL DIRIGIDA POR

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La psicofísica pone en relación el mundo físico y nuestra experiencia interna. De eso versa precisamente este trabajo. Esas sensaciones internas, transcurridos cuatro años plenos de expectativas, estímulos, incentivos, decisiones, ajustes, éxitos, errores... son las que quisiera compartir en este momento con vosotros. No elegí un camino dulce, elegí un camino salado y ácido… pero tuve el bálsamo del aceite, el bálsamo de vuestro apoyo. Gratitud eterna.

A *Juanma, Manuel Miguel y viceversa*… mi modelo de disociación convergente aditiva.

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A mi madre Dolores

A mi hija Cris

A todas las mujeres que dedicaron su vida

a la búsqueda del conocimiento

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1 ABSTRACT

This dissertation aims to improve the understanding of the psychological processes involved in organoleptic evaluation, providing a new characterization of the tasting situation that allows for a comprehensive analysis of the sensory and decisions dynamics that take place when complex gustatory stimuli are tasted. To explore this issue, a detection task in the context of sensory analysis of basic flavors was designed to be carried out with novice tasters within the laboratory setting, but adopting an ecological validity approach. Different factors that would affect sensory and decision processes were manipulated using a dissociative model based on Signal Detection Theory: the Double Dissociation Additive Test, to separate effects on sensitivity and decision performance. Experimental designs followed the structure of full factorial between-subjects designs including at least one factor for each of the processes that were simultaneously manipulated, following the dissociative model mentioned above. Non-parametric measures of sensitivity A' and bias $B'_{D,}$ *and robust analysis of variance were used for separating sensory and decision processes. In agreement with the dissociative proposal of SDT and several findings within the context of olive oil tasting, selective influences on sensitivity and response bias were found providing support for the independence assumption and the methodological approach. Results also revealed that, aside tasters' sensitivity, decision-making processes take an essential role in tasting situations, endorsing the transfer of this methodology to a natural context for optimizing sensory evaluation. Implications for basic sensory research, food science and consumer's preferences domains are discussed.*

2 INTRODUCTION

In dynamic environments, living organisms are forced to decide among multiple courses of action, frequently binary choices, on the basis of uncertain information. For instance, an animal in a natural environment needs to be sensitive to the changing conditions of that environment, rejecting unsafe food and eating healthy food on the basis of its color or its flavor. Similarly, an expert evaluating the overall quality of a given food must accept or reject a product sample on the basis of the combination of its positive and negative attributes. These binary decisions may vary in their relative value or importance. For instance, the need of correctly identifying the safe food is more important in the winter, when food is scarce, and the cost of accepting a food of dubious quality may be lower than the cost of rejecting it, than in the spring, when food is plentiful and the animal can afford to reject edible food as there plenty of available alternatives.

This dissertation is about how humans, when confronted with a discrimination problem, adapt their choices to the changing environment in order to take optimal decisions. More specifically, this dissertation focuses on the problem of how tasters exposed to similar flavors are able to take advantage of contingencies in order to capitalize, for instance, the available rewards or the relevant contextual information. Although many studies find that human behave optimally (i.e., adopt the decision criterion that maximizes reinforcement or correct responses; see for example, McNicol, 2005; Swets, 1996; Wickens, 2002), little is known about decision-making processes under changing contingencies in the tasting domain. To this end, an experimental task involving a mixture of basic flavors was designed, and several sensory and cognitive factors were manipulated under ecological validity conditions. The innovative approach adopted here aims to provide a new characterization of the food tasting situation that allows for an integrated analysis of the sensory and decisions dynamics that take place when complex gustatory stimuli are tasted. To achieve this goal, a dissociation model based on Signal Detection Theory is proposed and tested: the *Double Dissociation Additive Test* (Ramos-Álvarez, Moreno-Fernández, Paredes-Olay, & Rosas, 2013). Non-parametric measures for quantifying processes and robust type statistical analysis complete this methodological proposal.

2.1 PSYCHOPHYSICS AND TASTE

"Psychophysics is the study of the relationship between physical events and our internal experience of these physical events" (Allan & Siegel, 2002). Detection or discrimination tasks are generally used for measuring sensitivity in psychophysical research. Usual tasks search for distinguishing between confusable, similar stimuli, different intensities of the same stimulus or also between the presence and the absence of a low intensity stimulus. In a standard psychophysical experiment, stimulus characteristics are systematically manipulated and observers are asked to report their perception of stimuli that vary as a function of those selected features. For instance, a typical detection task may require the participant to answer a simple question such as "*can you hear the tone?*" Alternatively, a discrimination task may require participants to distinguish between two similar visual stimuli. Detection or discrimination problems are quickly solved when the differences between stimuli are strong and clear. However, under conditions of weak signals and background noise, the task is performed under uncertainty, and observers usually fail to identify exactly which stimulus is presented. For instance, consider a tasting task in which a judge is required to detect saltiness in a series of low concentration solutions of salt and distilled water. Some of the stimuli will be obviously identified as salty, but others will be more difficult to assess. The judge will "draw a line", a criterion sensation of saltiness that is considered enough to make a decision, so that any stimulus stronger than such a criterion sensation will be named as "salty", and any stimulus weaker than such a criterion sensation will be named as "not salty". Every situation of detection and discrimination has at least two psychological components or processes: The sensory process (which transforms physical stimulation into internal sensations) and a decision process (which decides on responses based on the output of the sensory process).

2.1.1 Classical Psychophysical Methods

Classical psychophysics opened the possibility of studying human perception through scientific methods, providing sensitivity indexes valid for the different sensory channels. The classical psychophysical methods (limits, adjustment, and constant stimuli) developed by Fechner (1860/1948) were designed to infer the stimulus value corresponding to the theoretical threshold derived from the observed detection performance data. Sensory threshold was among the first quantitative concepts established in experimental psychology and, despite of receiving considerable criticism almost from its inception, it has been widely used, and still is. *Absolute threshold* was defined as the minimal amount of energy that may be noticed by an organism. By convention, the concept was operationally defined as the stimulus intensity value that elicits the response "perceived" on 50% of the trials. This approach assumes that sensations directly depend on the intensity of the stimulus features, so that they are perceived only when their intensity is above some specific absolute level or threshold. Under this conception of processing sensations, for any given attribute (e.g., saltiness) there is a stimulus value such that only greater intensities should produce the state of sensation (e.g., the degree of salt concentration needed to detect saltiness).

Nowadays we know that the classical view of a fixed threshold value is incomplete, and that methods and measures derived from this concept are limited in order of fully reflecting the complexity of human perception. The classical methods of psychophysics make effective provision for a single parameter, the one associated with the sensitivity of the observer. These methods do not include any analytical procedure for independent specification of the subjective components involved in human perceptual judgments. These two aspects of performance are confounded in experiments in which the dependent variable is the intensity of the stimulus that is required for a threshold response (Swets, Tanner, & Birdsall, 1961). Discrimination is usually required in ambiguous situations, with concurrent or previous stimuli that show slight differences with the target stimulus. Ambiguity favors the presence of biases and mistakes of different nature which contribution to performance will be undetected under the methods used by classical psychophysics.

Modern psychophysics brings a new concept of sensory process, replacing the notion of a fixed threshold value and dichotomized sensitivity by the idea of a continuous variable. From this perspective, sensation depends on the stimulus properties and the perceiver‘s sensitivity, but also on other individual factors such as the observer‘s motivation, beliefs or interests. For estimating these later aspects, modern psychophysics provides a quantitative and independent measure of the criterion of responding. There is left, as a result, a relatively pure measure of sensitivity (Swets, Tanner, & Birdsall, 1961). In the following section we briefly review the basics of this psychophysical approach.

2.1.2 Signal Detection Theory

Signal Detection Theory (SDT) was developed within the field of communications in the first half of the twentieth century. Some years later it was taken up within the field of experimental psychology as an attempt to understand some of the features of human behavior when confronting detection of weak stimuli that fall beyond the explanatory scope of the traditional theories of thresholds. SDT provided a new framework to describe human behavior in a variety of perceptual tasks, solving an old problem in psychophysics: Controlling or specifying the criterion that the observer uses to make a perceptual judgment (Swets, Tanner, & Birdsall, 1961). This framework showed to be so powerful and reliable that SDT became the basis for many models of discrimination across cognitive psychology, despite of its lack of explanatory power. The key of this success was that, from its earliest applications to psychophysics, SDT provided researchers with methodological tools for separating decision from discriminability processes (e.g., Swets, Tanner, & Birdsall, 1961).

Variability of the decision criterion across different observers or experiments had been seen as a nuisance that could potentially cloud or distort the estimates of accuracy. SDT model was relatively more successful than other accuracy estimates in treating this issue by developing an accuracy measure that is potentially independent of shifts or difference in criterion. That way, SDT develops two estimates, one for *sensitivity* and another one for *decision criterion*, that are assumed to be independent from each other (Macmillan & Creelman, 2005). Sensory performance refers to the ability to distinguish among different stimuli, depending on the observer's acuity and on the physical features of the stimulus. Sensitivity is assumed to be a relatively stable property of the sensory process. Alternatively, the decision criterion used by the observer represents the chosen cut point for responding (i.e., the limit or frontier that the observer establishes along the sensory continuum to consider that a given stimulus was presented), and it depends on subjective aspects as motivational states, past learning experiences, or attitudes.

Decision criterion is assumed that may vary widely from task to task and from time to time.

Thus, from SDT perspective, performance in a given perceptual task is understood as the result of two distinct cognitive processes that may and should be separately analyzed: A discrimination process or sensitivity (the actual ability to detect the stimulus or attribute), and a decision process or response strategy (the decision making result related to the value of sensation that determines when a given stimulus is going to be considered as present or as absent). By extracting these two parameters from the data, one related to decision, and one related to sensitivity, detection theory isolates the role of nonsensory factors, so that a relatively pure measure of sensitivity remains. Thus, SDT provides an analytical technique for separating two psychological processes, sensitivity and criterion, allowing for measuring each process independently from the other (Macmillan & Creelman, 2005; McNicol, 2005; Swets, 1996; Swets, Tanner, & Birdsall, 1961).

As mentioned above, SDT was initially developed for characterizing perceptual discrimination performance. In discrimination tasks, the goal is to measure the acuity with which individuals make perceptual or cognitive distinctions. To measuring an observer's detection sensitivity relatively uninfluenced by changes in decision criteria, the model requires to work with two types of detection trials: Some containing the *Signal* (target stimulus that needs to be detected), and some containing no signal (*Noise* stimuli). Observer sensitivity and response bias are measured by examining performance on both signal and noise trials. In the basic Yes/No task, participants are required to render a binary classification of each stimulus. In this experimental situation, a decision will have one of four possible outcomes: The observer may say "yes" or "no" and may in either case be correct or incorrect. In SDT terms, the outcome of this decision may be a hit, a miss, a correct rejection or a false alarm. To this goal, the hit and false alarm rates are computed. The *hit* rate is the probability of an observer saying "yes" when the signal is present. The *false alarm* rate is the probability of an observer answering "yes" when the signal is not present. Miss (saying "no" when the signal is present) and correct rejection (saying "no" when no signal is present) rates can be computed easily, as they mirror hit and false alarm rates, although these measures are not needed for further computations.

In Detection Theory, the signal is assumed to be characterized as a distribution of values on a continuum of sensory evidence. On any given trial there is some noise present in addition to the signal –the stimulus presented in the experiment. So, the trials on which a signal is present are typically defined as Signal+Noise (SN) trials. On trials where no stimulus is present, there is assumed to be some subjective sensation suggesting to the participant that a stimulus might be present. For instance, there may be some background interference or variability in the sensory registration process that is interpreted as evidence to favor stimulus detection. Thus, a distribution of values of Noise strength (N) is also assumed. Detection analysis can be applied whenever there is some overlap of both distributions. That is, whenever there is some range of values on the sensory evidence continuum for which the observer is unsure of whether a signal was presented or not. If the overlap of the distributions is minimal, signal and noise trials will be relatively easy to tell apart, and the observer will appear to be very sensitive. If the distributions overlap more, observer's sensitivity will be relatively low, as detecting the signal will be difficult. Thus, the distance between the signal and noise distributions can be taken as a measure of sensitivity.

An observer's performance will depend not only on how much overlapping there is between the signal and noise distributions, but also on where the response criterion is located. If the criterion is set at a relatively low level of sensory evidence, the observer will detect most of the signals (hits) but s/he will give many false alarms. Such a lenient observer is named as "liberal." If the criterion is set to a higher level of evidence, the observer will detect fewer signals and the hits rate will decrease. High criterion settings characterize a strict or "conservative" observer. In this sense, a criterion is usually described as lying on a continuum that goes from liberal (many hits and many false alarms) to conservative (few hits and few false alarms). In other words, conservative observers have a positive bias, or tendency to say "no", whereas liberal observers have a negative bias or tendency to say "yes" (Macmillan & Creelman, 2005).

As the hits rate is the probability of correctly identifying a signal, it can be defined as the area of the signal distribution that lies to the right of the response criterion. Similarly, the false alarms rate is the area of the noise distribution to the right of the criterion. It is assumed that both the signal and noise distributions are normal and have equal variance (see Figure I1). Under this assumption, a common measure of sensitivity, d', can be computed. This sensory index is defined as the distance between the means of the signal and noise distributions (Tanner & Swets, 1954). A d' of 0 describes chance-level discrimination (i.e., a complete overlap of the signal and noise distributions and a complete lack of discrimination). A d' of 1 shows moderate performance, and d' of higher values is interpreted as good performance. On the other hand, the response criterion is computed by the use of a decisional index that complements the sensory parameter. Beta (β) has been the most popular measure to compute response criterion. It is defined as the relative distance associated to the height of the signal and noise distributions at the point in which the observer establishes a response criterion (Macmillan & Creelman, 2005; Tanner & Swets, 1954).

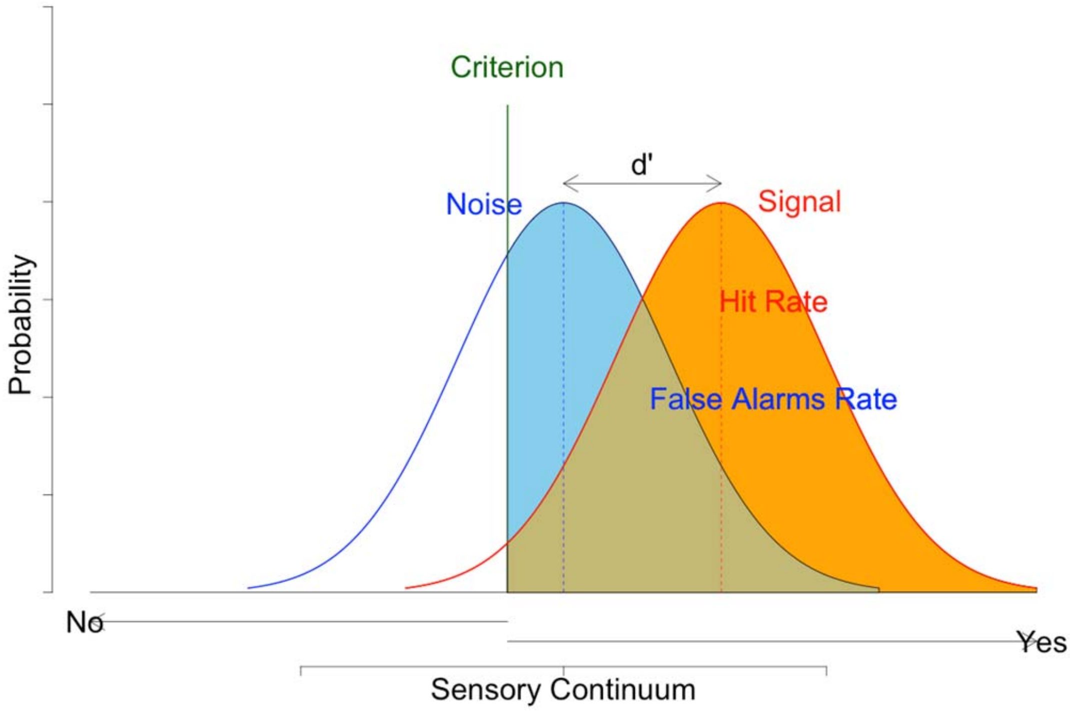

Figure I1: Signal Detection Theory. Representation of the distributions of values of noise and signal strengths.

2.1.2.1 Optimal criterion: Ideal observer versus Real observer

The relatively weak signals commonly used within Psychophysical experiments do not usually produce consistent "yes or no" responses due to large number of factors and psychological processes that may affect observers. In fact, any given observer may be naturally biased to respond either liberally or conservatively. Additionally, biases may be also experimentally induced. Without altering the stimuli used as signal and noise, shifts on the criterion location have been reported when the relative probability of signal trials has been modified (lowering the proportion of signal trials makes observers more conservative), when observers have received different incentives for giving "yes" or "no" responses, or when they have been instructed to be strict or lax with their senses (Macmillan & Creelman, 2005; Swets, 1996; Wickens, 2002). For instance, Ramos-Álvarez, et al, 2013) instructed participants to favor either "yes" or "no" responses within an olive oil tasting experiment, finding that participants behaved conservatively or laxly regardless of their sensitivity to discriminate the stimuli. Similar effects have been found when participants are informed about the upcoming signal-noise ratios (e.g., Swets, Tanner, & Birdsall, 1961), or when they are informed about differences in relative monetary payoffs for their hits, false alarms, misses and correct rejections (See, Warm, Dember, & Howe, 1997). Under these circumstances, SDT specifies the optimal cutoff criterion along the continuum on which the observed events are arranged as a function of both: Signal-noise base rates and payoff matrices. According to SDT, the optimal criterion value for any particular diagnostic setting and test purposes takes into account both, the prior probabilities of the two alternative conditions to be distinguished –p(N) vs. P(SN)-, and the benefits and costs of correct and incorrect decisions about these conditions (McNicol, 2005; Swets, Tunner & Birdsall, 1961; Wickens, 2002).

The *ideal observer* is a hypothetical individual that is able to make an optimal use of all the available information, placing the decision criterion to maximize a given decision goal. The ideal observer is the benchmark provided by SDT against which performance of human and animal subjects may be evaluated in a given task. Performance of the ideal observer indicates what is possible given the limits imposed by the random character of the presentation of the signals. In a situation in which there are different gains or costs associated to each outcome of responding, observers can adjust the criterion to minimize the cost or maximize the gain.

A main difficulty for SDT as a model of human performance follows from the discrepancy in behavior between performance of real observers and the expected performance of the ideal observer suggested by the model. In experimental situations, shifts on criterion positions under different manipulations are easily found, but real observers usually fall short of ideal behavior. Non-optimal decision behavior results when the observer establishes a fixed cut-point on the decision axis that does not maximize correct responses and the expected payoff, or when the cut-point varies from trial to trial. In this sense, many studies suggest that human observers fail to move their decision criterion to such an extreme position as the one required by SDT for optimal performance (Bohil & Maddox, 2003; Healy & Kubovy, 1981; Macmillan & Creelman, 2005; Swets, Tanner, & Birdsall, 1961; Thomas & Legge, 1970; Turner, Van Zandt, & Brown, 2011; Ulehla, 1966; Wickens, 2002).

2.1.2.2 Measuring Sensory and Decision Processes

The clearest advantage of the use SDT in decision-making situations is counting with a number of useful measures of performance. Observers' performance may be evaluated with respect to their sensory abilities, as in classical psychophysics, while being evaluated with respect to the location of their criterion at the same time. As stated above, sensory measures (e.g., d') are used to characterize the observer's sensory capabilities or the effective signal strength. A good sensitivity measure should be invariant when factors other than sensitivity change. Meanwhile, criterion measures (e.g. β) are used to measure the effects of subjective factors on decision. Response-bias statistics reflect the relative degree of preference for "yes" and "no" responses. Sensitivity measures increase with hits and decrease with false alarms, thus statistics that compute sensitivity should depend on the difference between those two terms. However, response-bias indexes depend on the sum of both ratios (Macmillan & Creelman, 2005).

A traditional approach used within SDT to characterize the sensory and decision processes is the computation of what has been called Receiver Operating Characteristics Curves (ROC). ROC curves can be created from the hits and false alarms rates of a given observer, allowing for a descriptive analysis of performance. This graph relates the probability of false alarms to hits, allowing the influence of the different variables that affect the observer's judgments to be visualized. Sensitivity is a function of curvature in these graphs. For instance, the more the curve bows to the upper left corner, the higher the sensitivity it represents (high number of hits combined with a low number of false alarms). Conversely, a flatter the curve represents lower sensitivity. All the points along a single ROC curve reflect the same sensitivity or d', so that ROC curves are iso-sensitivity functions. Differential sensitivity is shown by different ROC curves that may be generated by manipulating the discriminability of the stimulus, or the sensitivity of the observer. At the same time, different points along a single ROC curve represent different levels of bias. Technically, bias is defined as the slope of the ROC curve at a given point. The nearer a pair of false alarms and hits is to the right upper corner the more lenient the criterion reflected is. Points placed near the left bottom corner reflect stricter criterion. Thus, for a given d' a more conservative criterion is indicated by both lower hit and false alarm rates while a more liberal criterion is reflected in higher hit and false alarm rates. ROC analysis is also useful for assessing parametric requirements (i.e., Gaussian distributions and equal variances) in order to apply any index derived from SDT (McNicol, 2005). Data fit to the parametric model may be observed in the shape of the ROC (asymmetrical when the equal variance assumption is not satisfied). If the ROC curve is a straight line when it is transformed in z coordinates, the Gaussian assumption is met.

Despite its usefulness, ROC curves pose some limitations. Estimating sensitivity with this technique (i.e., by d') requires to count with several points of performance corresponding to changes in the criterion (see Macmillan, & Creelman, 2005; Sweets, 1996; Wickens, 2002). As a consequence, it is not possible to obtain a direct measure of the sensory process, as the sensory measure depends on the criterion process and may be contaminated by it. In addition, those points of performance corresponding to changes in the criterion are commonly obtained by requesting participants to rate the certainty of their responses, assuming that changes in confidence only reflect changes in the decision strategy. However, confidence judgments may vary also as a function of other factors such as perceiver's strategy, task's difficulty and the presence of feedback (i.e. Stillman, Brown, & Troscianko, 2000).

The use of the more direct estimations provided by SDT indexes overcome the problems associated to the use of ROC curves described above. Detection theory indexes are categorized as parametric or nonparametric on the basic of their distributional assumptions. It is common practice to use pairs of sensitivity and bias indexes that have been similarly categorized (See et al., 1997). As stated above, classical indexes d' and β have been the most commonly used indexes in psychophysical tasks. The use of d’ and β is only justified when the mathematical assumptions of normality and homogeneity of the variances about the density and probability underlying functions have been confirmed (Tanner & Swets, 1954). These requirements restraint its general use in situations in which the amount of available information is limited. In addition, contrarily to what it is assumed by SDT, several results suggest that d’ and Beta are not strictly independent from the statistical point of view. Specifically, Beta index has a restricted margin of variation when sensory index d’ has low values (see a simple demonstration in Macmillan & Creelman, 2005). As a consequence, dissociation between processes may depend on the chosen indices (Snodgrass & Corwin, 1988) and researchers face the complex issue of establishing which combination of sensory and decision indexes would be optimal to dissociate between the two processes. This is not a trivial issue, given that over thirty computation formulas have been proposed to evaluate sensory and decision processes within the SDT framework (e.g., Balakrishnan, 1998; Snodgrass & Corwin, 1988). In the context of the research conducted in this dissertation the choice of the proper indexes is especially important, given that flavor tasting only allows for counting with a limited number of observations, making unlikely to fulfill the parametric assumptions. Thus, we will pay special attention to the role of nonparametric indexes.

Nonparametric indexes proposed for estimating sensitivity and decision processes are based on ROC space. Pollack and Norman (1964) proposed a measure (later named A’) based on the area below the curve for quantifying sensory process. Analogously, Hodos (1970) proposed a nonparametric measure for estimating the decision process. However, the explicit computation expression for these indexes was derived by Grier (1971): A’ index for sensitivity and B’ index for the criterion estimation. Snodgrass and Corwin (1988) examined dependencies between sensory and bias measures showing that B’ index was limited at low levels of discrimination. Some years later Donaldson (1992) proposed B'_D index that came to solve this dependency problem. Computation for A’ and B'_D indices is as follows:

$$\left\{ \begin{array}{c} Grier\ A' = 0.5 + \left[sign(H - FA) \dfrac{(H - FA)^2 + |H - FA|}{4 \cdot Max(H, FA) - 4H \cdot FA} \right] \\ Donaldson\ B'_D = \dfrac{(1 - H)(1 - FA) - H \cdot FA}{(1 - H)(1 - FA) - H \cdot FA} \end{array} \right\}$$

See et al. (1997) conducted three experiments in a vigilance task involving factors that affect response bias with the goal of evaluating the effectiveness of the five alternative indexes of bias defined by SDT (β, c, B'', B'_H, and B'_D). Parametric measure c was the most effective of all five indexes. When only nonparametric measures (B'', B'_H and B'_D) were taken in account, B'_D showed a relatively greater responsiveness to nonperceptual manipulations of probability and payoff, remaining effective at chance performance levels (c.f. parametric indexes discussed above). They recommended using c rather β whenever a parametric model is involved, and using B'_D when a nonparametric model is used. An extended discussion of this and other SDT based measures may be found in Macmillan (1993), McNicol (1972), and Stanislaw & Todorov, (1999).

As a follow up in the line of research that searches for the best dissociation between sensory and criterion processes, Ramos-Álvarez et al. (2013) have recently developed a method that allows for assessing the interaction or independence between the sensory and criterion indexes within a single experimental design, avoiding the confounds generated by indirect inferences (i.e., Stillman et al., 2000). This method, derived from the Sternberg' Additive Factors Method (1969, 1998), has been named as the *Double Dissociation Additive Test* (Ramos-Álvarez et al., 2013). This model has been successfully applied to study the dynamics of the psychological processes in olive oil tasting situations. Within the context of olive oil tasting, Ramos-Alvarez et al. (2013) also showed the suitability of using a non-parametric approach to the sensory analysis (see also Paredes-Olay, Moreno-Fernández, Rosas, & Ramos-Álvarez,, 2010). Given the restraints of sensory evaluation already raised, the best choice in this situation would be the use of a nonparametric alternative to compute sensory and decision indexes. Ramos-Álvarez et al. (2013) compared different pairs of psychophysical indices in the olive oil tasting context (A'- B'_D, A'-B', d'-c, and d'-Log Beta) confirming that indices A' and B'_D were the most appropriate for food sensory evaluation as they have the lowest degree of bias on measurement (see also See et al., 1997). Additionally, as the assumptions of classic statistics are easily broken in tasting experiments, and the results are likely to include extreme values, the use of more powerful robust estimators is recommended by the authors as being the most suitable to the performance analysis in food science.

2.1.3 Sensory evaluation of food

Sensory evaluation is defined as a scientific method to measure, analyze, and interpret human responses to the food features perceived through the senses (Stone & Sidel, 2004). This discipline aims to understanding psychological responses to physical stimuli, and thus it is related to the specialized fields of psychophysics. However, a sensory judgment may also be considered as the result of a decision-making process because it ends producing a final choice among several alternative possibilities. Evaluation methods are regulated by international organisms that unify and supervise the properness of the sensory practice. Food analysis is governed by a series of International Organization for Standardization (ISO) standards. For instance, the International Olive Council (IOC) is the organization that protects developing and growing of the olive grove and its products, and as such, it has established the general method for the organoleptic evaluation of oils that should be internationally followed (IOC 2007, 2012, 2013).

In food science, sensory measures are established with respect to the variations along a physical continuum as the intensity of an attribute or concentration. Evaluation may be addressed to characterizing of sensory performance under threshold conditions (i.e., forcing the taster to reach a performance limit) and also under suprathreshold conditions that cover the daily-life range of stimulus intensities more realistically. Threshold measures allow for an accurate analysis of sensitivity of a detailed sensory function. Suprathreshold measures allow for the study of the performance and integrative functioning of sensory systems over their entire operational range. In both cases performance is commonly measured through two types of tests: Discriminative (difference and sensitivity tests) and descriptive tests. Difference tests are conducted to find a difference between the control and target food samples, while sensitivity tests are aimed to detect sensory characteristics. Finally, descriptive tests are carried out for a joint evaluation of qualitative and quantitate features of the food (Poste, Mackie, Butler, & Lardmon, 1991).

Human senses are used as an analytical tool in sensory analysis. Trained judges are frequently used to evaluate qualitative and quantitative features of a food, although no-experienced panels may also be established for preference testing and consumption research. An assumption in sensory analysis is that the flavor of a food may be quantitatively described in terms of a set of separate attributes. For this goal, tasters learn to identify, quantify and describe the properties and attributes of a given food separately. A basic question that falls outside the scope of this approach is whether there are perceptual changes when multiple taste compounds are presented together or even if mixing the components produces a singular new flavor (Rochman, Guinard, & O'Mahony, 1997). When stimuli are complex the difficulty of the decision is increased given the possible interaction among their components. Research on this topic has reported that central phenomena in taste perception: Adaptation, cross-adaptation, enhancement or suppression may occur when adding stimuli of the same or different qualities together (e.g., Bartoshuk, 1975; Gillan, 1984; Keast & Breslin, 2003; Lawless & Heymann, 2010; Meiselman, 1968; Moskowitz, 1972; O'Mahony & Wingate, 1974).

Variability across tasters may also be increased by physical fluctuations that cause very slight changes in the perceived intensity of a food upon repeated tasting. Such changes are usually unnoticeable during normal eating but they may affect performance on difference tests (Lee & van Hout, 2009). To produce reliable and valid data, panelists must have an ability to optimally perform the task and to repeat their judgments. It is therefore necessary that certain physical, physiological and psychological conditions which might affect human judgments are avoided or controlled. For example, panelists must be free from taste and odor perception disorders, allergies or those medications that may alter their ability to taste. Physiological factors as adaptation or fatigue and other psychological features that could bias decisions should be also taken into account (e.g., expectations, attitudes, and previous experiences, information related to the food or the mere aspect of the sample; i.e., size, shape, and color). Thus, there are a number of factors involved in the tasting situation that may affect tasters performance, and that should be taken into account –e.g., the experimental procedure, non-gustatory information and cognitive parameters (e.g., Lawless & Heymann, 2010; Rosett, Klein, & Ennis, 1997 Schifferstein, 1996; Swets, 1996). Non-sensory factors may be controlled to a certain degree by using strategies to minimize their effects, such as an appropriate methodological design and counting with panelists well versed in sensory testing. However, even with these precautions, variance cannot be fully eliminated. Taste interactions and non-sensory factors should be included for a complete evaluation. It is important to study these factors as an integral part of the tasting situation to avoid incorrect conclusions that may occur when results are entirely attributed to sensory effects (Rosett, Klein, & Ennis, 1997).

Most food assessment research has been developed using a methodological perspective derived from classical psychophysical models and threshold traditions. Thus, the analytic limitations of classical psychophysical models pointed out above, are also valid for the traditional sensory analysis based on the threshold concept, as it equally ignores unnoticed variations on responses criteria associated to subjective factors or response biases. For instance, low intensity stimuli may evoke different taste sensations below the recognition thresholds that could be chosen by the taster as a criterion for detection (O'Mahony, 1972; O'Mahony, Gardner, Long, & Heintz, 1979; O'Mahony, Kingsley, Harji, & Davies, 1976). The wide variation in criteria introduces an uncontrolled variability for threshold values; consequently, criterion free measures of sensitivity (such as those developed for SDT) together or instead threshold procedures is a more adequate method to accurately capture performance (Bartoshuck, 1978). In addition, threshold measurements are of limited usefulness because they do not describe the dynamic range of the sensory function and they also fail to provide an accurate characterization of supra-threshold sensitivity.

In summary, traditional sensory analysis of food presents a number of limitations that steam from the human nature of the measuring instruments, from the classical psychophysics methodology used, and from other factors related to each individual panel. Moreover, in this complex discipline decision-making processes take an essential role. Sensory scores should represent the objective characteristics of a food and should not be dependent of subjective factors. Consequently, changing the traditional methodology used in sensory analysis of food by an alternative methodology based in contemporary psychophysical models that allow for estimating the contribution of cognitive aspects to psychophysical performance seems a more appropriate approach.

2.2 EXPERIMENTAL MANIPULATION OF SENSITIVITY AND RESPONSE CRITERION

As in other perceptual tasks, observers in tasting situations use their knowledge to aid detection and making an optimal judgment about a feature or component of the food. As this judgment is the result of a number of physical, physiological, and psychological processes, no theory of perceptual judgments is complete without the understanding of the functional dynamism due to the interplay between factors affecting the sensory process, such as perceptual acuity, and factors affecting cognitive processes such as tendencies, response biases or task specific conditions (Schifferstein, 1996). The need to separate the sensory and cognitive components in assessing flavors is clearly stated by Rosett, Klein and Ennis (1997) in a task using the salty taste. The separation of both processes is essential to discover small differences in sensory quality and development of accurate models.

The sensory process is affected by physical parameters as the salience of stimuli. As any sensory system, taste system is affected by the intensity of sapid compounds (i.e., the concentration of an attribute or component), but it varies in its range of responsiveness. Unlike other sensory systems such as the auditory one, the taste sensory system stops responding to increases in concentration fairly quickly. At low concentrations of sapid stimuli, the rise in perceived intensity is proportional to a rise in concentration. However, at high concentrations sensitivity may appear independent of the increases of the concentration. This result is found when the receptor system becomes saturated and no further increases in perceived intensity are attained. The taste function shows an asymptote at maximum taste intensity and the final shape of the curve resembles a hyperbole (Keast & Breslin, 2003). As stimuli become more complex, as in real situations, a set of quantitative and qualitative changes and interactions may occur (e.g., synergy, suppression or adaptation) affecting particular perceptual functions (for a review see Keast & Breslin, 2003). Although taste intensity functions and psychophysical curves (physical intensity vs. perceived intensity) have been constructed for the four basic qualities (e.g., Bartoshuck, 1975; Meiselman, 1968; O'Mahony & Wingate, 1974), most of them have been estimated using substances with a single component, and following variations of the method of direct magnitude estimation without a measure of the response criterion.

Decision criterion seems to depend on task instructions, on the base rates of presentation for each type of stimulus (i.e., the relative frequency of signal trial vs. noise trial), and on the payoff value (i.e., the relative cost of making the two types of errors, False Alarms and Misses, and the relative benefit of making the two types of correct responses, Hits and Correct Rejections). These effects seem to be well established in different research domains, although their study within the field of the sensory analysis of food is scarce (Macmillan & Creelman, 2005; Swets, 1996; Wickens, 2002). By contrast, the role of feedback on human performance is an unclear question. Feedback on performance may influence the sensory process (i.e., affecting the separation between the curves of Signal and Noise) but also the decision process.

An inherent ambiguity makes an individual's report more easily prone to be influenced by cognitive factors, and it may lead the observer to use quite different decision criteria at different times. If the proper index of sensitivity is not used, changes in decision criterion will be incorrectly interpreted as changes in sensitivity. These situation may be experimentally established by keeping the signal and noise events the same while introducing manipulations that are supposed to induce the observer to alter the criterion. The experimenter may vary the a priori probability of signal occurrence, and instruct the observer to maximize the percentage of correct responses. In this experimental situation, a strict criterion, and few positive responses are suitable when that probability is low, and a lenient criterion, and many positive responses, are suitable when that probability is high. Alternatively, variable values and costs may be assigned to the four possible decision outcomes while the observer is instructed to maximize the obtained gain. In this case, response bias tends to be lenient when either costs are low or rewards are high, but conservative when the converse is true (e.g., Buchner, Erdfelder, & Vaterrodt-Plünnecke, 1995; See et al., 1997; Snodgrass & Corwin, 1988). Each of these manipulations only concerns the observer's decision criterion and may typically be conducted without substantially altering the sensitivity (Wickens, 2002).

Finally, although the standard procedure is to give the participant feedback about his or her performance after each trial, any given perceptual task may be manipulated with respect to the feedback rate, making it more akin to natural situations in which the feedback is not always available outside participant's own response. Feedback could have a direct effect on adjusting the response criterion when other decision variable is manipulated (McNicol, 2005). Some studies report that providing trial by trial feedback observers adjust their responses to the stimuli base rates, while an uncertain pattern is found when feedback is removed (e.g., Tanner, Haller, & Atkinson, 1967; Tanner, Rauk, & Atkinson, 1970). The absence of information about correctness of responses could promote the use of a biased response strategy on the participants. The role of feedback on tasting is an issue scarcely explored, though it potentially may affect both, decision and sensitivity processes.

2.3 OVERVIEW OF SOME OPEN QUESTIONS IN THE LITERATURE

Throughout the introduction we have raised the need to separate sensory and cognitive components to achieve a correct characterization of performance in assessing flavor qualities. The particular complexity of this perceptual situation may promote the emergence of a response bias in tasters' judgments that could go unnoticed when using the standard food sensory evaluation. SDT methodology has been applied to the analysis of both, simple (e.g., Lee, Van Hout, Hautus, & O'Mahony, 2007) and natural stimuli, such as olive oil (e.g., Ramos-Álvarez et al., 2013). The use of simple stimuli sacrifice generalizability, while the use of natural stimuli sacrifice control, as the interaction among the components of a natural stimulus cannot be easily manipulated in isolation. A solution to this problem is to use complex matrices of compounds that may be manipulated under laboratory conditions. The use of a combination of basic flavors has the advantage with respect to the use of natural foods of increasing the experimental control, as it simplifies the manipulation of the combination of flavors while keeping the situation fairly close to the natural situation in which tasters usually confront complex stimuli. This is the approach that will be taken within this dissertation.

As pointed above, Ramos-Álvarez et al., (2013) have developed a dissociative test to establish the dissociation of the effects of different manipulations affecting sensitivity and criterion in the field of tasting. The proven suitability of The Double Dissociation Additive Test to separate the effects of instructions and stimulus salience on the context of olive oil tasting suggests that this procedure may be successfully applied to the exploration of the effects of other factors such as external feedback, the relative frequency of the signal, and the payoffs matrices on the tasting domain. Although many studies find that human behave optimally in these experimental situations (see for example, McNicol, 2005; Swets, 1996; Wickens, 2002), little is known about decision-making under changing contingencies in the tasting domain. Additionally, in such dynamic context, available information could be crucial for making a decision. The goal of this dissertation will be to explore these issues while testing the suitability of SDT and the Double Dissociation Additive Test applied to the tasting domain in a situation that, while being akin to a natural evaluation of food, it allows for keeping a high level of experimental control.

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3 GOALS AND HYPOTHESES

The general goal of this dissertation was to extend the dissociative methodological approach based on SDT to the sensory analysis of complex stimuli that are artificially established by the mixture of two basic flavors, providing a new characterization of the tasting situation that allows for an comprehensive analysis of sensory and decisions dynamics within laboratory conditions, but keeping a high ecological validity at the same time. This ecological point of view also involves the sample of participants, as they were selected from the general population fulfilling the function of novice tasters.

This general goal breaks down in the specific goals and hypotheses summarized as follows:

Specific goal 1. Testing a methodological approach to the study of sensory evaluation of food including the *Double Dissociation Additive Test,* the experimental task for assessing complex taste mixtures, non-parametric measures for quantifying processes and robust type statistical analysis.

Hypothesis 1a: Given that the Double Dissociation Additive Test has been successfully applied to of sensory evaluation of olive oil (Ramos-Álvarez et al., 2013), it is expected to be useful to evaluate the dynamic of sensory and decision processes when evaluating combinations of basic flavors.

Hypothesis 1b: Experimental task designed for this research is expected to be adequate to approaching sensory evaluation of flavors within laboratory requirements but in similar conditions to the real tasting situations.

Hypothesis 1c: In agreement with results obtained in previous research using tasting procedures, nonparametric indexes of SDT are expected to be independent for quantifying sensory and decision processes.

Hypothesis 1d: Given that robust analysis of variance has been found to be an appropriate tool to statistical for tasting tasks (e.g. Ramos-Álvarez et al., 2013), it is expected that it will be suitable for this research.

Specific goal 2. To build the psychophysical function that relates stimulus intensity with sensory performance in basic flavor compounds, and to explore possible response biases or cognitive strategies that could emerge when complex stimuli are used.

Hypothesis 2a: Given that no variable associated with decisional processes will be manipulated, a neutral response pattern is expected. Under these conditions, an unbiased criterion placement is predicted by SDT (Macmillan & Creelman, 2005; Swets, 1996).

Hypothesis 2b: According to previous parametric analysis for taste mixtures (see Bartoshuck, 1975; Keast & Breslin, 2003), the expected psychophysical curve would be sigmoidal (e.g. logistic), with an expansive phase at low intensities, linear at intermediate intensities, and compressive with high values.

Specific goal 3. Exploring sensorial and decision performance on a tasting task by varying three factors simultaneously: Stimulus attributes, base rates, and feedback conditions.

Hypothesis 3a: According to previous SDT experiments (e.g., Macmillan & Creelman, 2005; Swets, 1996; Wickens, 2002) stimulus salience will affect the sensory index without affecting the criterion, while base rates should affect decision index without affecting sensitivity.

Hypothesis 3b: In agreement with most of the studies that report a positive effect of feedback by improving overall accuracy of performance (e.g., Herzog & Fahle, 1997), feedback is expected to affect the discriminability of the stimuli, improving performance.

Hypothesis 3c: Decision criteria will be adjusted to the signal- noise base rates when feedback is provided (e.g., Tanner, Haller, & Atkinson, 1967; Tanner, Rauk, & Atkinson, 1970).

Hypothesis 3d: Following SDT assumptions, the use of symmetrical probability manipulations for conservative and lenient conditions, equally symmetrical and opposite criterion placement is expected (see McNicol, 2005; Wickens, 2002).

Specific goal 4. Exploring the role of manipulating the payoff received by tasters on the decision criterion evaluating the extent criterion may change under unbalanced payoffs and whether symmetrical effects are induced for lenient and conservative conditions.

Hypothesis 4a: According to previous SDT experiments (e.g., Macmillan & Creelman, 2005; Swets, 1996; Wickens, 2002) stimulus salience will affect sensory index without affecting criterion, while payoff matrices will affect decision index without affecting sensitivity.

Hypothesis 4b: Given that previous studies have shown that response bias tends to be lenient when either costs are low or rewards are high, but conservative when the converse is true (e.g., See et al., 1997; Snodgrass & Corwin, 1988), it is expected that response bias will be most strict in the conservative payoff condition (high costs and low values) and most lenient in the liberal payoff condition (low costs and high values).

Hypothesis 4c: Following SDT assumptions, as payoff manipulations will be symmetrical for conservative and lenient conditions, we expected the biases criterion placement to be symmetrical as well (see McNicol, 2005; Wickens, 2002).

Specific goal 5. Exploring the usefulness of the modern psychophysics in the field of tasting natural flavors by reviewing the application of these methods to the field of olive oil tasting, preparing a summary of this research that may be accessible to olive oil experts.

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4 METHODOLOGICAL PROPOSAL

This dissertation presents an innovative methodological approach to the tasting context. We apply a procedure based on a dissociative model that allows for obtaining independent measures of sensitivity and criterion performance: the *Double Dissociation Additive Test*. Additionally, a new experimental task designed for the sensory evaluation of olive oil is applied to the basic tastes. Non-parametric measures for quantifying processes and a robust-type statistical analysis complete this methodological proposal.

4.1 THE DOUBLE DISSOCIATION ADDITIVE TEST

In this dissertation we used and developed the research approach proposed by Ramos-Álvarez et al. (2013) that allows for overcoming the limitations of the standard approaches to the dissociation tests between sensory and criterion processes described above. Within this method, the research conducting to dissociate between the two processes will be defined in such a way that at least one factor for each process will be manipulated following the structure of a fully-crossed factorial design. This approach allows for testing whether the factors interact or add to each other (see Kirk, 1995). Factors should be chosen so that they are expected to affect each process separately, following a theoretical model that connects processes with factors. The two indexes provided by SDT are supposed to be independent from each other. However, this is a theoretical assumption that needs to be tested, so that the independence property is fulfilled within the specific context of the developed research. Taken in account both requirements, the dissociative logic will be applied twice: Confirming that the factor associated to the sensory process affects to the sensory index but not to the criterion index, and testing whether the factor associated to the decision process affects the criterion index at the same time that it does not affect the sensory index. This strategy allows for a direct evaluation of the dynamics of the processes, given that the inferences about the interaction/independence between sensory and decision processes will be obtained in a convergent way for the two indexes, allowing for a direct comparison between them, and solving the problem of an indirect estimation. The lack of interaction in such a context would lead us to infer that cognitive processes associated to both factors are independent from each other.

Following the logical of the *Double Dissociation Additive Test*, each experimental design includes at least two independent factors (i.e., one factor for each process) that are simultaneously manipulated combining its levels according the structure of a factorial design with complete crossing. Each factor should affect a single cognitive process. That is, factors should be independent from each other. The magnitude of salt concentration is not expected to influence the response criterion, while signal-noise base rates and payoffs manipulations should affect the response criterion, but should not influence the sensory process. The absence of interaction in such context would lead us to confirm that cognitive processes associated to each factor are independent. In summary, these manipulations should allow for testing whether signal salience only affects sensory index without affecting decision index. Additionally stimuli probabilities and payoff matrices should exclusively affect decision index, without effects on sensory index. If that were the case, this strategy would allow for having a convergent confirmation of the lack of interaction.

4.2 THE TASTING TASK

To explore the issues discussed above, a detection task in the context of sensory analysis of basic flavors was designed to be carried out within the laboratory setting, but adopting an ecological validity approach. Given that our ultimate goal is to understand the psychological processes involved in organoleptic evaluation, the research was conducted by taking to the laboratory the restrictions imposed by the sensory evaluation within a natural tasting situation. For this purpose, methods, materials and setting of the study were designed to reproduce the real-life situation that is under investigation. This ecological point of view also involves the sample of participants selected for our research from the general population. All participants were students from the University of Jaén without experience with the task or formal training on sensory evaluation in order to evaluate performance on novice tasters.

A classical paradigm that allows for conducting an SDT analysis of performance is the psychophysical Yes–No procedure (a detection task). Participants are exposed to one out of two possible stimuli (Signal+Noise or Noise) that are repeatedly presented in random succession. Participants are required to render a binary classification on each presentation. In this experimental situation, there are two possible decisions that combine with two different results: The observer may say yes (the signal was present) or no (the signal was absent) and may in either case be correct or incorrect. This analytic approach may be applied for food sensory evaluation. For instance, in a standard discrimination test, a judge may be required to discriminate between 2 similar and confusable sapid stimuli. In the simplest case, the signal sample may be a mixture containing a specific ingredient and the noise stimulus without this component. The task of the judge is to compare the 2 samples attempting to identify the type of sample (signal or noise).

Following this procedure, a tasting task was implemented in the laboratory using two taste compounds in aqueous solution, one playing the role of a Signal (SN), and the other playing the role of a Noise (N). The noise mixture was made with 1.5% of a sour compound [Pulco Lemon Flavor, Orangina Schweppes: lemon juice (40%), water (56%), and pulp of lemon (4%)], and 98.5% of distilled water. Signal stimulus was prepared by adding a small amount of salt (sodium chloride) to the mixture. Intensity of saline stimulus was manipulated across a wide range of concentrations (from 0.07% to 0.75%). Salt is a relatively simple, familiar and distinct quality. Sensory analysis studies for the four fundamental taste qualities indicate that salt, when perceived, is clearer and less ambiguous than the other qualities. This substance is easily graded quantitatively and can be varied over a relatively wide range. Moreover, salt solutions have no disagreeable effects, even after repeated tasting, and can be made to disappear relatively quickly (Holway & Hurvich, 1937). Many psychophysical experiments have used saline stimuli, frequently in a limited range of concentrations (e.g. Holway & Hurvich, 1937; O'Mahony, 1972; O'Mahony, Gardner, Long, & Heintz, 1979; O'Mahony & Wingate, 1974) to experimentally determine the functional relationship between differential sensitivity to the compound and the concentration of the stimulus-solution. Although it is a basic quality, as with many taste stimuli diluted in aqueous solution, detection of NaCl is difficult. The second stimulus used in these experiments was a sour compound. Experimentation with sour flavor is restricted to a relatively narrow range, inasmuch the use of sour stimuli produce an astringent sensation at high concentrations (Holway &

Hurvich, 1937). Since the amount of acid substance was optimally adjusted and remained constant, this possibility presented no problem for the tasters.

Twenty-five samples were presented to each participant (one practice trial plus twenty-four experimental trials) in every experimental session. The first sample was used only for practicing the tasting procedure. Solutions were presented in plastic glasses at room temperature. Each glass contained 7 ml. An inter-stimulus procedure of mouth-rinses with water to remove residuals from prior tastings and avoid the taste sense adaptation was used between samples.

Experiments were developed in individual cabins provided by a computer with specific software to control the stimulus presentation *(LearnOlive).* This software was explicitly developed within our research team to conduct flavor experiments, and allows participants to easily follow the complete sequence of the task without intervention of the experimenter. The versatility of the program allows the implementation of different designs and the manipulation of sensory and decision variables. The program permits collecting socio-demographic information of participants, provides instructions about the tasting protocol, response feedback when it is required, and collects performance data. General procedure followed a 5-phase protocol: (1) Participants' recruiting and debriefing about the requirements to participate in the experiment, (2) Stimulus and taste sample preparation an hour before the experiment, (3) Cubicle preparation: Sample distribution according to the experimental setting and the randomizing provided by the software, and arranging of the setting for the participants including an arrangement of water, and cleansing elements, (4) Participants' reception, random assignation of the experimental location for each participant, and general instructions about how to perform the task, and (5) Performance of the experimental task. During the test, the protocol followed by each participant was: (1) Picking the sample according to the established sequence, (2) tasting the sample, (3) giving the response about its content (Yes/No), (4) leaving the glass aside, and (5) cleansing her or his palate. There was no time for performing the task, though most participants finished the complete procedure between 30 and 40 min after their arrival to the laboratory.

4.3 DEPENDENT VARIABLES AND STATISTICAL ANALYSIS

Hits rates (probability of responding Yes in a signal trial) and False Alarms rates (probability of responding Yes in a noise trial) were computed using the 24 tasting trials. Short tasks have the risk of involving extreme rates (maximum hits rates or null false alarms rates). Due to this probability of observing extreme rates, a logarithmic-linear corrective strategy was used by applying a constant amount to all the frequencies before computing the rates. This strategy is commonly used in psychophysics research (e.g., Snodgrass & Corwin, 1988; Stanislav & Todorov, 1999). The review of Brown and White (2005) suggests that the best computational strategy is to add a constant value ranging between .25 and .50 to all the frequencies, regardless of their absolute value. For our research, we decided to adopt the most commonly used value in the literature, .50. A methodological design including nonparametric performance indexes and robust analysis of variance was chosen for detecting independent variations in sensory and criterion decision indexes. Both alternatives complete the methodological proposal designed to improve the characterization of the tasting processes.

4.3.1 Nonparametric indices

As stated above, the choice of the appropriate indexes depends on the specific field of application. Tasting tasks impose the use of a small number of trials to avoid saturating participants' senses. This feature makes unlikely the fulfillment of the implicit assumptions of SDT parametric indexes: Gaussian distributions of probability associated to the signal and noise with equivalent variances (Wickens, 2002). This limitation led us to choose a nonparametric alternative less restrictive with respect to the Normality assumptions, but still adequate from the methodological point of view. The nonparametric approach has been used in a large number of reports (see Macmillan & Creelman, 1990, 1996) and it is especially recommended within the sensory analysis of food (see Ramos-Álvarez et al., 2013) Specifically, we chose A' index for the sensory process (computationally developed by Grier, 1972; from Hodos, 1970), and the B'_D index developed by Donaldson (1992) for the decision process.

4.3.2 Robust statistical analysis

As stated above, assumptions of classic statistics (Normality or Homocedasticity) are easily broken in tasting experiments due to the small number of data. Similarly, outliers are likely to be found in tasting tasks, and that would invalidate the use of conventional statistical techniques. To explore these assumptions while summarizing the data, variability and central tendency indexes are presented in Box-Plot graphs according to robust statistics based on median (Wilcox, 2005). This graph is complemented with Kernel Density and Normal Q-Q Plots. Robust statistics have shown to be useful in olive oil tasting situations and they have been proposed as a general analytic approach to tasting research (see Ramos-Álvarez et al., 2013). Robust analyses of variance on trimmed means were conducted by using Yuen-Welch ($T_{Y\text{-}W}$) test for between-groups pairwise comparisons, and Robust contrasts of a sample were conducted by a T-test Trimmed variant (T_t).

All the analyses were performed using the free-GNU R software, R version 3.0.3 (R Foundation for Statistical Computing, http://www.r-project.org/) with {car}, {data.table}, {Hmisc} and {sm} libraries, and Wilcox' ''Rallfun-v20'' library (http://www-rcf.usc.edu/~rwilcox/. Ask for the functions ''t1wayv2'', "t2way", ''t3way'', "mcp2atm", "mcp3atm", and ''lincon''). The modelization of sensibility curve was performed with nls {stats} library and SSlogis and SSweibull Self starting algorithms. Statistical significance was set at $p \leq .05$.

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5 EXPERIMENTAL STUDIES

Different factors that would affect sensory and decision processes in the field of tasting were analyzed. The *Double Dissociation Additive Test* within the SDT framework was used to separate the effects of manipulating Salience, Signal-Noise Base Rates, Payoffs Matrices and Feedback on sensitivity and decision processes within a tasting task involving the mixture of salty and sour basic flavors. Experimental designs followed the structure of full factorial between-subjects designs including at least one factor for each of the processes that were simultaneously manipulated following the dissociative model explained above. Salt concentration would be included in all experimental designs that comprise this dissertation as the sensory factor, together at least to one cognitive factor affecting response bias, except in the parametric study in which only signal salience was manipulated. Experiments were carried out within laboratory requirements but adopting similar conditions to the real tasting situations. A simple Yes-No detection task with two types of sapid stimuli allowed to derive both sensory and criterion estimates computing hits and false alarms rates from participants' performance. Results were analyzed by using measures non-parametric of sensitivity and bias, as well as robust statistics.

The different studies that integrate this dissertation are presented as independent studies in the following sections. This type of presentation is justified because the studies are either already published, under review, or will be sent out for publication shortly. We are aware that this form of presentation necessarily involves some reiterations in the descriptions of the experimental work. However, we thought that the occasional redundancy was a small price to pay in exchange for giving the reader the opportunity to judge the work compressed in this dissertation in the form it is thought to be published. Finally, the differences in formal aspects of each study are due to the specific requirements of the journals where the studies have been sent, or they are intended to be sent to.

5.1 PSYCHOPHYSICAL CURVE FOR SALTY QUALITY

This section presents a parametric analysis of human sensitivity to salty quality. In this experiment, sensitivity was characterized by using six levels of salty compound (from 0.07% to 0.75%). To achieve the best characterization of sensory performance, the low salience condition (0.07%) was selected to be sufficiently difficult to elicit a sensory performance when discriminability is at or near chance. In contrast, the high condition (0.75%) was chosen to reflect sensitivity close to the asymptotic performance. The medium values were selected in a relatively low range given the rapid growth of the psychophysical function for this flavor. In general, sensitivity index increased with the increase in signal salience. Data obtained were represented by a Weibull function that seems to optimally describe binary taste interactions and to better predict the growth trend than other models. A slight but reliable lenient response bias was found regardless of the salt concentration.

PSYCHOPHYSICAL CURVES FOR TASTING BASED ON A BIPROCESUAL DISSOCIATION MODEL

SHORT TITLE: PSYCHOPHYSICS OF TASTING

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Abstract

An experiment on taste sensory analysis of an artificially arranged compound of salty and sour flavors was conducted with the goal of evaluating sensory performance to a mixture of flavors akin to natural food, but that allows for keeping a higher experimental control than natural foods do. Participants performed a detection task in which the concentration of salt was manipulated between-subjects (from 0.07% to 0.75%). A procedure based on a dissociative model that allows for obtaining independent measures of sensitivity and criterion performance was used. In general, sensitivity index increased with the increase in signal salience, with actual performance approaching a Weibull distribution. A slight but reliable lenient response bias was found regardless of the salt concentration. The relevance of using independent measures of sensitivity and bias in sensory evaluation of complex compounds, and its relevance for sensory analysis of food is discussed.

Practical Applications

In tasting situations, perception seems to be easily influenced by cognitive factors and different response biases might appear, modifying the response criterion location. Difficulty of discrimination may also increases by qualitative changes that occur in more complex mixtures. Signal Detection Theory allows the measurement of both: sensory and non-sensory components. Taking apart cognitive and sensory components is central to uncovering small differences in sensory qualities and developing accurate models of perception. This approach is of special interest to study the psychological processes involved in tasting situations, including the evaluation of training programs conducted to improve tasters' discriminative abilities. In addition, function modelization has important implications for the area of perceptual research since psychophysical functions for binary compounds as it allows conducting predictions about interaction effects between studied components in complex stimuli.

Keywords: sensory evaluation, taste mixtures, salty, sour, Signal Detection Theory, Sigmoidal psychophysical models, sensory process, decision criterion, response biases

Recent reports in the literature show that there is a number of cognitive and sensory factors that may affect analysts' performance on food tasting situations, showing that perception of a given food is a highly complex and variable experience that needs of composite and sensitive tools to be properly evaluated (e.g., Lawless & Heymann, 2010; Lee et al., 2001; Moreno-Fernández et al., 2012; Rosett et al., 1997; Schifferstein, 1996; Paredes-Olay et al., 2010). For instance, an essential issue is whether there are perceptual changes when multiple taste compounds are presented together in a food or a beverage, so that a unique new flavor, different from the sum of the flavors presented alone, may be established (Rochman et al., 1997). How this question is answered has important implications for the training of panelists. In sensory panels, tasters learn to separately identify, quantify and describe the properties and attributes of a given food. Tasters' evaluation increases in difficulty when confronting a mixture of flavors due to the interactions among the components of the food. Note that this is the usual way food is presented, as a complex interaction among flavors and attributes.

The singular features of food perception make it difficult to analyze the tasting situation even under strictly controlled laboratory conditions. At sensory level, physical fluctuations produce slight changes in the perceived intensity of a food upon repeated tasting. Such changes may go unnoticed during normal eating but they are important enough to affect performance in difference tests (Lee & van Hout, 2009). With the goal of increasing control, traditional basic sensory research has used extremely simple stimuli, usually basic tastes, which lacked the complexity of standard foods. However, this increase of control does not come without cost. As stated in the previous paragraph, mixtures of flavors may give away a different new flavor. Thus, an excess of simplification of designs and stimuli may lead to a decrease on the generalization of the obtained findings to a more complex, natural stimuli, so that ecological validity is sacrificed (see Meiselman, 1992, 1993).

The analysis of the interactions among taste stimuli is a research area that interests psychologists as much as other food scientists, as these interactions determine the overall attractiveness of flavors (Lawless & Heymann, 2010). Research on this topic has found that central phenomena in taste perception such as adaptation, cross-adaptation, enhancement or suppression may occur when presenting stimuli together (e.g., Bartoshuk, 1975; Gillan, 1984; Lawless & Heymann, 2010; Meiselman, 1968; Moskowitz, 1972; O'Mahony & Wingate, 1974). The most commonly observed interaction within flavor mixtures is a change of the gustatory intensity, with a mutually suppressive effect of each component on the other. However, suppression is not always identical for the components of the mixture. For instance, mixtures of sweet and salt develop an “unblended” or “clashing” taste, in which domination of the components alternates, while mixtures of sweet with either sour or bitter modify the qualitative aspect of sweetness (e.g., Moskowitz, 1972). These examples illustrate the complexity of the flavor sensory analysis even when simple mixtures are used. In fact, results in the literature are contradictory, probably due to factors such as individual variations in taste perception, and differences in experimental protocols or in the sapid compounds chosen for the tests (for a revision of the sources of variability in mixture interactions literature, see Keast & Breslin, 2003).

A related issue within the evaluation of mixtures’ attributes is whether tasters’ judgment is only affected at the sensory level. Human perception is a dynamic process and any given judgment is based on the combination of a number of physiological, psychological and contextual variables (e.g., Lawless & Heymann, 2010; Lee et al., 2001; Schifferstein, 1996). With complex stimuli such as food, the difficulty of a decision increases due to the interactions among their components. Also, the final decision may be affected by the experimental procedure, by non-gustatory information and by cognitive processes (e.g., Lawless & Heymann, 2010; Rosett, et al., 1997; Schifferstein, 1996; Swets, 1996). Thus, non-sensory factors, as well as interactions among flavors, should be included for a complete evaluation of any natural food to avoid incorrect conclusions that may be reached when results are entirely attributed to sensory effects (Rosett et al., 1997).

One approach that allows assessing mixture interactions over a range of concentrations is to develop a psychophysical function for the compound of interest: First, subjective variations based on changes in the intensity (concentration) of one of the components alone are characterized in a single curve. Then, a second curve is established by adding a weak concentration of the second stimulus to the original concentrations along the function of the primary compound. By comparing the two curves, this experimental protocol allows defining the sensory profile to the sapid compound and the different expressions of interaction between its components, such as synergy or suppression. The problem with this type of protocols is that they do not allow for studying the effects of other psychological factors such as cognitive strategies or response biases that may be involved in the final judgment. For example, adding a new flavor to the primary flavor could alter the requirement level to conclude that the intensity of the later changed. Thus, interactions among stimuli could mask changes in response criterion. The present study approaches this problem by proposing an alternative way to construct the psychometric function: Adding a constant amount of one stimulus at different concentrations of the primary component, in a situation in which concurrent analysis of the response criterion allows for simultaneously estimating the contribution of non-sensory effects to the final performance.

Most methodological approaches commonly used in food science does not allow for this complex analysis. The use of traditional threshold measures and direct estimation methods present a variety of problems such as unnoticed variations associated to the subjective factors or response biases. For instance, direct estimation methods ignore any individual differences and assume that the mechanism of perception is purely sensorial (Green & Luce, 1974; Luce, 1990). Luce (1990) found that introducing a background noise in loudness judgments produces a pronounced deviation in the shape of the magnitude estimation from a power function. Regarding threshold measures, saltiness has been described by two thresholds: The detection threshold, when the presence of NaCl is noticed but not recognized as salty, and the recognition threshold, when the salty taste appears. Studies on sensitivity thresholds for salty taste in aqueous solution found different taste sensations below the recognition threshold that could be chosen as a criterion for detection (O'Mahony, 1972; O'Mahony et al., 1979; O'Mahony et al., 1976). These findings suggest that the language currently used in tasting situations may not describe all the categories of sensations satisfactorily. They also suggest that the wide variation in criteria introduces an uncontrolled variability for threshold values, and that qualitative modulation should be taken also into account. In fact, the usefulness of threshold measurements is quite limited, given that, first, they do not describe the dynamic range of the sensory function, and second, they fail to provide an accurate characterization of supra-threshold sensitivity. The use of criterion-free measures of sensitivity together or instead threshold procedures is a more adequate method for accurately capturing tasting performance (Bartoshuck, 1978).

Within the psychophysical context, Signal Detection Theory (SDT) has been shown as an appropriate framework to dissociate between sensorial performance and variations in response criterion (Green & Swets 1988; MacMillan & Creelman, 2005). SDT understands performance as the outcome of two different processes: A sensory process based on observers' skills to detect the attributes and physical properties of the stimulus; and a decision process corresponding to the response strategy that is affected by cognitive factors. The analytical method of SDT may isolate the effect of the position of the decision criterion, so that a pure measure of intrinsic discrimination acuity is obtained (Swets, 1996). This methodological approach allows measuring both, sensory and non-sensory components, having important implications for research in food science. However, in spite of its potential usefulness, the application of SDT model to the sensory analysis of taste is not generalized, compared to its application to other perceptual contexts (see Macmillan & Creelman, 2005, Pastore & Scheirer, 1974, and Swets, 1996). In the context of food, Paredes-Olay et al. (2010) applied SDT based methods to the study of olive oil tasting under controlled conditions (see also Ramos-Álvarez et al., 2013). There are also several examples of its application with the study of basic flavors such as sucrose (Moore et al., 1965; Pursell et al., 1973), or salt (Lee et al., 2007; O'Mahony, 1972). Other studies have used SDT measures to explore perceptual learning phenomena such as the "easy-to-hard" (Moreno-Fernández et al., 2012) or "warm-up" effects (Mata-García et al., 2007), and to sensory evaluation of food by consumers (e.g., Ishii, Kawaguchi et al., 2007; Rousseau et al., 2002). There are a number of studies that also suggest the use of the Receiver Operating Characteristic curve (or ROC) in food sensory science, an analysis that allows for exploring the cognitive strategies associated with different tests (Lee et al., 2007; Hautus et al., 2008; O'Mahony & Hautus, 2008; Paredes et al., 2010).

Thus, SDT methodology has been applied to the analysis of either simple (e.g., Lee et al., 2007), or natural stimuli, such as olive oil (e.g., Ramos-Álvarez et al., 2013). The use of simple stimuli sacrifice generalizability, while the use of natural stimuli sacrifice control, as the interaction among the components of a natural stimulus cannot be easily manipulated in isolation. The general goal of the present study was to cross that bridge, extending the test of the application of SDT methodology to the sensory analysis of complex stimuli that are artificially established by the mixture of two basic flavors, so that the experimental control may be kept with respect to more natural situations without fully sacrificing generalizability. Specifically, this study was intended to provide a profile of the human sensitivity to the salty quality in a taste mixture using an independent measure of sensory accuracy, and to explore possible response biases and effects on a decisional level in a situation in which only taste concentration is manipulated.

Method used was a classical paradigm of SDT, a detection task (Yes/No) in which participants' role is to determine whether a Signal stimulus is present or not. In the present study, participants had to judge the presence or the absence of a small amount of salt in a stimulus compound. They are exposed to samples randomly arranged, half with a small amount of salt diluted in other components (Signal+Noise stimulus for SDT model), and the other half without salt (Noise on SDT). The observer had to answer whether the stimulus was present or absent, which determines two types of response: Hits (the judge identifies the sample that contains salt, saying yes to a Signal+Noise trial) and False Alarms (the judge identifies salt in a sample that does not have it, saying yes to a Noise trial). The decision criterion is set in agreement with the observer's perception of the prior probabilities of the two possible stimuli (Signal or Noise) and with the costs and benefits of the different type of response (Swets, 1996).

Sodium chloride (NaCl) was chosen as the signal stimulus. Saltiness is a relatively simple, familiar and distinct quality. Sensory analysis studies for the four fundamental taste qualities indicate that salt, when perceived, is clearer and less ambiguous than the other qualities. This substance is easily graded quantitatively and may be varied over a relatively wide range. Salt solutions have no disagreeable effects, even after repeated tasting, and may be eliminated relatively quickly (Holway & Hurvich, 1937). Many psychophysical experiments have used saline stimuli to determine the functional relationship between differential sensitivity to the compound and the concentration of the stimulus-solution. These studies have been conducted to address different issues such as comparing among sensory difference tests such as triangle, duo-trio, 2-AFC and same-different methods (Kim et al., 2006); exploring effects of adaptation and interstimulus procedures (Meiselman, 1968; O'Mahony & Wingate, 1974); or studying several phenomena as the warm-up (Angulo et al., 2007). Additionally, some authors emphasize the relevance of this research for the field of health. Both, hyposensitivity or hypersensitivity, could be related to some physical alterations in perception of this quality, and in general with the risks of high sodium intake (i.e. there seems to be a linkage between high blood pressure, salt intake and sensitivity, perinatal environment, and obesity, Arguelles et al., 2007). Furthermore, the application of psychophysical curves plays an important role in the design of diets aimed to reduce sodium in foods without significant effects on flavor (Liem et al., 2011).

A sour compound was added to the mixture to produce a complex tasting situation akin to tasting a realistic complex food, while maintaining controlled laboratory conditions. Previous research has reported that salt and sour mixtures symmetrically affect each other's intensity. The interaction effects that may occur between both qualities are enhanced at low concentrations, while suppression or no effects are found at high concentrations (e.g., Bartoshuk, 1975; Breslin, 1996; for a review see also Keast & Breslin, 2003).

Following the dissociative logic of the detection model, an experiment was conducted to build a psychophysical curve for changes in the concentration of salt, by measuring sensitivity and decision processes in a complex tasting situation. A large sample of participants (60) and a wide range of salt concentrations (from 0.07% to 0.75%) were used in order to clarify differences in sensitivity. An increase on detection as salt concentration increases was expected. However, the main focus of this study was on the criterion index. A neutral response pattern is expected given that no variable associated with decisional processes was manipulated. Under these conditions, an unbiased criterion placement is predicted by SDT (Macmillan & Creelman, 2005; Swets, 1996). However, and given the lack of related research using artificially arranged compounds, the specific goal of this experiment was to explore possible response biases or cognitive strategies that could emerge when complex stimuli are used.

A subsidiary goal of this experiment was the study of the model that allows predicting tasters' sensibility from the increments in the intensity of the stimulus. Many psychophysical curves (physical intensity vs. perceived intensity) have been developed for the four basic flavors (e.g., Bartoshuck, 1975; Meiselman, 1968; O'Mahony & Wingate, 1974). Typically, the final shape of these curves resembles a hyperbole with a rise in the perceived intensity that is proportional to the physical intensity, losing such proportionality when reaching the asymptote at high values (Keast & Breslin, 2003). Parametric analysis for taste mixtures is scarce. According to some authors, the expected psychophysical curve would be sigmoidal (e.g. logistic), with an expansive phase at low intensities, linear at intermediate intensities, and compressive with high values. This S-Shaped curve would be based on binary taste interactions, showing enhancement, interactions of the mixture and suppression at low, moderate and high intensities, respectively (see Bartoshuck, 1975; Keast & Breslin, 2003). This study was designed to allow for exploring the psychophysical function that relates stimulus intensity with sensory performance in basic flavor compounds. A comparison with related functions is established by incorporating the dynamics of processes for taste compounds.

Method

Participants

Sixty undergraduate volunteers of the University of Jaén, 49 females and 11 males, participated in the study. They were between 17 and 33 years old (Mdn = 19). None of them had previous experience with the task or formal training on sensory evaluation. All of them read and signed an informed consent before starting the experiment and were free to leave the laboratory at any time, though none of them chose to use this option. Participants were instructed to come to the laboratory in the appropriate conditions to conduct a taste experiment. They were requested to avoid smoking or taking foods or drinks half an hour before the beginning of the tasting session. Participants that had some temporary alteration of their taste sense produced by cold or allergy episodes were given an appointment for a different day. Within the tasting session, they were randomly assigned to each of the 6 experimental conditions corresponding to the six levels of the salty compound involved in the experiment, so that each group included 10 participants. Age and gender distribution was uniform across groups.

Materials and Apparatus

Two types of taste stimuli in aqueous solution were used in each session: Noise (N) and Signal + Noise (SN). Noise mixture was made with 1.5% of a sour compound [Pulco Lemon Flavor, Orangina Schweppes: lemon juice (40%), water (56%), and pulp of lemon (4%)], and 98.5% of distilled water. A small amount of salt was added to the mixture to conform the Signal stimulus (for a revision of protocols, see Keast & Breslin, 2003). Six different SN stimuli were prepared, varying on the amount of salt in each concentration (0.07%, 0.09%, 0.1%, 0.15%, 0.3% and 0.75% respectively).

Solutions were presented in plastic glasses at room temperature. Each glass contained 7 ml. An inter-stimulus procedure of mouth-rinses to remove residuals from prior tastings and avoid taste sense adaptation was used between samples. Participants cleaned the palate using water. A numbered plastic sheet was placed at the table so that participants could leave the samples after tasting them, so that it was easy for the participant to keep track of the course of the experiment, minimizing the risk of losing participants due to mistakes on the tasting sequence.

The tasting laboratory consisted of 7 individual cabins equipped with a desk, a chair and a computer provided with specific software to control the stimulus presentation

(LearnOlive). A 17" TFT computer screen, a rubber keyboard and a mouse were placed in front of the participant. LearnOlive software was explicitly developed by M.M. Ramos-Álvarez to conduct tasting experiments, and allows participants to easily follow the complete sequence of the task (see a detailed description in Ramos-Alvarez et al., 2013).

Procedure

Twenty-five samples were presented to each participant (one practice trial plus twenty-four experimental trials randomly intermixed). The first sample was used only for practicing the tasting procedure.

Sensory process was manipulated by using six levels of salty compound in six different groups of participants: 0.07%, 0.09%, 0.1%, 0.15%, 0.3%, and 0.75%. Decision process was not manipulated in this experimental design so that no response strategy (positive or negative bias) was induced. Signal and Noise stimuli were equiprobable (12SN and 12N). After signing the written consent, and filling a socio-demographic questionnaire, participants received general instructions about how to taste the samples. Participants confronted a simple detection task in which they should indicate whether each presented sample contained or not salt. The protocol followed by each participant was: (1) Picking the sample according to the established sequence, (2) tasting the sample, (3) give the response yes or not to the question: Do you think the sample that you have just tasted contained salt? (4) Leaving the glass aside, and (5) cleansing her or his palate. Participants received feedback about the accuracy of each of their responses (correct/incorrect).

There was no time between samples limit for performing the task, though most participants finished the complete procedure within 30 min. after their arrival to the laboratory.

Environmental conditions of lighting and temperature were maintained constant (20-24 Celsius degrees), so that participants could develop their tasting in a comfortable, neutral situation.

Dependent Variables and Data Analysis

Yes/no responses were used to compute Hits and False Alarms rates and then calculating the sensitivity and decision indexes. Due to the probability of observing extreme rates, a logarithmic-linear corrective strategy was used by adding a constant amount, .50, to all the frequencies before computing the rates. Tasting situations do not allow for using a large number of trials without saturating the senses, what makes unlikely the fulfillment of the implicit assumptions of SDT parametric indexes. Non parametric Grier's (1971) A', and Donaldson's (1992) B'_D have been proposed as sensory and decision indexes, respectively, in tasting situations (Ramos-Álvarez et al., 2013).

The use of a small number of trials also makes difficult to verify assumptions such as Normality and Homoscedasticity, not to speak of the presence of outliers that are likely to be found in tasting tasks, and that would invalidate the use of conventional statistical techniques. To explore these assumptions while summarizing the data, variability and central tendency indexes are presented in Box-Plot graphs according to robust statistics based on median (Wilcox, 2005). Robust statistics have shown to be useful in olive oil tasting situations and they have been proposed as a general analytic approach to tasting research (see Ramos-Álvarez et al., 2013). Robust analyses of variance on trimmed means were conducted by using Yuen-Welch ($T_{Y\text{-}W}$) test for between-groups pairwise comparisons, and Robust contrasts of a sample were conducted by a T-test Trimmed variant (T_t).

Function of taster sensitivity from increments in intensity of the stimulus was conducted using non-linear least-squares estimates of the parameters as implemented by Bates and Chambers (1992), and Pinheiro and Bates (2000) from Ratkowsky (1983) statistical approximation. Model details may be seen in Table 1 and Figure 4. Ratkowsky (1983, 1989) has shown that replacing some of the original parameters of sigmoidal type models by their exponential may improve the model function to estimate empirical data. Weibull model, that replaces θ_3 parameter on the original model by $\exp(\theta_3)$, as implemented by R software was used (see Table 1 for details).

Insert Table 1 about here

All the analyses were performed using the free-GNU R software, R version 3.0.3 (R Foundation for Statistical Computing, http://www.r-project.org/) with {car}, {data.table}, and {sm} libraries, and Wilcox' ''Rallfun-v20'' library (http://www-rcf.usc.edu/~rwilcox/. Ask for the functions ''t1wayv2'' and ''lincon''). The modelization of sensibility curve was performed with nls {stats} library and SSlogis and SSweibull Self starting algorithms (details of the adjusted models may be seen at http://www4.ujaen.es/~mramos/TasteModels.R). Statistical significance was set at $p \leq .05$.

Results

Figures 1 and 2 present the descriptive-exploratory analysis for the sensitivity and decision indexes (A' and B'_D) at each level of salt concentration (from $S_{0.07}$ to $S_{0.75}$). Graphs corresponding to the sensitivity index A' are presented in Figure 1, while graphs corresponding to the bias index B'_D, are presented in Figure 2. Within each panel, the top graph represents Kernel density functions, the bottom-left graph presents the Box-Plot, and the bottom-right graph presents the Normal Q-Q Plot.

Box-Plot chart for the sensitivity index A' suggests a staggered increase on detection as salt concentration increases. That is, uniform low A' values for the lowest concentrations that drastically increase on higher magnitudes. Additionally, all the values are on the right of the null detection line, representing positive detection values. Kernel density functions on top of Figure 1 show that the two groups with highest salt concentrations have lower variability than the other four groups. As shown in the Q-Q Plot, Normality assumption is fulfilled in general terms, though the Box Plot suggests extreme values in one out of the six groups (see $S_{0.3}$ Q-Q Plot on the right of Figure 1), and a large difference between the lowest and the greatest variance (compare $S_{0.3}$ and $S_{0.1}$ boxes on Figure 1). Statistical analyses confirmed these general impressions. A between one-way Robust Omnibus Wilcox Analysis conducted with A' found a significant effect of Salience, 20%-Trimmed Means for the six increasing levels of salience: 0.635, 0.561, 0.595, 0.617, 0.955, and 0.954, respectively; $V_W(5, 54) = 12.852$; $p = .0002$; *Robust Effect Size* $\varepsilon = 0.557$. Detailed pairwise analysis found no differences between the 4 lower concentrations [largest between groups difference: $S_{0.07}$ vs. $S_{0.09}$: $T_{Y\text{-}W}(7.16) = 0.571$; $p = 0.586$; $SE = 0.130$]. No differences were found between the two highest concentration groups either, $S_{0.3}$ vs. $S_{0.75}$ [$T_{Y\text{-}W}(6.55) = 0.038$; $p = 0.971$; $SE = 0.017$]. However, significant differences were found between any of the 4 lower concentration levels and any of the two higher concentration levels [smallest $T_{Y\text{-}W}(5.19) = 2.703$; $p = 0.041$; $SE = 0.118$; for the comparison between $S_{0.07}$ and $S_{0.75}$].

Insert Figure 1 about here

Performance for the decision index B'_D, is presented in Figure 2. The Box-Plot graph suggests that salt concentration did not have an effect on participants' performance. As a whole, index values were slightly negative, though close to the neutral bias value. Performance on the decision index seem to fulfill Normality and homoscedasticity assumptions, as shown in Kernel distributions, and in the similar wideness of the boxes across concentrations; with a single outlier in one of the groups. The Robust Omnibus Wilcox Analysis conducted with B'_D found that the salt concentration level did not affected the level of the bias, and the 20%-Trimmed Means were similar across concentrations: -0.340, -0.231, -0.213, -0.163, -0.292, and -0.097; respectively; $V_W(5, 54) = 0.650$; $p = 0.666$; *Robust Effect Size* $\varepsilon = 0.246$.

Although no differences among biases were detected as a function of the concentration level, exploratory analysis suggested the emergence of a negative response bias that was not expected, given that no variable affecting criterion was theoretically manipulated in this design. Global trimmed mean estimate of -0.234 was different from zero [$T_t(35) = -4.782$; $p = 0.000$; $SE = 0.049$].

Insert Figure 2 about here

Figure 3 graphs the functional relationship between stimulus concentrations and sensitivity values for all participants in this experiment, adjusted from different types of growth models. In panel A, the lines represent the actual median, and sigmoidal based psychophysical functions: The logistic function that has been reported in the literature as the one followed by binary taste mixtures (Keast & Breslin, 2003), and a variation of the sigmoidal curve that seems to better capture our data, the Weibull model (see Ratcliff, 1979; and Rouder et al., 2005, for a comparison of this model against exponential and logistic models).

Insert Figure 3 about here

Panel B presents the data from this experiment against other models that have been proposed in research about psychophysics curves of taste interactions, such as power, hyperbolic, and exponential (Keast & Breslin, 2003). Looking at the two panels, data from this experiment seem to be better adjusted to S-Type models than to E-Type models. Actual data suggest some asymmetry on the curve, so that the initial expansive phase may be plainer than the compressive phase. Logistic model tends to represent symmetrically both phases. Thus, this distribution of data seems to be best represented as a Weibull model (R^2 of .43 versus .39, respectively).

Discussion

A complex tasting situation, under high ecological validity conditions, was implemented to detect the possible emergence of strategies and/or response biases that may occur when complex sapid stimuli are evaluated. To pursue this goal, a SDT based experimental methodology was applied to obtain independent measures of sensory and non-sensory factors. A bias-free measure (A') allowed for estimating sensitivity to salt in a taste mixture, while a criterion index (B'_D) was used to capture biases and cognitive effects at decisional level within a detection task. As expected, the increase of salt concentration improved detection. Moreover, a trend towards a consistent slight negative bias was found.

Research about psychophysical curves of taste stimuli shows accelerating (exponential or hyperbolic) concentration-response functions: At low concentrations of salt compound, the rise in sensitivity is proportional to the rise in the concentration, while at high concentrations of the compound, no further increases in perceived intensity are attained (see Bartoshuk, 1975; Holway & Hurvich, 1937; Meiselman, 1968; O'Mahony & Wingate, 1974, for basic tastes and taste–taste interactions). However, the data obtained here seem to fit better to the sigmoidal curves proposed for taste mixtures (Keast & Breslin, 2003) than to the exponential ones (see Figure 3). As stated above, the Weibull model seems to represent the data trend obtained in this experiment more adequately than the logistic model originally proposed to explain taste-taste interactions. The Weibull distribution has been used to represent the processing stages in different psychological models (Ratcliff, 1979, and see Rouder et al., 2005). Extensions of the Weibull distribution have been proposed to enhance the capability of this function to fit different data related with biological processes such as vegetative growth, and they are widely used in reliability and survival analysis (see Lai, 2014, for an extensive revision of this model). However, to our knowledge there has been no systematic exploration of its applicability to psychophysical taste tasks.

Sigmoidal, logistic, and Weibull models all predict the three phases, expansive, linear and compressive at low, moderate, and high intensity, respectively, but the Weibull curve seems to better capture the asymmetry of growth. This model includes 4 parameters: θ_1 (the horizontal asymptote on the right side), θ_2 (relates to the intercept),

θ_3 (the rate at which the response change from initial to final value), and θ_4 (the power of x). The two initial parameters are only necessary to properly escalate the function to the specific data sample (θ_1 is the trend to the ideal sensibility of the perceptual system, and θ_2 correspond to the sensibility when stimulus concentration is null). The most relevant parameters are θ_3 and θ_4, as they allow characterizing the specific shape of the model: θ_3 establishes the rate at which the sensibility changes from the minimum to the optimal value, and θ_4 regulates the changes from sigmoid versus exponential sensibility growth type model (as in Steven's power law, 1969). However, it is basically θ_3 the one that regulates the degree of asymmetry between expansive and compressive phases in the curve. Figure 4 presents the impact of changing each of the four parameters upon the functions the model predicts.

Insert Figure 4 about here

Weibull function can describe binary taste interactions (enhancement and suppression). Although additional studies will be required to justify the use of this complex model, rather than the simpler Logistic one initially applied to taste-taste interactions, the use of the Weibull function is justified by its great flexibility. As shown in Figure 4, by changing the four parameters implemented in our study the model may become like any sigmoidal or exponential model in the literature. Additionally, the Weibull proposal has other advantages. It has shown already its usefulness in the context of Mixed Models Analysis (Pinheiro & Bates, 2000), allowing for an optimization of the statistical analysis of research concerning sensory performance involving repeated measures manipulations (e.g. feedback of learning).

It should be noted that function Modelization has important implications for the area of perceptual research. Psychophysical functions for binary compounds allow predicting interactions between the components of complex stimuli obtained from binary mixtures in aqueous solutions (e.g. Pangborn, 1960, 1961, 1962; Pangborn & Chrisp, 1964; Pangborn & Trabue, 1964). In general, psychophysics of compounds can help understanding of taste interactions in more complex stimuli such as food, resulting as a reliable method for the food science research.

In the experiment reported here a slight bias to a lenient criterion was found. This bias was similarly found across different physical intensities (see the significantly negative average found in B'_D index). In complex tasting situations participants may have greater difficulty in adopting the optimal response strategy and different response biases might appear, modifying the criterion location. A possible explanation is that tasters, depending on the complexity of gustatory stimuli, could adopt different cognitive strategies. In the field of visual perception, Irwin and Francis (1995) found variations at a decisional level due to the complexity of stimuli, with same/different judgments. The difficulty of discrimination can also increase by qualitative changes that occur in more complex mixtures (Moskowitz, 1972). In tasting situations, perception seems to be easily influenced by cognitive factors. For instance, in the context of food there are many examples of changes in the perception of a product due to contextual or cognitive factors (e.g., Caporale et al., 2006; Siret & Issanchou, 2000; Stefani et al., 2006; Tuorila et al., 1998). Sensory evaluation needs a sensory, but also a cognitive and affective approach. These aspects should be integrated in experimental designs to get a better understanding of phenomena in tasting studies.

In the present study, a measure of the true sensitivity that is uncontaminated by criterion variation was obtained while a biased response was captured. Criterion may be considerably variable in sensory judgments. As mentioned above, traditional methods used in food science to construct psychophysical functions (basically direct estimation methods) do not consider subjective factors. These methods are used to set the direct relationship between the magnitude of a physical stimulus and its perceived intensity obtaining a single measure of sensitivity. Although this approach provides simple estimates, ignores variations associated to the contextual factors or response biases providing measures that may be contaminated. SDT approach is uncovered as an appropriate methodological framework for this complete evaluation, allowing the measurement of both: Sensory and non-sensory components (Green & Swets 1988; MacMillan & Creelman, 2005). Taking apart cognitive and sensory components is central for uncovering small differences in sensory qualities and developing accurate models of perception. This proposal is of special interest for the study the psychological processes involved in tasting situations, including the evaluation of training programs conducted to improve tasters' discriminative abilities.

Finally the results of this study suggest a variety of research questions that needs to be addressed in future research. First, there is a need of more methodological research that clarifies which tools should be used within which situation. Aspects such as the choice of organoleptic characteristics, the type of task and other procedural issues should be probably based on the specific food chosen to be rated, and the research determining which methods should be used within each situation is far from being complete. Second, at a practical level, it is necessary to extend experimentation to the study of different factors affecting sensory evaluation, and their interactions. Stimuli in sensory evaluation need to be sufficiently complex to allow for extending the results to the analysis of realistic complex foods. Exploring complex matrices of compounds, and also a wide range of intensities (beyond threshold level) is required to study not only quantitative, but also qualitative changes that occur when a stimulus is perceived within a mixture. Third, conceptual aspects of sensory evaluation must be taken in account within the research in this area. Most sensory evaluation studies have a practical orientation, and there is a lack of a real theory sustaining the data. And finally, there is also a need for integration of basic sensory research, food science and consumer's preferences dimensions with the goal of reaching a full understanding of how tasting processes work.

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Table 1: Taste Psychophysical Modelization of A' sensitivity index from a Weibull type Model.

Note: The specific version of the Weibull-type model adjusted, and the meaning of the four parameters that involves is detailed. In panel B, estimates, Standard Errors (SE), Statistic value (t), its probability associated p(t), are reported for each parameter (Asymptote, Intercept, Rate, and Power). Residual standard error (RSE) and R-Squared estimations are also reported. See also Figure 4.

A) Adjusted Weibull Model.

$$y_i = \theta_1 - \theta_2 \exp\left[-\exp(\theta_3) x_i^{\theta_4}\right] + \varepsilon_i$$

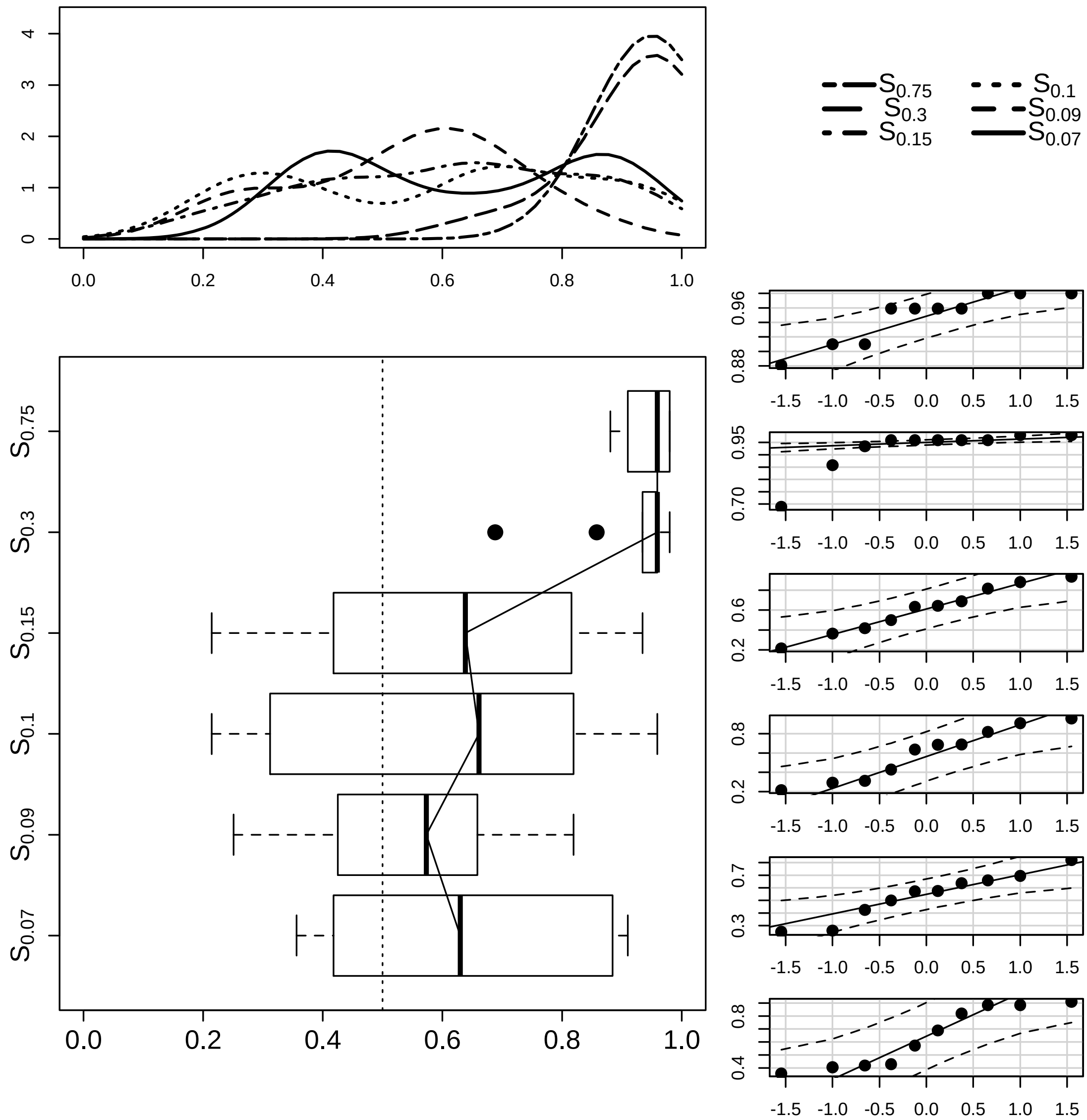
- θ_1: Horizontal asymptote on the right side. Trend to the ideal sensibility of the perceptual system (A' index≈1).
- θ_2: Relates the intercept (the y-value for x=0), the change from asymptote to the y intercept. The sensibility when stimulus concentration is null (the stimulus only contains noise).
- θ_3: The natural logarithm of the rate constant, which quantifies the rate at which the response change from initial (θ_2) to final (θ_1) value, and in this model, the degree of asymmetry in the curve. The asymmetry between expansive phase at low intensities and compressive with high values.
- θ_4: Power of x. Logistic-Sigmoid versus Power-Exponential sensibility growth type model.
- The inflection point of the curve (change from a tendency to the reverse) is related to θ_3 and θ_4 parameters, so that a proper characterization of the shape of this model involves both parameters jointly.

B) Non-Linear adjust details of Weibull Model.

Parameter	Estimate	SE	t	p(t)
θ_1 Asymptote	0.948	0.060	15.712	0.000*
θ_2 Intercept	0.357	0.07187	4.970	0.000*
θ_3 Rate	8.097	8.931	0.907	0.369
θ_4 Power	5.894	7.101	0.830	0.410

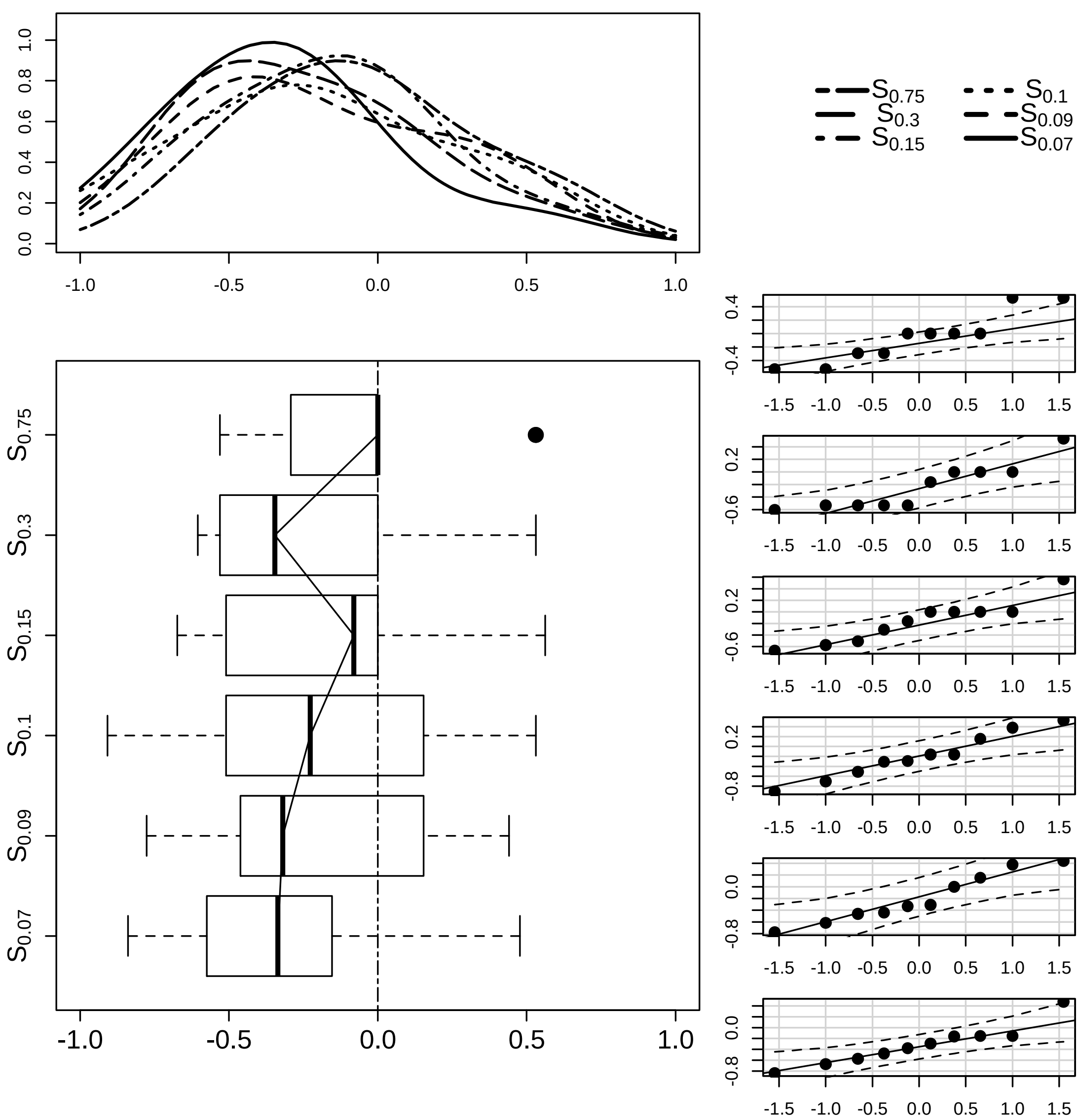
RSE = 0.191 with 56 df R^2 = 0.433

FIG. 1. DESCRIPTIVE-EXPLORATORY ANALYSIS FOR SENSITIVITY INDEX A'.



Within each panel, the top graph represents Kernel density functions, the bottom-left graph presents the Box-Plot, and the bottom-right graph presents the Normal Q–Q Plot functions. The $S_{0.07}$ to $S_{0.75}$ conditions reflect the six concentration levels manipulated.

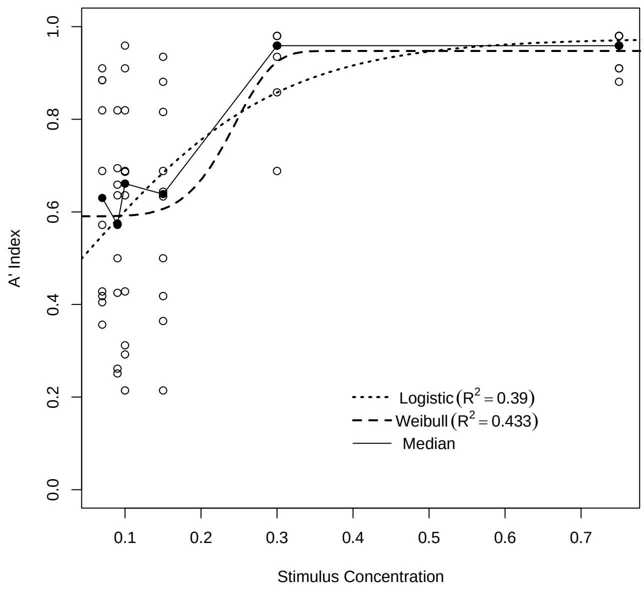
FIG. 2. DESCRIPTIVE-EXPLORATORY ANALYSIS FOR BIAS INDEX B'$_D$.



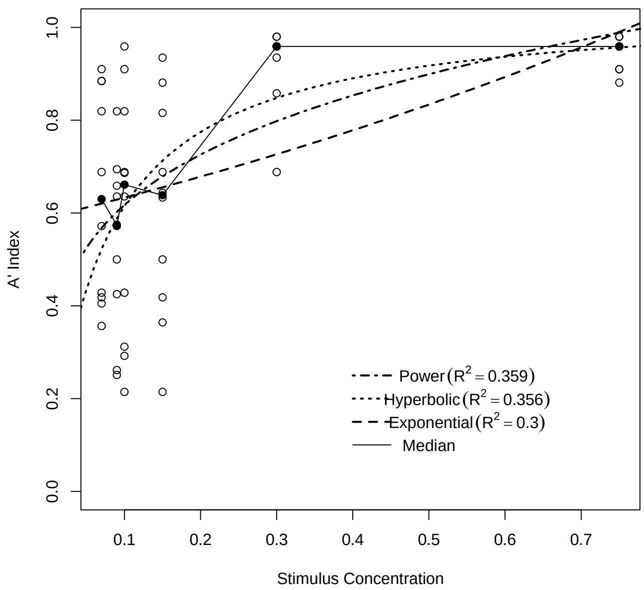
See Figure 1 for details

FIG. 3. MODELIZATION OF A' SENSITIVITY INDEX.

A) Sigmoidal-Family Models

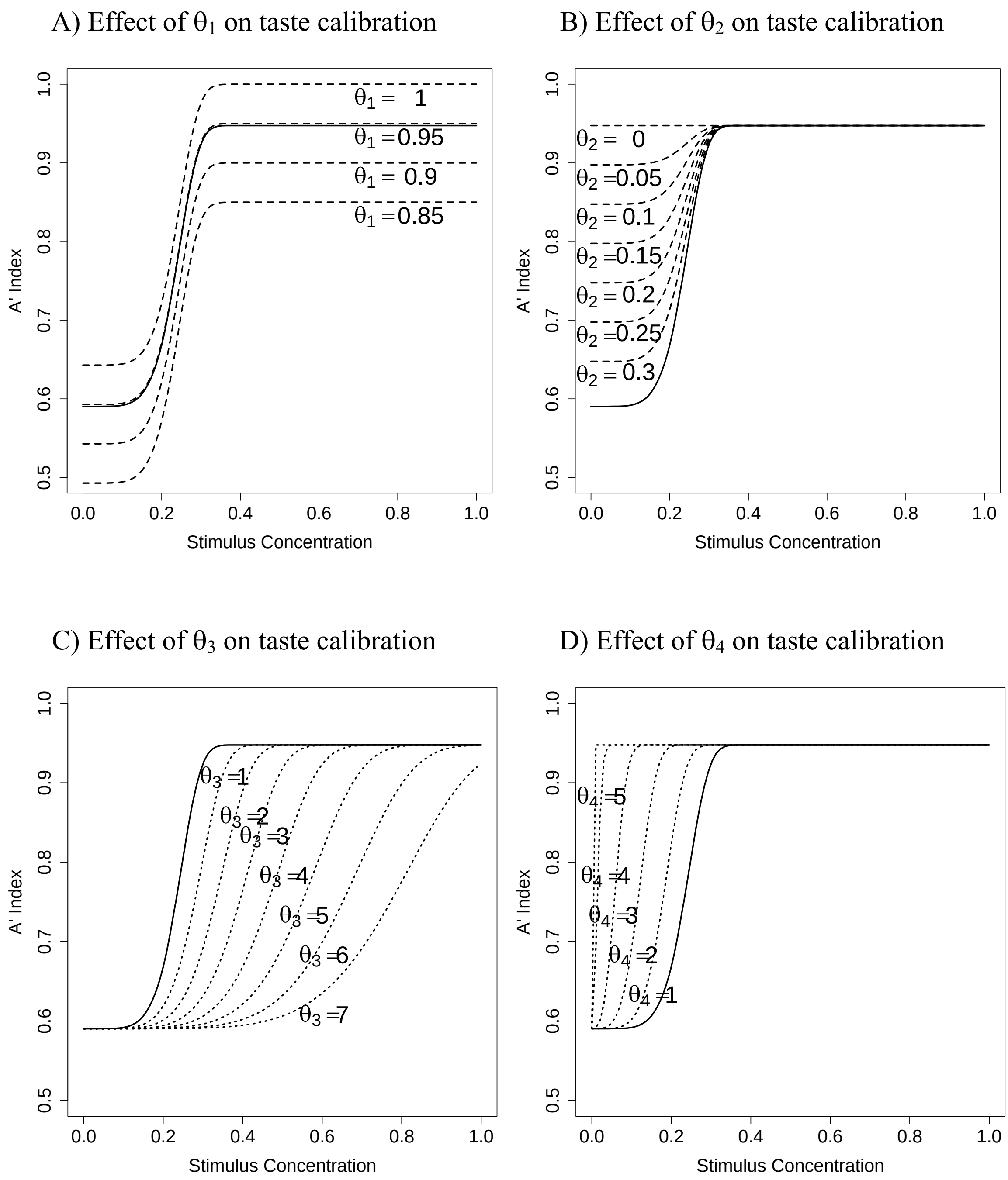


B) Exponential-Family Models



Panel A (Top) presents the charts corresponding to the Sigmoidal family models, Logistic and Weibull, while Panel B (Bottom) presents the charts corresponding to Power, Hyperbolic, and Exponential models. The points correspond to the A' values observed for each participant on each of the six salt concentration levels manipulated. The solid line links the Medians of the six conditions.

FIG. 4. EFFECTS ON THE TASTE TASK CALIBRATION CURVE OF ADJUSTING A WEIBULL-TYPE MODEL BY CHANGING THE VALUES OF EACH OF THE FOUR PARAMETERS OF THE MODEL.



See Table 2 for details

5.2 THE ROLE OF FEEDBACK AND EXPECTANCIES ON DECISION PERFORMANCE

In this section we describe a tri-factorial study in which stimuli salience was simultaneously manipulated with other cognitive factors: Signal-Noise Base Rates and Feedback. Specifically, the sensory process was manipulated by using two levels of salt concentration (0.09% and 0.75%) and the decision process was manipulated through the frequency of the Signal vs Noise trials to induce a neutral, conservative or lenient response criterion. In the neutral condition, distribution of signal and noise stimuli was uniform while in the other two conditions, a priori probabilities were calculated to produce symmetrical but opposite positive and negative effects. External feedback was manipulated with two levels: Trial-by-trial feedback and no feedback. As expected, stimuli salience only affected sensory performance improving discriminability as salt concentration was increased. In addition, better accuracy was observed under feedback condition. Signal-noise stimulus base rates and feedback both affected the decision process. Feedback allowed criterion to be set according to the stimulus probabilities presented: A positive, negative or neutral bias was obtained when induced criterion was conservative, lenient or neutral, respectively. However, the relationship between base rates and response bias was reversed when feedback was absent. The opposite effects on the criterion for the lenient and conservative strategies were symmetrical under the feedback condition but not in the absence of the external feedback. A significant interaction Feedback x Induced Bias was found suggesting that feedback modulates the type of induced bias.

Dissociating Sensory and Decision Processes in Tasting: Salience Affects Sensitivity While Expectancies and Feedback Interact, Affecting Decision Criterion

Short title SALIENCE, EXPECTANCIES AND FEEDBACK IN TASTE

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Abstract

The Double Dissociation Additive Test was used to separate the effects of manipulating salience, signal-noise base rates, and feedback, on sensitivity and decision processes within the Signal Detection Theory framework. Participants performed a tasting task involving the mixture of salty and sour basic flavors. Participants' discrimination improved as salt concentration increased, regardless of the induced bias or the presence or absence of feedback, thought feedback led to a general increase in sensitivity. Signal-noise stimulus base rates and feedback both affected the decision process. When feedback was present, detection judgments tended to approach true signal-noise stimulus base rates. However, the relationship between base rates and response bias was inverted when feedback was absent. Implications for research in sensory evaluation and perceptual learning are discussed.

Keywords: Signal Detection Theory, The Double Dissociation Additive Test, sensory evaluation, Taste, feedback, signal-noise base rates.

Dissociating Sensory and Decision Processes in Tasting: Salience Affects Sensitivity While Expectancies and Feedback Interact, Affecting Decision Criterion

Sensory analysis through tasting is an important tool on the analysis of the quality of aliments, especially for those that have been defined as functional foods such as olive oil. The tasting process is a psychophysical situation in which measurement of the psychological attributes is established by reference to variations in a physical continuous such as the intensity of different substances (Lawless & Heymann, 1988). In tasting situations, observers use their knowledge to aid detection and make a judgment about a feature or component of the food. This judgment is actually the outcome of a number of physical, physiological, and psychological processes. No theory of perceptual judgments is complete without the understanding of the functional dynamism due to the interplay between factors affecting the sensory process, such as perceptual acuity, and factors affecting cognitive processes such as tendencies, response biases or task specific conditions (Schifferstein, 1996). Dissociation between sensory and decision processes contributes to an optimization of the evaluation of the food quality, facilitating comparisons between experts' and regular consumers' evaluations (e.g., Martín-Guerrero, Paredes-Olay, Rosas, & Ramos-Álvarez, 2014). For instance, Moreno-Fernández, Ramos-Álvarez, Paredes-Olay and Rosas (2012) found that an easy-to-hard training schedule improved the ability for detecting an attribute within the context of olive oil tasting, but it simultaneously produced a bias towards the use of a conservative strategy of responding. These results imply that the use of this type of training schedule in the context of flavor tasting needs to be combined with the use of an strategy that allows tasters correcting the bias, such as the use of specific instructions that may prevent trainees to be overly conservative.

To establish such a dissociation in the field of tasting, Ramos-Álvarez and his colleagues have applied research methods based on Signal Detection Theory (SDT) to the field of olive oil tasting, a model of perceptual processing that allows for separating and quantifying sensory and decisional components, granting independent measures of perceptual sensitivity and response biases (Green & Swets, 1966; Macmillan & Creelman, 2005). For instance, Ramos-Álvarez, Moreno-Fernández, Paredes-Olay and Rosas (2013) manipulated olive oil concentration (0.4%, 0.8%, or 1.6%) and instructions (lenient or conservative), finding that the sensory process was only affected by olive oil concentration, while the decision process was only affected by the instructions (see also Moreno-Fernández et al., 2012; Paredes-Olay, Moreno-Fernández, Rosas, & Ramos-Álvarez, 2010).

Signal Detection Theory (SDT) is based on a task defined in terms of a decision matrix plotted by combining at least two different stimuli (Noise *versus* Signal+Noise trials) and two complementary responses (i.e., Yes or No). The dependent variable is computed as a combination of Hits [p(Yes/Signal + Noise)] and False Alarms [p(Yes/Noise)] rates. This information allows for computing two different indexes, one quantifying the sensory process, and the other quantifying the decision process. Sensitivity, defined as the acuteness on responsiveness to external stimuli, is generally assumed to be fixed for any given task. Sensitivity is often quantified by index d', defined as the distance between the probabilistic distributions associated to Signal and Noise. Decision criterion represents the likelihood of giving one response rather than the other, and it is often operationalized by index Beta, defined as the relative distance associated to the height of the Signal and Noise distributions at the point in which the observer establishes a response criterion or decision frontier (Macmillan & Creelman, 2005). Within SDT studies, the information to take a decision is usually ambiguous, so that a large number of factors and psychological processes may affect observers' judgments. In addition, criterion shifts may be experimentally induced: Decision criterion seems to depend on task instructions, on the base rates of presentation for each type of stimulus, and on the payoff value (Macmillan & Creelman, 2005; Swets, 1996; Wickens, 2002).

Allowing for differentiating between sensory and decision processes is among the greatest contributions of SDT to experimental psychology. The most common way of using this advantage is to infer which process is affected by the manipulation of any given independent variable through the effects that it produces in the sensory and decision indexes separately (i.e., d' versus Beta). Ramos-Álvarez et al. (2013), evolving from the methodological proposals made by Sternberg (1969, 1998) have recently proposed and applied what they have called the Double Dissociation Additive Test to the field of tasting. Within this method, the research conducting to dissociate between the two processes will be defined in such a way that at least one factor for each process will be manipulated following the structure of a fully-crossed factorial design. This approach allows for testing whether the factors interact or add to each other (see Kirk, 1995). Factors should be chosen so that they are expected to affect each process separately, following a theoretical model that connects processes with factors. The two indexes provided by SDT are supposed to be independent from each other. However, this is a theoretical assumption that needs to be tested, so that the independence property is fulfilled within the specific context of the developed research. Taken in account both requirements, the dissociative logic will be applied twice: Testing whether the factor associated to the sensory process affects to the sensory index but not to the criterion index, and evaluating whether the factor associated to the decision process affects criterion index but not the sensory index. This strategy allows for a direct evaluation of the dynamics of the processes, given that the inferences about the interaction/independence between sensory and decision processes can be obtained in a convergent way for the two indexes, allowing for a direct comparison between them. The Double Dissociation Additive Test solves the problem of indirect estimation that affects other dissociation approaches. Several points of criterion performance are required to be able to estimate sensitivity with the SDT prevalent method (i.e., by d') (see Macmillan, & Creelman, 2005; Sweets, 1996; Wickens, 2002). As a consequence, it is not possible to obtain a direct measure of the sensory process, given that, within this approach, the sensory measure depends on the criterion process and may be contaminated by it.

Additionally, the SDT framework is useful to derive measures of the processes that are independent from a statistical-methodological point of view. This does not necessarily imply that both processes should be always independent in the sense of not being affected by the same manipulation (c.f. Howe, Rabinowitz, & Grant, 1993). There are some reports in the literature finding that experimental manipulations that should selectively affect only one of the processes, affected both, so that no dissociation between processes is found (see for instance Stillman, Brown, & Troscianko, 2000; Yonelinas & Jacoby, 1996). Even more, dissociation may depend on the chosen indexes, confounding statistical and empirical independence (Snodgrass & Corwin, 1988). The only way to break this vicious circle involves developing a theoretical model that specifies why and when the independence between measures will be expected, together with the use of a reliable methodological model that guaranties the properness of the indexes used (see Ramos-Álvarez et al., 2013).

The present study applies the Double Dissociation Additive Test to evaluate the role of feedback on perception of flavors, by including two additional factors that theoretically affect sensory and decision processes independently: Stimulus salience, and signal/noise base rates. Also, the tasting task chosen in this work involves the mixture of salty and sour basic flavors, rather than the natural foods used by Ramos-Álvarez et al. (2013). The use of a combination of basic flavors has the advantage with respect to the use of natural foods of increasing the experimental control, as it simplifies the manipulation of the combination of flavors while keeping the situation fairly close to the natural situation in which tasters usually confront complex stimuli.

The role of feedback on performance is an issue widely discussed in the literature, perhaps because its effects do not always follow a simple pattern; neither have they seemed to allow for a simple explanation of their mechanisms of action. An unclear question is whether feedback is necessary for learning to develop, or it only affects performance. Some authors find robust learning effects without external feedback (Fahle & Edelman, 1993; Petrov, Dosher, & Lu, 2006). Others suggest that although people learn more slowly in the absence of feedback, the same final level of performance may be achieved in both conditions (e.g., Mackintosh, 2009). In other cases, feedback seems necessary for learning when the task is complex, but it may be irrelevant with simple tasks (e.g., Kluger & DeNisi, 1996; Liu, 2011; Shiu & Pashler, 1992). At any rate, regardless of whether feedback is necessary for learning or not, there is a general agreement in the literature about the most common effect: Lowering the rate of feedback leads to an impairment on performance and to an increase in variability (Dobres & Watanabe, 2012; Herzog & Fahle, 1997). The explanation of this effect may relay on feedback focusing observers' attention to mistakes associated with a particular response, allowing them to improve their performance. Conversely, reduced frequency of feedback often forces observers to try different actions in their attempts to identify correct and incorrect responses, allowing for developing unsuccessful strategies that lead to impairments of performance (Goodman & Wood, 2004). Following this idea, an effect of feedback on the strategy of responding would be anticipated. Feedback would be expected to have also an effect on the precision/accuracy itself (i.e., as measured by SDT d') but in the absence of interactions with other factors affecting the basic sensory process. Following the Double Dissociation Additive Test, it will be important to study the effect of feedback on accuracy along with some variable known to affect the sensory process, such as the stimulus salience.

As it has been argued, although feedback could have a direct effect on adjusting the response criterion, little is known about the effect of their absence on decision-making. This cast doubts about whether the effects of feedback on the decision criterion may depend on whether taster's criterion is lenient or conservative. Following up with this idea, it would be interesting to evaluate whether the presence or absence of feedback may interact with a factor affecting the decision-making process. Accordingly, we chose first a factor whose effects on criterion are well established: The probability of the presentation of the stimuli. As pointed out above, varying the frequency of signal and noise stimuli may experimentally induce a conservative or a lenient strategy of responding in participants, leading observers to approach the true stimuli base rate. In the framework of models based on SDT, this tendency has been interpreted to be a consequence of an adjustment of the decision criterion to the actual probabilities of the stimuli presented in the situation (Macmillan & Creelman, 2005; Swets, 1996; Wickens, 2002).

Some results in the literature suggest that there may be an interaction between feedback and signal probability that is worth to explore. When participants are previously informed about the probability distribution of signal and noise stimuli within the task, providing limited feedback do not seem to affect the effect of signal probability on performance (e.g., Ratcliff, Shen, and Gronlund, 1992; Swets, Tanner, and Birdsall 1961). However, when participants are not aware of the signal/noise distribution, and feedback is not provided, decreasing the probability of the signal do not seem to make participants' criterion more conservative (e.g., Parducci and Sandusky, 1965; Tanner, Haller, & Atkinson, 1967; Tanner, Rauk, & Atkinson, 1970). A reasonably interpretation of this result is that participants tend to believe that the stimulus probabilities are identical in the absence of feedback so that their responding does not reflect the actual asymmetric distribution of stimuli (Macmillan & Creelman, 2005).

The main goal of the study presented here was exploring sensorial-decision dynamics, an issue relatively neglected in taste perception research, by varying three factors simultaneously: Stimulus attributes, base rates and feedback conditions. In the recognition domain, Estes and Maddox (1995) explored the effects of these three variables and some of their interactions, finding that hits and false alarms levels were independent of the base rate in the absence of feedback (or relevant prior knowledge). With feedback added, false alarm rates tended to approach true stimulus base rates when random triads of consonants or digits, but not words, were used as stimuli.

Following the Double Dissociation Additive Test described above, three independent factors were simultaneously manipulated in a complete factorial design. The intensity of the flavor was manipulated by varying the salt concentration in the salt-sour compound. Stimuli preparations were chosen to maximize the separation between

Signal and Noise distributions using two different extreme values of signal salience (0.09% and 0.75%). According to SDT this factor should affect the sensitivity process but it is not expected to influence the response criterion. Base-rates were manipulated by varying the signal-noise proportion. Three levels of probabilities were used to guide participants to adopt a conservative, lenient or neutral pattern in their judgments about the presence of salt in the sample. Probabilities a priori were designed to produce a symmetrical but opposite bias. Thus, according the SDT this factor should affect the decision process but should not influence the sensory process. Following the logical display of the Double Dissociation Additive Test, the absence of interaction in such context will give support to the idea that cognitive processes associated to both factors are independent from each other within the tasting situation.

Finally, a third variable was included in the experimental design: The external feedback. Feedback on performance may influence the sensory process (i.e., affecting the separation between the curves of Signal and Noise) but it may also affect the decision process (e.g., Estes & Maddox, 1995). We estimate simultaneously the effects of feedback manipulation on sensitivity and response criterion. The key issue in this study was how feedback interacts with flavor intensity and base rates, and whether it would affect the sensitivity process, the decision process, or both.

Method

Participants

A hundred and eighty undergraduate volunteers of the University of Jaén, 142 females and 38 males, participated in the study. They were between 17 and 47 years old (Mdn = 21). None of them had previous experience with the task or formal training on sensory evaluation. All participants read and signed an informed consent before starting the experiment and were free to leave the laboratory at any time, though none of them chose to use this option. Participants were instructed to come to the laboratory in the appropriate conditions to conduct a taste experiment. They were requested to avoid smoking or taking foods or drinks in the half hour before the beginning of the tasting session. Participants that had some temporary alteration of the taste sense produced by cold or allergy episodes were given an appointment for a different day. Within the tasting session, they were randomly assigned to each of the 12 experimental conditions involved in the experiment, so that each group was composed by 15 participants. Age and gender distribution was uniform across groups.

Materials and Apparatus

Two types of taste stimuli in aqueous solution were used in each session: Noise (N) and Signal+Noise (SN). Noise mixture was made with 1.5% of a sour compound [Pulco Lemon Flavor, Orangina Schweppes: lemon juice (40%), water (56%), and pulp of lemon (4%)], and 98.5% of distilled water. A small amount of salt was added to the mixture to conform the Signal stimulus. Two different SN stimuli were prepared, varying on the amount of salt in each concentration (0.09% and 0.75% respectively).

Solutions were presented in plastic glasses at room temperature. Each glass contained 7 ml. An inter-stimulus procedure of mouth-rinses with water to remove residuals from prior tastings and avoid taste sense adaptation was used between samples. A numbered plastic sheet was placed at the table so that participants could leave the samples after tasting them.

The tasting laboratory consisted of 7 individual cabins equipped with a desk, a chair and a computer provided with specific software to control the stimulus presentation *(LearnOlive)*. LearnOlive software was specifically developed by M.M. Ramos-Álvarez to conduct tasting experiments, and allows participants to easily follow the complete sequence of the task (see a detailed description in Ramos-Alvarez et al., 2013). A 17” TFT computer screen, a rubber keyboard and a mouse were placed in front of the participant.

Procedure

After signing the written consent, and filling a sociodemographic questionnaire upon their arrival to the laboratory, participants received general instructions about how to taste the samples.

Twenty-five samples were presented to each participant (one practice trial plus twenty-four experimental trials). The first sample was used only for practicing the tasting procedure.

Sensory process was manipulated by using two levels of the salty compound: 0.09%, and 0.75%. Decision process was manipulated varying the frequency of the signal to induce a neutral, conservative or lenient response criterion. In the neutral condition, distribution of signal and noise stimuli was uniform (12 SN and 12 N), while in the other two conditions, a priori probabilities were calculated to produce a symmetrical but opposite bias –positive (4 SN and 20 N) or negative (20 SN and 4 N). The final base-rate values used were 0.50, 0.16 and 0.84 respectively. External feedback was manipulated with two levels: Trial-by-trial feedback and no feedback. Participants receiving feedback were informed about of correctness of their response (correct/incorrect), while no information was given to participants without feedback.

Twelve independent conditions resulted from the complete factorial crossing of two concentrations levels with three levels of bias and two levels of feedback.

Participants performed a simple detection task in which they had to indicate whether each presented sample contained salt or not. The protocol followed by each participant was: (1) picking the sample according to the established sequence, (2) tasting the sample, (3) giving the response about its content (Yes/No), (4) leaving the glass aside, and (5) cleansing her or his palate.

There was no time limit for performing the task, though most participants finished the complete procedure within 30 min after their arrival to the laboratory.

Dependent Variables and Data Analysis

Yes/no responses were used to compute Hits and False Alarms rates and then calculate the sensitivity and decision indexes. Due to the probability of observing extreme rates, a logarithmic-linear corrective strategy was used by adding a constant amount, 0.50, to all the frequencies before computing the rates.

Over thirty different formulas have been proposed to compute sensory and decision processes, with very diverse aims and scopes (e.g., Balakrishnan, 1998; Kadlec, 1999; Macmillan & Creelman, 1990; Reales & Ballesteros, 1994; Snodgrass & Corwin, 1988; Stanislaw & Todorov, 1999; Van Der Goten & Vandierendonck, 1997; Wright, Horry, & Skagerberg, 2009). Methodological research suggests that SDT d' or Az (Donaldson & Good, 1996) are the most appropriate indexes for evaluating sensory processes (Swets, 1986), while index c (Ingham, 1970) or LogBeta seem to be better than Beta for characterizing the decision criterion (Macmillan & Creelman, 1990; Snodgrass & Corwin, 1988; Wickens, 2002). However, the choice of the appropriate indexes to be used should depend on the specific field of application (Balakrishnan, 1998). In the case of tasting situations, sensory evaluation necessarily involves a small number of tasting trials to avoid saturating the senses, making it difficult to fulfill parametric requirements (e.g., Wickens, 2002). Indexes with less restrictive underlying assumptions may be used to solve this problem, such as A' as a sensory index (Donaldson, 1993; Macmillan & Creelman, 1996; Smith, 1995; Zhang & Mueller, 2005) and B' or B'_D as a criterion index (Donaldson, 1992; see also See, Warm, Dember, & Howe, 1997). Ramos-Álvarez et al. (2013) compared different pairs of psychophysical indexes within a tasting situation (A'– B'_D, A'– B', d'– c and d'– Log Beta) confirming that indexes A'– B'_D

were the most appropriate for this type of research, as they have the lowest degree of bias on measurement. Following the findings of Ramos-Álvarez et al. (2013), non parametric Grier's (1971) A', and Donaldson's (1992) B'_D were computed as sensory and decision indexes, respectively.

The use of a small number of trials makes it difficult to verify assumptions such as Normality and Homoscedasticity. Additionally, in tasting tasks is likely to find outliers, making the use of conventional statistical techniques inappropriate. To explore these assumptions while summarizing the data, variability and central tendency indexes are presented in Box-Plot graphs according to robust statistics based on median (Wilcox, 2005). Robust statistics have shown to be useful in olive oil tasting situations and they have been proposed as a general analytic approach to tasting research (see Ramos-Álvarez et al., 2013). Robust analyses of variance on trimmed means were conducted by using Yuen-Welch ($T_{Y\text{-}W}$) test for between-groups pairwise comparisons, and Robust contrasts of a sample were conducted by a T-test Trimmed variant (T_t).

All the analyses were performed using the free-GNU R software, R version 3.0.3 (R Foundation for Statistical Computing, http://www.r-project.org/) with {car}, {data.table}, {Hmisc} and {sm} libraries, and Wilcox' ''Rallfun-v20'' library (http://www-rcf.usc.edu/~rwilcox/. Ask for the functions ''t1wayv2'', ''t3way'', "mcp3atm", and ''lincon''). Statistical significance was set at $p \leq .05$.

Results

Descriptive-exploratory analysis are presented in Figures 1a and 1b for index A', and in Figures 3a and 3b for index B'_D. In each of the four figures the top graph represents Kernel density functions, bottom-left graph presents the Box-Plot, and Bottom-right graph presents the Normal Q-Q Plot. The twelve conditions that appear in Figures 1a and 1b (for dependent variable A') and in Figures 3a and 3b (for dependent variable B'_D) reflect the complete factorial crossing of two concentration levels (0.09 vs. 0.75) with three levels of prompted bias (E-, E+, and E0, for lenient, conservative or neutral, respectively) and two levels of Feedback (With feedback versus Without feedback).

Insert Figures 1a and 1b

Box-Plot chart for sensitivity index A' suggests a parallel increase on detection by salt concentration, regardless of the induced bias (conservative, lenient or neutral) and type of feedback (With feedback versus Without feedback) [compare $S_{0.09}$ with $S_{0.75}$ in any of the graphs of Figure 1a, With-feedback, or in the graphs of Figure1b, Without-feedback]. Variability is somewhat irregular across groups, as confirmed by Kernel density functions on top. However, as shown in the Q-Q Plot, Normality assumption is fulfilled, though there are outliers in five out of the twelve groups of the study [see all conditions except $B_{E+}S_{0.09}$ in Figure 1a and $B_{E0}S_{0.75}$ in Figure 1b]. A 2 (Salience) x 3 (Induced Bias) x 2 (Feedback) Robust Omnibus Wilcox Analysis conducted with A' found a significant main effect of Stimulus Concentration, V_W (1,168) = 111.188; $p < 0.000$. The main effect of Feedback was significant, V_W (1,168) = 4.875; $p < 0.032$, but the main effect of Induced Bias was not, V_W (2,168) = 0.055; $p > 0.974$. No interaction was significant: Either for Stimulus Concentration x Feedback, V_W (1,168) = 0.006; $p > 0.939$; for Stimulus Concentration x Induced Bias, V_W (2,168) = 1.576; $p > 0.47$; for Feedback x Induced Bias, V_W (2,168) = 1.74; $p > 0.435$; or for Stimulus Concentration x Feedback x Induced Bias, V_W (2,168) = 1.879; $p > 0.407$. The results of index A' are better summarized in the top panel of Figure 2 (panel a) where descriptive analysis are presented using a Dot-Plot in which performance is organized so that it allows to compare all the variables of the trifactorial design within the same Figure. The 20%-Trimmed Means for the sensory index A' clearly shows the parallel increase on detection as salt concentration increases, regardless of the induced bias and of the type of feedback, statistically supported by the analysis above (marginal 20%-Trimmed means were 0.641 and 0.925 for 0.09 and 0.75 concentrations levels) as well as the general increase on the sensibility index when feedback is present with respect to the absence of feedback (marginal 20%-Trimmed means were 0.845 and 0.781 respectively).

Insert Figure 2

Figures 3a and 3b present performance for decision index B'_D. The Box-Plot graph for conditions With-feedback (Figure 3a) suggests that participants showed a positive bias when expectation was conservative (E+ on $B_{E+}S_{0.09}$ and $B_{E+}S_{0.75}$ conditions), a negative bias when expectation was lenient (E- on $B_{E-}S_{0.09}$ and $B_{E-}S_{0.75}$) and a zero value when expectation was neutral (E0 on $B_{E0}S_{0.09}$ and $B_{E0}S_{0.75}$). However, the Box-Plot graph for the Without-feedback condition (Figure 3b) shows a different pattern, suggesting that feedback variable modulates the type of induced bias (compare conditions E+, E-, and E0 of Figures 3a and 3b). Performance on the decision index breaks Normality assumptions, showing Heteroscedasticity and outliers. Kernel density functions and Q-Q Plot suggest asymmetry. The Box Plot shows extreme values in three out of the twelve groups, and a large difference between the lowest and the highest variance (see Group B_E-$S_{0.09}$ and Group B_E-$S_{0.75}$ boxes in Figure 3b). A 2 (Salience) x 3 (Induced Bias) x 2 (Feedback) Robust Omnibus Wilcox analysis found a significant main effect of Feedback, V_W (1,168) = 7.075; p < 0.012. Neither the main effect of Stimulus Concentration, V_W (1,168) = 0.299; p > 0.59, nor the main effect of Induced Bias were significant, though in this latter case probability was close to 0.05, V_W (2,168) = 6.484; p > 0.054. Among the interactions, only Feedback x Induced Bias interaction was significant, V_W (2,168) = 62.769; p < 0.001; Stimulus Concentration x Feedback, V_W (1,168) = 0.002; p > 0.966, Stimulus Concentration x Induced Bias, V_W (2,168) = 2.977; p > 0.247, and Stimulus Concentration x Feedback x Induced Bias, V_W (2,168) = 1.350; p > 0.523, were not significant.

Insert Figures 3a and 3b

To detail the only significant interaction observed for the B'_D index, an analysis of the simple effect of Induced Bias was performed on each level of the Feedback variable. In the condition With Feedback significant differences were found for every comparison between two levels of Induced Bias: E- vs. E+ [$T_{Y\text{-}W}$ (32.87)= 10.387; *SE*= 0.102; critical value of 2.510], E- vs. E0 [$T_{Y\text{-}W}$ (31.16)= 6.224; *SE*= 0.098; critical value of 2.516], and E+ vs. E0 [$T_{Y\text{-}W}$ (33.49)= 5.224; *SE*= 0.087; critical value of 2.507]. Robust t-tests confirmed that induced bias was effective, given that trimmed means were significantly lower than zero in E-, -0.592, [T_t = -7.609, *SE* = 0.0778]; significantly greater than zero in group E+, 0.470, [T_t = 7.287, *SE* = 0.065]; and statistically equivalent to Zero in group E0, 0.015 [T_t = 0.266, *SE* = 0.057, p > 0.7936]. Instructed bias had a symmetrical effect as no significant differences between E- and E+ groups were found when the analysis was conducted with absolute values [$T_{Y\text{-}W}$ (33.29)= 1.268; *SE*= 0.102; critical value of 2.508, p > 0.2140].

In contrast, for the condition Without Feedback there were significant differences between E- and E+ [$T_{Y\text{-}W}$ (27.49)= 3.484; *SE*= 0.183; critical value of 2.535], or between

E- and E0 [$T_{Y\text{-}W}$ (30.66)= 2.819; *SE*= 0.194; critical value of 2.517], but not between E+ and E0 [$T_{Y\text{-}W}$ (32.86)= 0.635; *SE*= 0.146; critical value of 2.510; p>.5297]. The Robust t-test revealed a pattern of bias that deviated from the one predicted by SDT: The trimmed mean of E-, 0.149, was not statistically different from zero [T_t = 0.956, *SE* = 0.156, p > 0.3524], the mean of E+, -0.489, was statistically lower than zero [T_t = -5.330, *SE* = 0.092], and the mean of E0, 0.015, was also lower than zero [T_t = -3.580, *SE* = 0.111]. The Robust Omnibus Wilcox highlights the lack of a significant effect of the Induced Bias with absolute values of B'_D index as dependent variable [V_W (2,177) = 0.277; p > 0.760]; thus, all three conditions are equivalent in terms of the magnitude of the bias induced.

The complex pattern of results is more simply summarized in panel b of Figure 2, which a descriptive analysis using a Dot-Plot is presented for index B'_D. Performance is organized so that it allows comparing all the variables of the trifactorial design within the same Figure. The 20%-Trimmed Means for index B'_D show a different pattern depending on whether feedback was present or not, regardless of the concentration. When feedback was provided, B'_D index was neutral for E0, positive (conservative) for E+, and negative (lenient) for E-. In the absence of feedback, the pattern was more complex, with negative values when bias was neutral or conservative (E+ and E0 conditions), and positive or neutral values for lenient expectation (E- condition).

Discussion

The main goal of this study was to evaluate the interactions between salience, signal/noise base rates and feedback in both, the tasters' ability to discriminate between the presence and the absence of a taste within a complex flavor, and the tasters' ability to adapt their decision criterion as a function of the manipulation of these variables. To this end, The Double Dissociation Additive Test was applied to a tasting situation within laboratory requirements but adopting an ecological point of view.

The most relevant finding in this study was related to the effect of the feedback manipulation on both sensory and decision-making processes. With respect to the sensory process, trial-by-trial-feedback affected sensibility for detection of salty stimuli. Participants improved their performance when feedback was available. This effect was independent of the intensity of the stimulus. Results are in agreement with most of the studies that report a positive effect of feedback by improving overall accuracy of performance and reducing variability (e.g., Herzog & Fahle, 1997).

The most noticeable difference between Without-feedback and With-feedback conditions involved the response bias. A significant interaction Feedback x Induced Bias was found in the decision index, suggesting that feedback modulates the type of induced bias. Feedback allowed criterion to be set according to the stimuli probabilities presented: A positive, negative or neutral decision index value was obtained when induced criterion was conservative, lenient or neutral, respectively. In this case, results were clearly adjusted to normative predictions derived from SDT (e.g., Macmillan & Creelman, 2005).

When feedback was omitted a somewhat complex pattern of results was found though, in general, an inverse relation between expectations and response bias was observed. Although this effect occurred with the both unequal base rates, the trend to a negative bias was greater, given how neutral condition was affected by the absence of feedback. In agreement with Tanner et al. (1970; see also Parducci and Sandusky, 1965), these results seems to indicate that the influence of the presentation schedule on criterion performance depends on whether or not the participant receives information about the accuracy of his or her response. If no information is given to the participant, hits and false alarms decrease as probability increases. If feedback is provided, the relationship is reversed. Feedback and knowledge of the relative frequencies of the signals allow participants to adjust their reports to the actual distribution of signal and noise presentations. In the absence of explicit feedback about their response accuracy, participants are not able to adapt their criterion according to the criteria induced by the base rates manipulation, and different response biases emerge. These findings are at odds with previous data reported without feedback (e.g., See et al., 1997) and could be partially in contradiction to the assumption of participants adapting their criterion to the actual signal/noise probability predicted by SDT (Luce & Green, 1974).

As mentioned in the introduction, a simple interpretation of these effects is that in the absence of information, participants tend to believe that the presentation probabilities of signal and noise stimuli are equal (Macmillan & Creelman, 2005). Alternatively, it has been suggested that a common property of many judgments' tasks is the tendency to equalize the frequency of all the available responses; in this case, that tendency would lead to distribute equally "yes" and "no" responses (Arons & Irwin, 1932; Luce & Green, 1974; see also Creelman & Donaldson, 1968; Dorfman, 1969; Parks, 1966; Thomas & Legge, 1970). Luce and Green (1974) also suggest that this effect is related with the degree of experience in this type of experiments, concluding that naive participants invariably reduce false-alarm rates as the signal probability is increased. Experience seems to provide information to participants making them aware of the factors manipulated and therefore helping them to adjust their responses, avoiding unsuccessful strategies. It should be noted that here participants were not experienced with the task; neither had they formal training on sensory evaluation. In addition, most researchers agree in concluding that with no external feedback, learning might be possible but improvement is slow (e.g. Mackintosh, 2009). This may be the reason because some authors have found an adjustment of criteria in the absence of feedback with longer sessions and trained participants in tasks using massive training, such as the vigilance task used by See et al. (1997), in which, stimuli were single white lines presented at a rate of 20 events/min during 40 minutes, and participants received training in the form of a two-alternative forced-choice discrimination task as well as a 10-min practice session. Thus, another way to stabilize responding and reduce response biases might be increasing the number of trials. But this solution is not simply applied to sensory evaluation, given that this kind of evaluation necessarily involves a small number of tasting trials to avoid saturating the senses. This feature highlights the importance of measuring response biases in sensory evaluation.

In this study, the Double Dissociation Additive Test was used to test the suggested independence of sensory and decision processes within the SDT framework. As expected, salience of stimuli and probabilities a priori, differentially affected to sensory and decision parameters respectively, then two separate processes were influenced by two different factors. The lack of interaction in such context gives support to the idea that psychological processes associated to both factors are independent from each other. Nonparametric indexes and robust analysis of variance allowed for detecting these independent variations in sensory and criterion measures. This analytic approach showed to be especially suitable to tasting research in agreement with previous results within the field of olive oil tasting (Paredes-Olay et al., 2010; Ramos-Álvarez et al., 2013). In general, results were also in agreement with those reported within other experimental research paradigms such as vigilance, memory, diagnostic, etc. (see Swets, 1998 for a review). Thus, the ecological perspective adopted for this experiment also showed to be adequate.

In summary, feedback seems to be important in a range of circumstances. Here we have shown that feedback may be a necessary feature to the adjustment of the criterion to the actual stimuli base rates; but it may be also a requirement of the task if the experimenter is interested in looking at changes in the response criterion when different costs and rewards are associated with performance (McNicol, 2005). The overall task difficulty and the initial accuracy could also two important factors to be taken in account in future research in this field (Petrov, Dosher, & Lu, 2006). Further research will be needed to find out which task properties and factors modulate feedback effects and vice versa.

In addition, studying the effects of various feedback manipulations is of obvious significance too. Different types of feedback schedules (e.g., trial by trial, partial, in blocks) may also have distinctive effects on the overall performance and differentially affect decision criterion and sensitivity in perceptual learning (Aberg and Herzog, 2012; Herzog and Fahle, 1997). Aggregated block feedback seems a particularly interesting form of feedback that may be as efficient as trial-by-trial feedback in conditions when no-feedback learning fails, and trial-to-trial feedback is difficult to apply (Herzog & Fahle, 1997). In most SDT experiments participants receive trial-by-trial feedback in which they are informed about the stimulus just presented. Additionally, they are informed about the proportion of signal and no-signal trials at the start of each session. According to SDT, those features of the procedure may enable participants to adjust their response criterion to ideal values. In this experimental situation some authors found a significant main effect for probabilities manipulation even providing limited information about accuracy -block or error feedback (e.g., Ratcliff, Shen, and Gronlund, 1992; Swets, Tanner, and Birdsall 1961). However, it seems that extensive feedback procedures can help observers to report the more likely stimulus and additional manipulations that make the different stimuli probabilities even more salient, can act reinforcing the effect (Estes & Maddox, 1995; Rhodes & Jacoby, 2007). The issue of the role of different feedback manipulations will be needed to be approached in further research within the field of tasting.

Although in a different domain, Estes and Maddox (1995) research is the closest to the present experiment. Estes and Maddox (1995) found that in the absence of feedback, hits and false alarms level were independent of the base rate. In our case, the base rate did affect the decision index since leaving unaltered the sensory ones. With feedback added, false alarm rates tended to approach true old-stimulus base rates, and all recognition measures depended strongly on stimulus properties. Our experiment also found evidence of decision setting the odds scheduled but somewhat differently, only the sensory index was affected by stimulus properties (i.e. magnitude of the salt concentration). An important difference is that those researchers based much processual inferences on responses raw (hits and false alarms of the Old items) rather than the SDT index; and when the indexes (i.e. d ') were used, their estimates were indirect and non-convergent analysis of the two indices were performed, but focus on one or the other.

As in Estes and Maddox (1995), the general approach has been to estimate the receiver operating characteristics curve (ROC), a curve that relates pairs of hits and false alarms. To estimate sensitivity with this technique (i.e., by d'), several points of performance are required corresponding to changes in the criterion (see Macmillan, & Creelman, 2005; Sweets, 1996; Wickens, 2002). Accordingly, it is not possible to obtain a direct measure of the sensory process, given that this measure depends on the criterion process and may be contaminated by it. Additionally, all the points of the ROC curve are collapsed to infer the bias leading to a similar problem (see the review of See et al., 1997). Finally, the most common strategy to obtain those points of performance will be to request participants to rating the certainty of their responses on a likert-type category scale (see for instance, Metz, 2008) and it is assumed that changes in the confidence only reflect changes in the decision strategy. However, these changes could be also due to the simplicity of the task –i.e., the degree of confidence may increase when the task is getting simpler, especially if feedback of performance is provided, something quite common in this context.

As pointed by Double Dissociation Additive Test, a better strategy of analysis would be to focus in the SDT index, rather than in the ROC curves, as these indexes show the processes in a more direct way. For these purposes the analytical approach of the Double Dissociation Additive Test is a useful methodological tool to separate the effects of factors on sensitivity and decision processes, would also allow locate the impact of the other types of feedback schedules within the processual dynamics.

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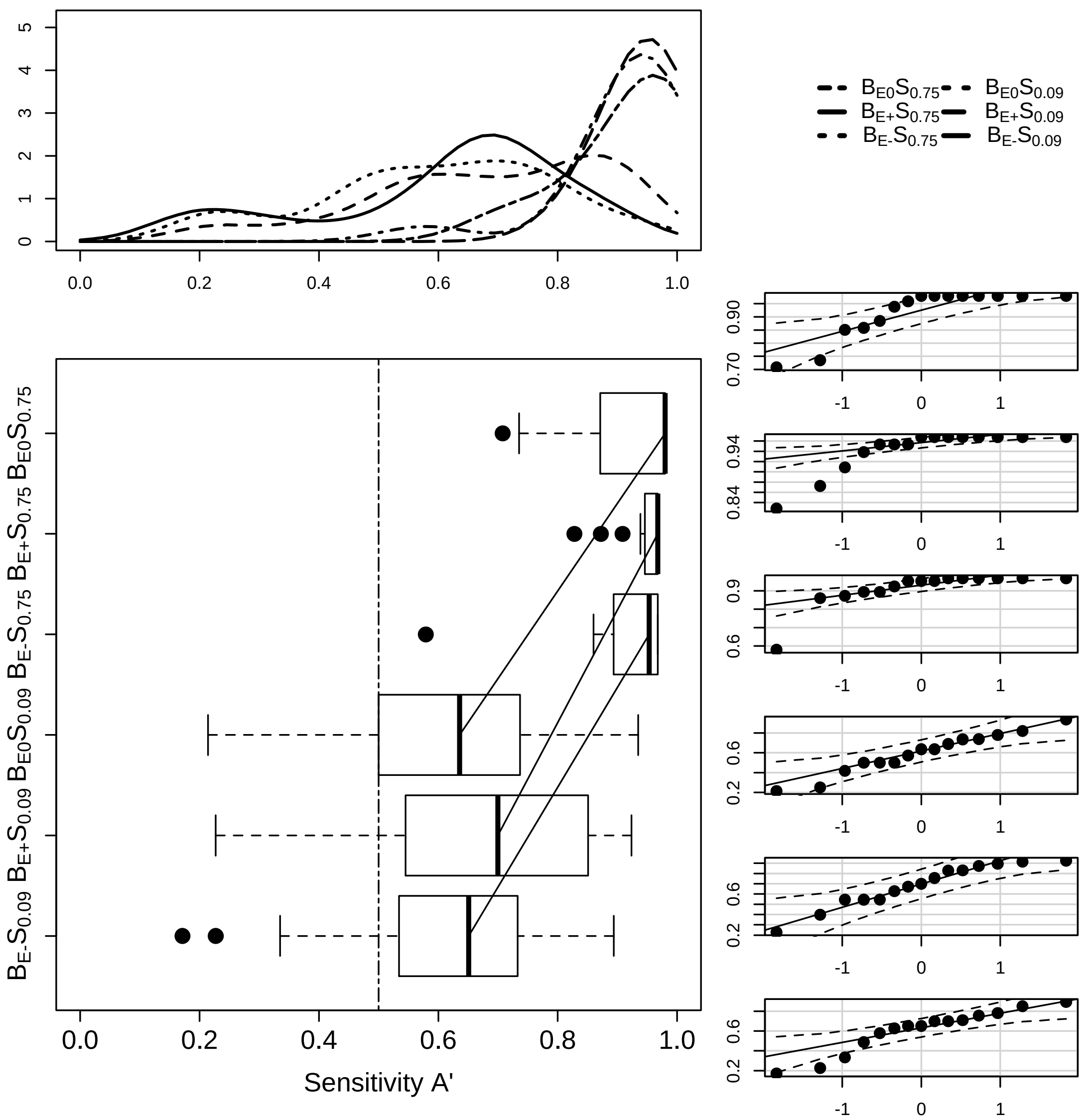


Figure 1a. Descriptive-exploratory analysis for index A’ in the condition with feedback for the factorial crossing of the 2 concentration levels with the 3 levels of induced bias. The top graph represents Kernel density functions, the bottom-left graph presents the Box-Plot, and the bottom-right graph presents the Normal Q-Q Plot functions.

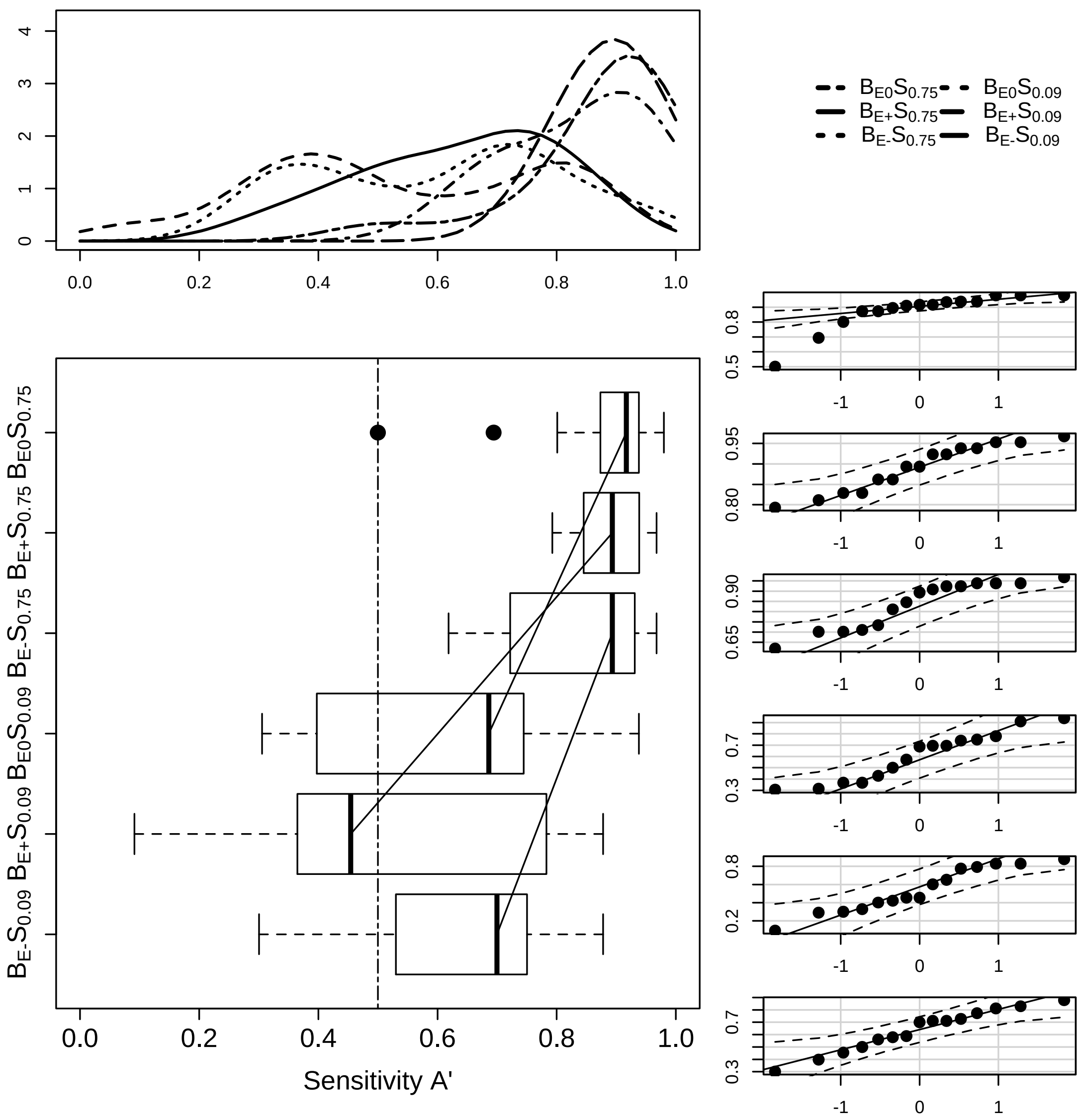
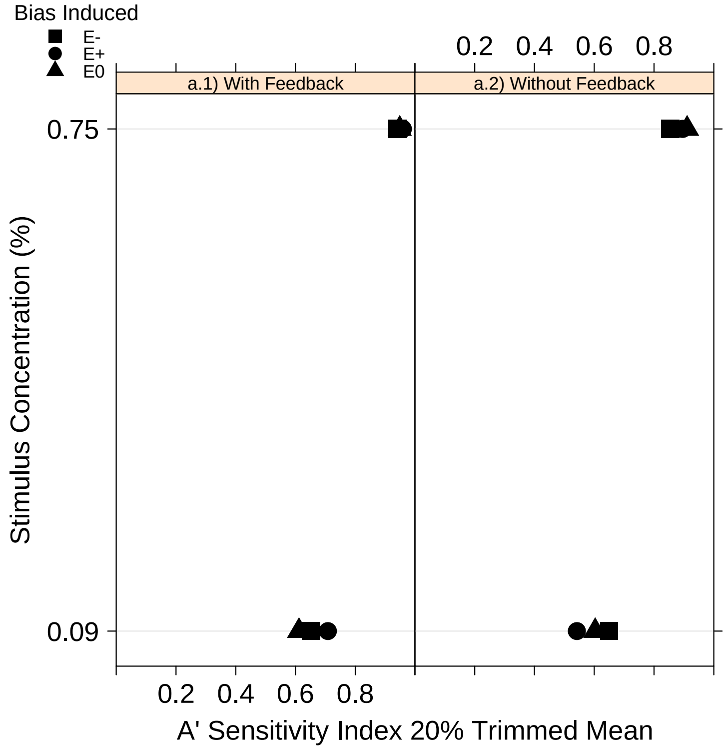


Figure 1b. Descriptive-exploratory analysis for index A' in the condition without feedback for the factorial crossing of the 2 concentration levels with the 3 levels of induced bias. The top graph represents Kernel density functions, the bottom-left graph presents the Box-Plot, and the bottom-right graph presents the Normal Q-Q Plot functions.

a) Sensitivity index A'



b) Bias index B'$_D$

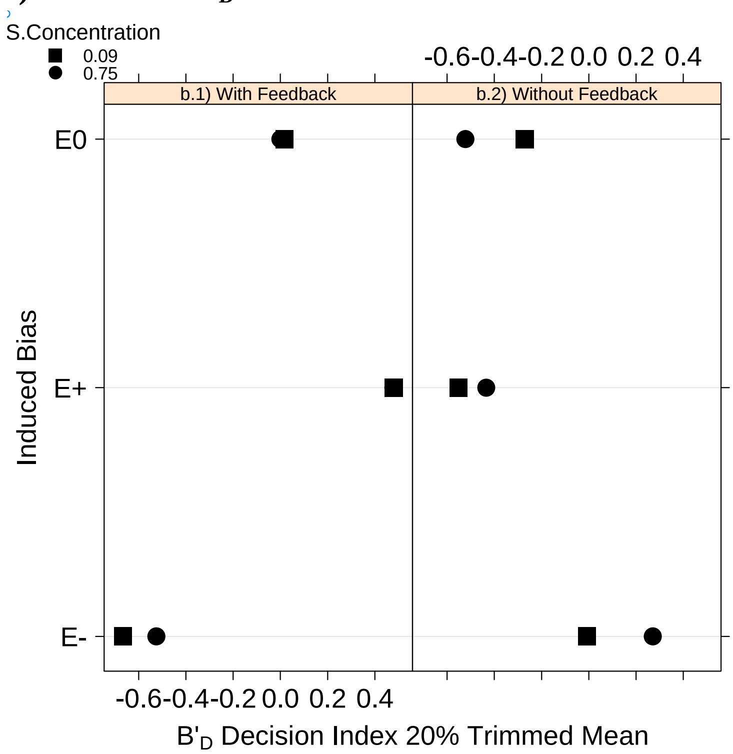


Figure 2. Descriptive analysis for indexes A' (panel a) and B'$_D$ (panel b). Within each panel the graph represents the Dot-Plot for trimmed means. The twelve conditions within each graph reflect the factorial crossing of the 2 concentration levels with the 3 levels of induced bias and the 2 levels of feedback.

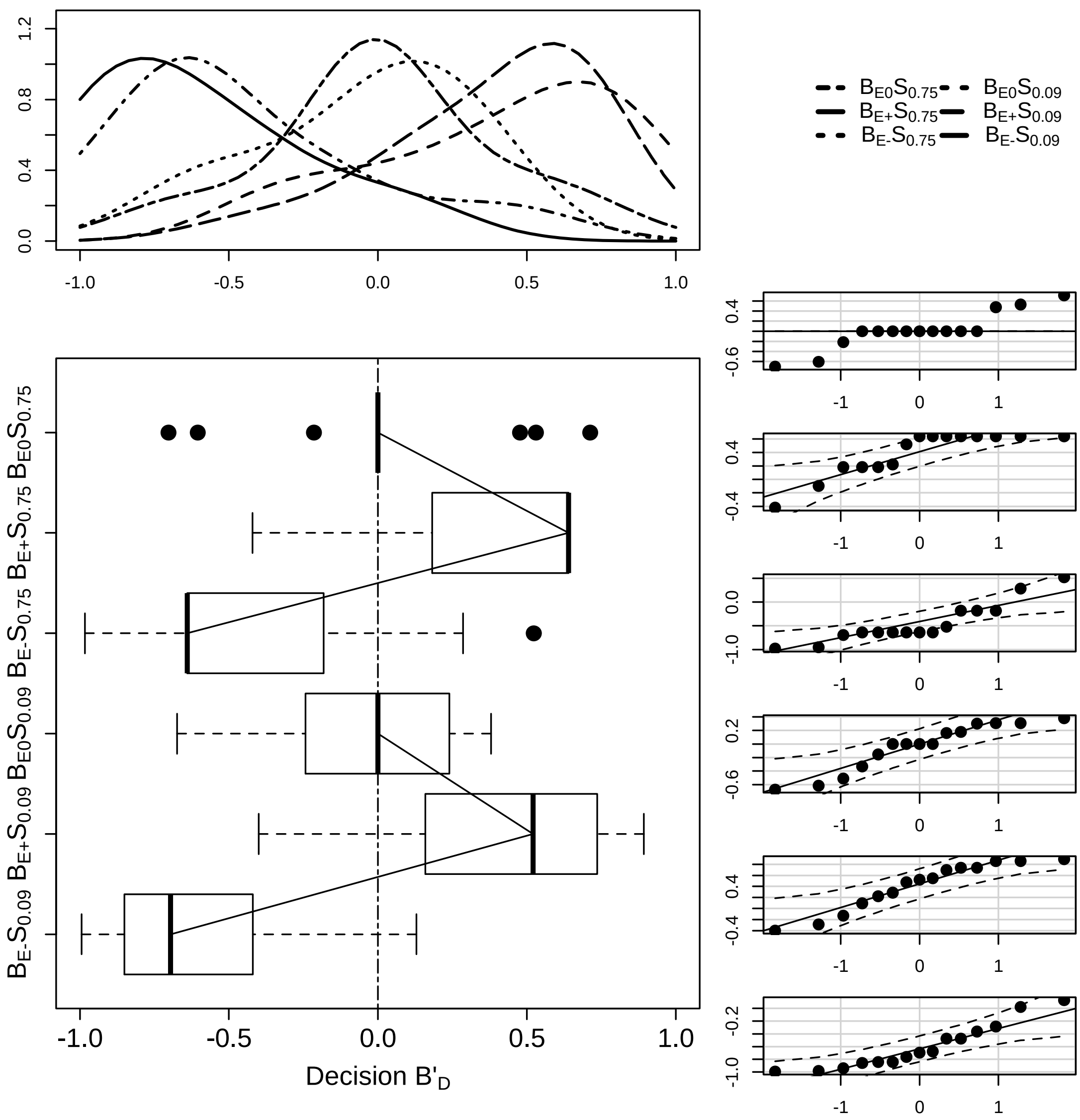


Figure 3a. Descriptive-exploratory analysis for index B'$_D$ in the condition with feedback for the factorial crossing of the 2 concentration levels with the 3 levels of induced bias. The top graph represents Kernel density functions, the bottom-left graph presents the Box-Plot, and the bottom-right graph presents the Normal Q-Q Plot functions.

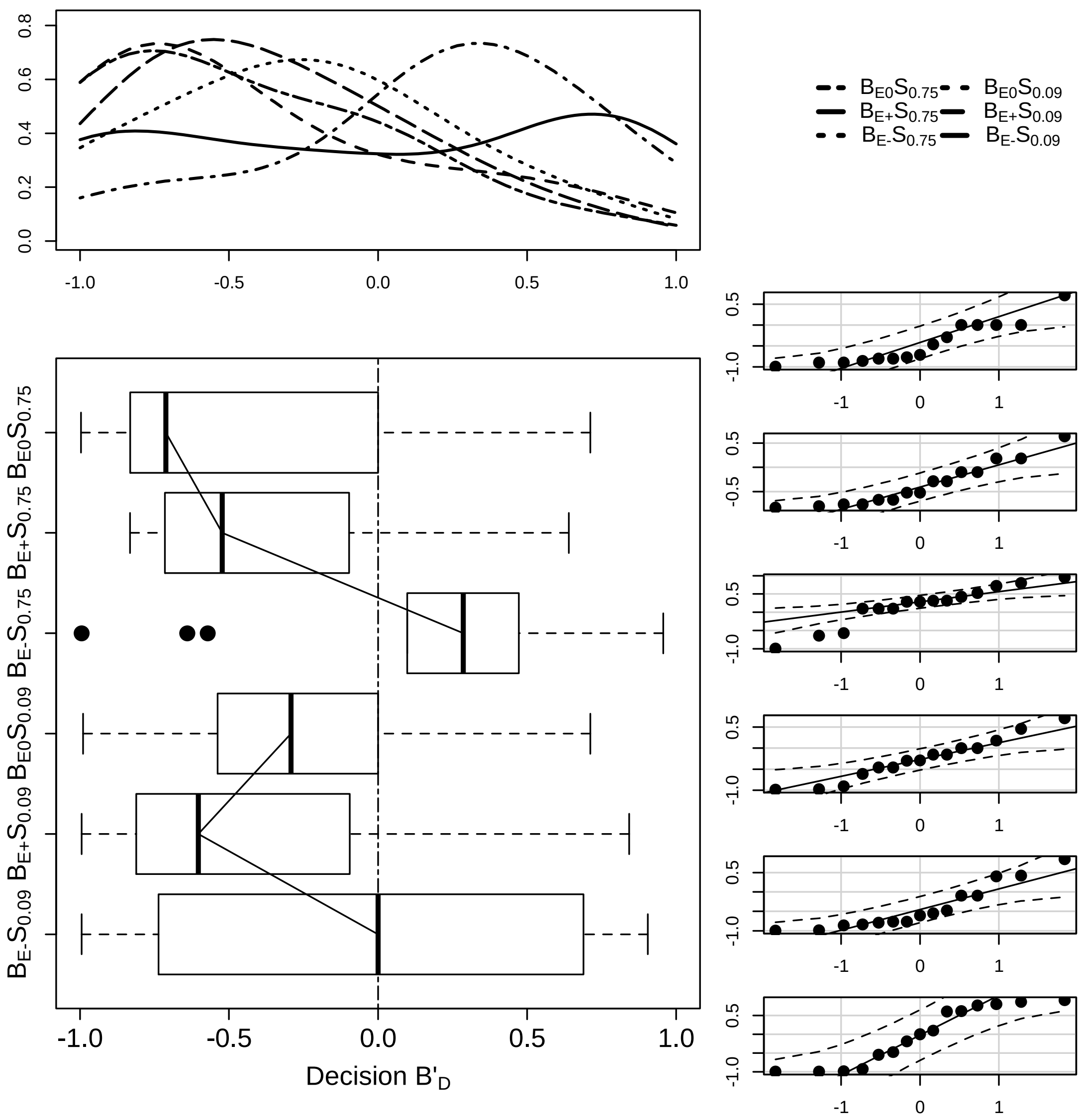


Figure 3b. Descriptive-exploratory analysis for index B'$_D$ in the condition without feedback for the factorial crossing of the 2 concentration levels with the 3 levels of induced bias. The top graph represents Kernel density functions, the bottom-left graph presents the Box-Plot, and the bottom-right graph presents the Normal Q-Q Plot functions.

5.3 DECISION CRITERION IN A PAYOFF-DRIVEN EXPERIMENT

In this section we examine sensory and decision performance in a payoff-driven experiment involving three discriminability conditions (0.07%, 0.1%, and 0.75%), and three payoffs matrices (conservative, neutral, and lenient). As expected, sensory factor only had effects on participants' discriminability that showed better accuracy as signal intensity was increased. At decisional level, a negative bias was found when they were encouraged to be lenient through the associated gains (high rewards and low costs), a positive bias when they were encouraged to be conservative (high costs and low rewards), and tended to null values when they received the earnings neutral scheme. As with the probabilities manipulation, payoffs matrices were calculated to produce symmetrical but opposite positive and negative effects, and those in fact were the results found in this experiment.

Symmetrical Payoff-Driven Adjustments on the Decision Criterion under Different Concentrations of Salt in a Tasting Task

Short Title: PAYOFF-DRIVEN DECISION CRITERION ADJUSTMENTS

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Abstract

An experiment on taste sensory analysis was conducted to evaluate the effects of manipulating signal salience and incentives on sensitivity and decision processes under high ecological validity conditions. An experimental methodology based on Signal Detection Theory (SDT) was used, allowing for obtaining independent measures of sensory and non-sensory factors. Participants confronted a tasting situation in which salt concentration (0.07%, 0.1% or 0.75%) and payoff matrices (lenient, conservative, or neutral) were manipulated in a full factorial between-subjects design. Salt concentration only affected sensory processes (sensory index A') while payoffs only affected decision processes (decision index B'_D). Payoff manipulations led to a symmetrical effect on the decision index for lenient and conservative conditions. Reported criterion adjustments were close, but somewhat less extreme than the values predicted by the SDT model for an optimal performance under unbalanced payoffs.

Keywords: Decision Processes, Sensory Processes, Incentives, Payoff Matrices, Optimal Criterion, Salt Tasting, Stimulus Intensity, Signal Detection Theory, Sensory Analysis of Food

Symmetrical Payoff-Driven Adjustments on the Decision Criterion under Different Concentrations of Salt in a Tasting Task

Optimal choice of a food (or food features) in natural environments requires the integration of several sources of information: i.e., sensory evidence (e.g., distinguishing different food types); the knowledge about the relative probabilities of events; or the outcomes of performance (e.g. costs and benefits of detecting or making errors). Signal detection theory (SDT) specifies how these sources of information should be integrated in order to optimize the relative choices to reach a specific decision goal such as maximizing the number of correct responses or the overall earnings attained in a given situation (Stüttgen, Yildiz, & Güntürkün, 2011; Wickens, 2002).

SDT model of perceptual processing describes the relationship between the stimulus physical parameters and the behavior, providing two measures or indexes of performance that may be interpreted in terms of different underlying psychological mechanisms: *Sensitivity,* or the observer's accuracy to distinguish between stimuli; and *decision criterion*, anchor point on the continuum of sensations that allows the decision maker to shift towards an alternative response or the other (estimated often through *Bias* –the extent to which the observer favors one response over another regardless of the stimulus characteristics). Decision criterion is influenced by a host of factors that may affect observers' judgments, such as motivational states, past learning experiences, or attitudes, among others. SDT provides analytical tools for obtaining independent measures of this *sensory and decision processes* (Macmillan & Creelman, 2005; McNicol, 2005; Swets, 1996; Swets, Tanner, & Birdsall, 1961).

A standard laboratory procedure commonly used for conducting an SDT analysis of performance is the psychophysical Yes–No task (Green & Swets, 1966; Macmillan & Creelman, 2005; Swets, Tanner, & Birdsall, 1961). Participants are exposed to one out of two possible stimuli (Signal or Noise). Stimuli are repeatedly presented in random succession. Observers are required to render a binary classification on each presentation, pointing out whether the signal is present or no. In this experimental situation, observers may say "yes" or "no" and in either case they may be correct or incorrect. In SDT terms, the outcome of the observer's decision may be a hit, a miss, a correct rejection or a false alarm.

The same task may be used as a discrimination test within the field of food science. Consider a taster having to discriminate between two similar food samples. To apply the

Yes-No task to this situation it will suffice with designating one of the samples as the signal, and the other as the noise. The task of the judge will be comparing the two samples, trying to identify which one has tasted (signal or noise). Given the similarity between Signal and Noise, judges confront a difficult decision in this situation. In general terms, the judges' responses will depend on two different factors: The sensitivity of their sensory systems to distinguish between the samples, and which response they decide it will be more likely to be correct. Depending on where they draw the line in their perceptual continuum and place their decision criterion, they will be more prone to categorize the sample as the Signal or the Noise.

Stimulus changes are not expected to affect the decision criterion. However, observers may be experimentally induced to shift the location of this criterion along the decision axis regardless of which stimuli are used as Signal and Noise (Macmillan & Creelman, 2005; Swets, 1996; Wickens, 2002). As the criterion becomes laxer, participants are more willing to respond affirmatively to both, signal and noise presentations, resulting in an increase of both hits and false alarm rates. The opposite is found when observers set strict criterion. Lenient vs. conservative strategies of responding may be experimentally encouraged by either changing a priori probability of Signal versus Noise presentations, or by manipulating the Payoffs matrix. Observers may be experimentally inclined to respond affirmatively by either increasing the frequency of the signals or by differentially rewarding hits. Conversely, rate of "no" answers may be induced by either decreasing the frequency of signal trials or by providing a differentially lower penalty for misses. In a simple Yes-No experiment with two stimuli and two responses coupled, there are four values that may be manipulated: the amounts paid (or debited) for the observer's hits, misses, false alarms, and correct rejections performed by the observer. Each set of payoffs produces a separate 2 x 2 data matrix. Different payoff schemes may be used to induce a lenient or a conservative criterion (Macmillan & Creelman, 2005).

In most psychophysics experiments, symmetrical payoff matrices (i.e. equal values for the two types of correct or incorrect responses) are used to promote good performance (e.g., Creelman & Donaldson, 1968; Stüttgen, Yildiz, & Güntürkün, 2011). However, equal rates of reinforcement are the exception rather than the rule in natural environments (i.e., some locations may be more likely to provide food than others). Now consider a case in which reward for correct "yes" responses is larger than for correct "no" responses, with the cost being identical for both types of incorrect responses. In that case, it will be desirable to increase the number of correct "yes" responses by moving the decision criterion to a more relaxed positioning. Thus, shifting the decision criterion from a neutral location may be beneficial when the payoff matrix is unbalanced or asymmetrical. SDT takes this into account by allowing the computation of the optimal allocation of responses under each condition, as a function of two factors: The a priori probabilities of occurrence of signal and noise, and the gains (values positive or negative) associated with the individual decision outcomes, or payoffs matrices (McNicol, 2005; Swets, Tunner & Birdsall, 1961; Wickens, 2002). The optimal value of the criterion can be derived from a simple equation, providing a benchmark to evaluate performance of a participant in a given task:

[Insert *Equation 1* here]

The *ideal observer* is the hypothetical individual that would make an optimal use of all the available information, placing the decision criterion in a point that maximizes either the number of correct responses or the attained gains (Wickens, 2002). Non-optimal decision behavior occurs when the observer establishes a fixed cut-point on the decision axis that does not maximize gains (or correct responses), or if the cut-point varies from trial to trial. The experimenter may vary the a priori probability of signal occurrence, and instruct the observer to maximize the percentage of correct responses. Alternatively, variable values and costs may be assigned to the four possible decision outcomes (G_H, G_M, G_{FA}, G_{CR}, for gains linked to Hits, Misses, False Alarms, and Correct Rejections respectively on Equation 1), and the observer may be incentivized to maximize the expected gain (Swets, 1996). An equivalent optimal value for the probabilities and payoffs manipulations may be computed. In addition, a symmetrical induced-Criterion (positive-Strict and negative-Lax) may be programmed with both manipulations, by assigning the complementary values to the lenient and conservative scheme. The present study was focused on the effect of manipulating the incentives. Consequently the signal and noise were equally likely so *that a priori probabilities* ratio for that factor were set at a neutral value of 1 [p (N) / P (SN), Equation 1]. Figure 1 (see the methodology section below) shows the computed values used in this study to induce opposite symmetrical criterion strategies by programming differential incentives.

Placement of decision criteria is often assumed to be controlled by the observer. However, real observers are not ideal performers, and they usually fall short of ideal behavior (Wickens, 2002). Many studies suggest that human observers fail to move their decision criterion to such an extreme position as the one established by SDT for optimal performance (e.g., Thomas & Legge, 1970; Ulehla, 1966; for the case of unbalanced payoffs manipulation see Bohil & Maddox, 2003; Green & Swets, 1966; Healy & Kubovy, 1981; Turner, Van Zandt, & Brown, 2011). This phenomenon is called *"conservative cutoff placement"*. Deviations from the optimal value are sometimes explained by reference to "subjective" rewards and by other practical and theoretical issues. All suggest that criterion equation (Equation 1) seems to capture only some of the real basis for human decision making (Macmillan & Creelman, 2005). There is some empirical support for the hypothesis that different cognitive processes and factors play a significant role in tasting situations (e.g., Lawless & Heymann, 2010; Moreno-Fernández, Ramos-Álvarez, Paredes-Olay, & Rosas, 2012; Paredes-Olay, Moreno-Fernández, Rosas, & Ramos-Álvarez, 2010; Ramos-Álvarez, Moreno-Fernández, Paredes-Olay, & Rosas, 2013; Rosett, Klein, & Ennis, 1997; Schifferstein, 1996). The payoff manipulation represents another non-perceptual manipulation that may influence performance. Many studies have explored the effect of manipulating the payoff matrix on decision making (e.g., Bohil & Maddox, 2003; Buchner, Erdfelder, & Vaterrodt-Plünnecke, 1995; Healy & Kubovy, 1981; See, Warm, Dember, & Howe, 1997; Snodgrass & Corwin, 1988). However, to our knowledge, the effect of payoffs manipulation has yet to be explored in the taste research domain. This is an important issue given the peculiarities of tasting situations. They necessarily involve the use of a small number of trials to avoid saturating the senses, and that may affect the way cognitive and sensory processes are affected by different manipulations, aside leading to a break in Normality assumptions (Paredes-Olay et al., 2010; Ramos et al., 2013).

As advanced above, the goal of the experiment reported here was to explore the role of manipulating the payoff received by tasters on the decision criterion. A complementary goal was to evaluate the extent in which criteria may change under unbalanced payoffs and whether symmetrical effects may be induced for the lenient and conservative conditions. Following the *Double Dissociation Additive Test* (Ramos-Álvarez et al., 2013), our design included two independent factors that were simultaneously manipulated in a complete factorial design: The magnitude of salt concentration and the payoff matrices. A mixture of salt and sour flavors with three intensity levels was used as signal stimulus to determine sensibility. The different intensities corresponded to different concentrations of the salty flavor in the compound

(0.07%, 0.1%, and 0.75%). These specific concentrations were chosen by using the calibration curve described by Martín-Guerrero, Rosas, Paredes-Olay, and Ramos-Álvarez (2015). The low salience condition (0.07%) was selected to be sufficiently difficult to elicit a sensory performance when discriminability is at or near chance. In contrast, high condition (0.75%) was chosen to reflect sensitivity close to the asymptotic performance. The medium value of concentration (0.1%) was selected in a relatively low range given the rapid growth of the psychophysical function for this flavor in the expansive phase (see Martín-Guerrero et al., 2015). Thus, the design allowed for testing the effects of the payoff manipulation under three different expected levels of sensory performance.

The use of a combination of basic flavors has the advantage with respect to the use of natural foods of increasing the experimental control, as it simplifies the manipulation of the combination of flavors while keeping the situation fairly close to a natural setting in which tasters usually confront complex stimuli. As in Snodgrass and Corwin's (1988) experiment, three levels of payoff (conservative-strict, neutral, and lenient-lax) were manipulated while stimulus probabilities remained constant. The experiment involved the use of different payoffs matrices, in which differential rewards and costs were placed on correct and incorrect responses. Payoff matrices were manipulated as described in Figure 1 bellow, ensuring that the manipulation was symmetrical. The individual values associated with the four possible decision outcomes were varied between conditions in order to determine the range over which the participants can vary their criteria. Previous studies in other research fields have shown that response criterion tends to be lenient when either costs are low or rewards are high but conservative when the converse is true (e.g., Buchner et al., 1995; See et al., 1997; Snodgrass & Corwin, 1988). Hence we expected that response criterion would be most strict in the conservative payoff condition (high costs and low values) and most lenient in the liberal payoff condition (low costs and high values). Additionally, as payoff manipulations were symmetrical, we expected the criterion placement to be symmetrical as well, following SDT assumptions. Finally, since we assume that two factors affect two separate processes, we predict no interactions doubly for the sensory and the decision indexes.

Method

Participants

Hundred twenty six undergraduate volunteers of the University of Jaén, 108 females and 18 males, participated in the study. They were between 18 and 48 years old (*Mdn* = 21.4). None of them had previous experience with the task or formal training on sensory evaluation. All participants read and signed an informed consent before starting the experiment and were free to leave the laboratory at any time, though none of them did so. Participants received a small financial reward for their participation in the study (see procedure below). Participants were instructed to come to the laboratory in the appropriate conditions to conduct a taste experiment. They were requested not to have smoked, drunk or eaten within the 30 min previous to their arrival to the laboratory. In those cases in which these requirements were not fulfilled, participants were given an appointment for a different day. The same rule was applied to participants that had some temporary alteration of taste or smelling senses produced by cold or allergy episodes. Participants were called in sets of seven. They were randomly assigned to each of the 9 experimental conditions involved in the experiment, so that each group included 14 participants. Age and gender distribution was uniform across groups.

Materials and Apparatus

Two types of taste stimuli in aqueous solution were used in each session: Noise (N) and Signal+Noise (SN). Noise mixture was made with 1.5% of a sour compound [Pulco Lemon Flavor, Orangina Schweppes: lemon juice (40%), water (56%), and pulp of lemon (4%)], and 98.5% of distilled water. A small amount of salt was added to the mixture to conform the Signal stimulus. Three different SN stimuli were prepared, varying on the amount of salt in each concentration (0.07%, 0.1%, and 0.75%).

Solutions were presented in plastic glasses at room temperature. Each glass contained 7 ml. An inter-stimulus procedure of mouth-rinses with water to remove residuals from prior tastings and avoid taste sense adaptation was used between samples. A numbered plastic sheet was placed at the table so that participants could leave the samples after tasting them.

The tasting laboratory consisted of 7 individual cabins equipped with a desk, a chair and a computer provided with specific software to control the stimulus presentation *(LearnOlive)*. LearnOlive software was specifically developed by M.M. Ramos-Álvarez to conduct tasting experiments, and allows participants to easily follow the complete sequence of the task (see a detailed description in Ramos-Alvarez et al., 2013). A 17” TFT computer screen, a rubber keyboard and a mouse were placed in front of the participant.

Procedure

After signing the written consent, and filling a sociodemographic questionnaire upon their arrival to the laboratory, participants were randomly assigned to each experimental condition and trained with a game in which they experienced a virtual discrimination task for twenty trials. In each trial, two figures that varied slightly in size were presented to the participants (one representing the salty sample, and the other representing the no salty sample). They had to identify the figure that briefly appeared on the screen. The payoff matrix corresponding to participant's assigned condition, and continuous feedback were used so that participants could learn the monetary contingencies that were going to be used in the experiment later. Participants were instructed to try to earn the maximum number of points. If a given participant was not able to maximize the expected value, the game was repeated up to three times, ensuring that way that all participants understood the payment scheme.

Lenient strategy was induced through the following instructions:

In this simple visual game you must detect the possible presence of salt in the tasting glass, which is represented by a slightly larger figure. Also you should try to gain the maximum number of points according to the following rules:

- *When you answer "yes" and your answer is correct (because there was salt) you win 50 points.*
- *When you answer "yes" and your answer is incorrect (because there was no salt) you lose 10 points.*
- *When you answer "no" and your answer is incorrect (because there was salt) you lose 50 points.*
- *When you answer "no" and your answer is correct (because there was no salt) then you win 10 points.*

This means that ultimately, answering "Yes" will make you gain much and lose little, while, answering "No" will make you lose much and gain little.

In the conservative strategy, instructions were the same with the exception that the gains for *yes* and *no* correct responses were 10 and 50 points, respectively; and the penalties for *yes* and *no* incorrect responses were 50 and 10 points, respectively.

Finally, in the neutral strategy, all correct and incorrect responses were rewarded and penalized by the same amount of points: 30 points.

After this training with the payoff matrix, the actual tasting experiment started. Participants received general instructions about how to taste the samples (Turn-Smell-Taste-Clean procedure, see Paredes-Olay et al., 2010 for details).

Twenty-five samples were presented to each participant. The first sample was used only for practicing the tasting procedure. Participants were required to discriminate between a salty solution (Signal stimulus) and a no-salt solution (Noise stimulus). They confronted a simple detection task (yes-no) in which they should indicate whether each presented sample contained or not salt. The protocol followed by each participant was: (1) Picking the sample according to the established sequence, (2) tasting the sample, (3) giving the response about its content (Yes/No), (4) leaving the glass aside, and (5) cleansing her or his palate.

Following the logic of double dissociation, sensory and decision processes had each its specific independent variable associated in a factorial between-subjects design. Sensory process was manipulated by using three levels of salt concentration: Low (0.07%), Medium (0.1%) or High (0.75%). Decision process was manipulated by providing economic incentives. See Figure 1 for details.

Insert Figure 1 about here

Participants received small financial rewards and penalties for correct responses and incorrect responding that were identical to the ones used during the pre-training phase, with the exception that in this case points were substituted by cents of Euro. The instructions in this phase were a reminder of the payment scheme experienced during the pre-training phase, reinforced with an anagram similar to that shown in Figure 1 (see the Payoff column). Specifically, they were paid between 0.10€ and 0.50€ for each correct response while fined the same amount for an incorrect response. The maximum earnings per session remained constant for all conditions at 7.20€. Rewards and penalties' values were calculated to reflect variations in bias and to induce a conservative, lenient, or neutral response strategy –see Strict (I+), Lax (I-), and Neutral (I0) conditions of Figure 1. The neutral payoff matrix rewarded each hit and correct rejection with 0.30€ and penalized each false alarm and miss with 0.30€ as well. The lenient matrix rewarded hits more than correct rejections (+50 vs. +10), and penalized misses more than false alarms (-50 vs. -10). The conservative matrix did just the opposite, rewarding hits less than correct rejections (+10 vs. +50), and penalizing misses less than false alarms (-10 vs. -50). See Payoff column of Figure 1 for details. The observers were paid at the end of the session in accordance with their performance (monetary rewards correspond with euro cents). Thus, the maximum gain of all groups was matched: 0.30€ x 12S samples plus 0.30€ x 12SN samples, or 7.20€ for Neutral condition; 0.10€ x 12S samples plus 0.50€ points x 12SN samples, or 7.20€ for Strict; and 0.50€ x 12S samples plus 0.10€ x 12SN samples, or 7.20€ for the Lax condition.

Figure 1 also includes normative incentive details [Payoff matrix detailing gains (G) associated to each of the 4 types of possible performance, the type of feedback that involves each of the types of gain, and details of the calculation of the Signal Detection Theory Optimal Criterion].

Nine independent conditions resulted from the complete factorial crossing of the three concentration levels with the three levels of monetary payoff. In all conditions, distribution of signal and noise stimuli was uniform (12SN and 12N). Participants received continuous feedback about the accuracy of their response: Gain or loss on each trial and cumulated total earnings.

There was no time limit for performing the task, though most participants finished the complete procedure within 40 min after their arrival to the laboratory.

Dependent Variables and Data Analysis

Psychophysical analysis, Hit rates (probability of responding Yes in a Signal trial) and False Alarms rates (probability of responding Yes in a Noise trial) were computed using the 24 tasting trials. Due to the probability of observing extreme rates (maximum hit rates or null false alarm rates), a logarithmic-linear corrective strategy was used by adding a constant amount, .50, to all the frequencies before computing the rates, following Brown and White's (2005) review. Tasting tasks use few trials to avoid saturating participants' senses, making fulfillment of SDT parametric indexes assumptions (Gaussian distributions with equivalent variances, Wickens, 2002) unrealistic. Thus, Non parametric Grier's (1971) A', and Donaldson's (1992) B'_D was chosen as sensory and decision indexes, respectively (Ramos-Álvarez et al., 2013).

Statistical analyses. Using small number of tasters and trials makes it difficult verifying assumptions such as Normality or Homoscedasticity. Similarly, outliers are likely to appear in tasting tasks, invalidating the use of conventional statistics. To explore these assumptions while summarizing the data, descriptive-exploratory analysis is based on the Triplet-Graph: Box-Plot + Kernel Density + Normal Q-Q Plot (Ramos-Álvarez et al., 2013). Robust analyses of variance on trimmed means were conducted by using Yuen-Welch test for between-groups pairwise comparisons, and Robust contrasts were conducted by a T-test Trimmed variant (T_t), with Rom's sequentially rejective method used to control Type I error for multiple t-tests (Rom, 1990). Statistical significance was set at $p \leq .05$.

All analyses were performed using the free-GNU R software, R version 2.14.0 (R Foundation for Statistical Computing, http://www.r-project.org/) with {car}, {data.table}, {Hmisc}, and {sm} libraries, and Wilcox' "Rallfuv-v20" library (http://www-rcf.usc.edu/~rwilcox/. Ask for the functions ''t1wayv2'', "t2way", "mcp2atm", and ''lincon'').

Results

Figure 2 presents the descriptive-exploratory analysis for indexes A' for the nine conditions resulting of the complete factorial crossing of the three concentration levels (0.07, 0.10, and 0.75) with the three levels of prompted criterion (I-, I+, and I0, respectively for lax, strict or neutral). Box-Plot chart for sensitivity index A' (middle-left) suggests an increase on detection as salt concentration increases. Additionally, all the values are on the right of the null detection line, representing positive detection values for all conditions. The parallel between the lines that connect the medians in the three boxes representing each criterion condition for a given salt concentration suggests that the pattern of increase is similar regardless of the induced decision strategy. Variability is somewhat irregular across groups (compare conditions $S_{0.75}I_-$ and $S_{0.1}I_0$ boxes), as confirmed by Kernel density functions on top of the figure. However, as shown in the Q-Q Plots (middle-right), Normality assumption is fulfilled. A 3 (salience) x 3 (induced criterion) Robust Omnibus Wilcox Analysis conducted with A' found a significant main effect of salience, 20%-Trimmed Means: .57, .69, and.96, respectively for the three levels of increasing salience; $V_W\,(2,117) = 184.736$; $p = .001$. The main effect of induced criterion was not significant, 20%-Trimmed Means for Groups I_-, I_+, and I_0, .76, .75, and .77, respectively; $V_W\,(2,117) = 0.179$; $p = .917$. Neither was the salience x induced criterion interaction significant, 20%-Trimmed Means were .52, .70, and 0.97 for the three levels of increasing salience in Groups I_-, .54, .69, and .95 in Groups I_+, and .62, .63, and .96 in Groups I_0; $V_W\,(4,117)= 2.439$; $p = .689$. The results of index A' are better summarized in the bottom panel of Figure 2 where descriptive analyses of the trimmed means are presented using a Dot-Plot for the significant main effect of salt concentration, revealing a clear increase on sensitivity performance as the salt concentration increases. Significant differences were found for every comparison between two levels of Salience: $S_{0.07}$ vs. $S_{0.1}$ [$T_{Y\text{-}W}$ (45.75)= -2.250; *SE*= 0.155; critical value of 2.475], $S_{0.07}$ vs. $S_{0.75}$ [$T_{Y\text{-}W}$ (26.49)= -11.453; *SE*= 0.106; critical value of 2.541], and $S_{0.1}$ vs. $S_{0.75}$ [$T_{Y\text{-}W}$ (22.11)= -7.491; *SE*= 0.115; critical value of 2.573].

Insert Figure 2

Figure 3 presents the descriptive-exploratory analysis for indexes B'_D for the nine conditions resulting of the complete factorial crossing of the three concentration levels (0.07, 0.10, and 0.75) with the three levels of prompted criterion (I-, I+, and I0, respectively for lax, strict or neutral). The Box-Plot graph suggests that incentives were effective on affecting participants' performance. In general, participants showed a negative B'_D (or Lax criterion) when they were encouraged to be lenient through the associated gains (see the three median lines for I_- groups), while they showed a positive B'_D (or Strict criterion) when they were encouraged to be conservative (observe the three median lines for I_+ groups), and tended to null values when they received the earnings neutral scheme (observe the tree medians for groups I_0). Once again, the chart points to the absence of interaction, as the tendency lines are close to be parallel (see the three ">-shape" connection lines through concentrations levels). Performance on the decision index increased the problems with the Normality assumptions, showing heteroscedasticity and the presence of outliers. Kernel density functions and the Q-Q Plot suggest asymmetry (positive for groups with lenient tendency, and negative for the conservative groups). The Box Plot suggests extreme values in three out of the nine groups, and a moderate difference between the lowest and the greatest variance (compare conditions $S_{0.75}I_-$ and $S_{0.07}I_-$ boxes). A 3 (salience) x 3 (induced criterion) Robust Omnibus Wilcox Analysis conducted with B'_D found a significant main effect of Induced criterion, 20%-Trimmed Means were -.31, .35, and -.06 for Groups I_-, I_+, and I_0, respectively; V_W (2,117) = 29.491; $p = .001$. The main effect of salience was not significant, 20%-Trimmed Means: -.10, -.11, and .07; V_W (2,117) = 4.952; $p = .10$. The salience x induced criterion interaction was not significant, 20%-Trimmed Means were -.48, -.44, and -.05 in Groups I_-, .40, .31, and.31 in Groups I_+, and -.16, -.09, and .11 in Groups I_0; for the three levels of salience, respectively; V_W (4,117) = 4.204; $p = .423$.

Given that there is only a significant main effect of induced criterion that does not interact with salience, results of B'_D are better summarized in the bottom panel of Figure 3, where descriptive analyses of the trimmed means are presented using a Dot-Plot, regardless of the salience level. Robust t-tests confirmed that induced criterion was effective, given that there were differences between the three conditions, I- and I+ [$T_{Y\text{-}W}$ (44.58) = -5.430; *SE*= 0.368; critical value of 2.478]; I- and I0 [$T_{Y\text{-}W}$ (38.89)= -2.575; *SE*= 0.325; critical value of 2.493]; and I+ vs. I0 [$T_{Y\text{-}W}$ (43.48)= 3.275; *SE*= 0.354; critical value of 2.480]. Also, trimmed means were significantly lower than zero in I_-, -.31, [T_t = -3.675, *SE* = 0.084]; significantly greater than zero in group I_+, .35, [T_t = 3.739, *SE* = 0.094]; and statistically equivalent to zero in group I_0, -.06 [T_t = -0.738, *SE* = 0.080, p > 0.4675]. Importantly for the SDT predictions, induced criterion had a symmetrical effect on decision index as marginal trimmed means for conditions I_- and I_+ did not differ in absolute value [$T_{Y\text{-}W}$ (49.32)= 0.361; *SE*= 0.123; critical value of 2.009, p > 0.7194].

Insert Figure 3

Discussion

The main goal of the study reported here was to examine the tasters' performance in a payoff-driven experiment involving basic flavors. For this purpose, *The Double Dissociation Additive Test*, an analytic approach based on Signal Detection Model that allows separating between sensory and decision processes involved in sensory evaluation performance was applied (Ramos-Álvarez et al., 2013). A bias-free measure (A') allowed for estimating sensitivity to salt in a taste mixture. As expected, the increase of salt concentration improved detection. Sensory performance for high and low concentrations levels was in line with the data obtained in the salty quality parametric analysis by Martín-Guerrero et al., (2015) The intermediate value of concentration had a slightly greater effect on A' index. As stated previously, this condition was selected in a relatively low range of values given the rapid growth of the psychophysical function and expectable variability in this expansive phase. A criterion index (B'_D) was used to capture response criterion adjustments. Payoffs matrices were effective on affecting tasters' performance: Participants showed a negative tendency (or lax criterion) when they were encouraged to be lenient through the associated gains (high rewards and low costs linked to “Yes” response), a positive tendency (or strict criterion) when they were encouraged to be conservative (high costs and low rewards linked to “No” response), and tended to null values when they received the earnings neutral scheme. Both, opposite payoff matrix, had a symmetrical effect on decision index.

Nonparametric indexes and robust analysis of variance allowed for detecting these independent variations in sensory and criterion measures. The exploratory analysis of decision index performance showed heteroscedasticity and the presence of outliers confirming the problems caused by the restrictions associated to the tasting process, such as the small number of trials and participants leading to a break on the Normality assumptions (Paredes-Olay et al., 2010). Despite of the particularities of tasting situation, decision behavior was in line with findings reported in other research domains. *The Double Dissociation Additive Test* showed to be especially suitable to be applied to food sensory research in agreement with previous results within the field of olive oil tasting (Paredes-Olay et al., 2010; Ramos-Álvarez et al., 2013).

A complementary goal of this work was to evaluate the extent in which criteria may change under unbalanced payoffs and whether symmetrical effects may be induced for the lenient and conservative conditions. Following SDT assumptions, participants were responsive to changes in the values of the decision outcomes, although criteria did not move far enough to reaching optimal performance. A symmetrical effect was found, supporting SDT normative prescriptions, though criteria were somewhat less extreme than those prescribed by the model. As stated above, it is not expected identical performance on the human observer and the ideal detection individual. Aside the specific payoffs values, the particular experimental conditions, including the instructions and feedback given to the participants and the extent of their training could also account for the variations on the effect size. For instance, Creelman and Donaldson (1968) found that increasing the monetary rewards and penalties moves decision criteria closer to the optimal one than what it is usually found, although performance still remains far from expected value. Changes in values of payoff matrices could influence the decision criterion placement although they do not affect the value of the optimal decision criterion. For example, a payoff matrix multiplication (all entries of a matrix are multiplying by a constant) does not affect the theoretical optimal value but it does affect the steepness of the objective reward function (Maddox & Bohil, 2001). Maddox and Dodd (2001) also found that decision criterion learning is suboptimal in negative cost conditions compared to zero-cost conditions, which may be due to an increased emphasis on accuracy maximization in negative cost conditions (see also Maddox & Bohil, 2000). Related to this hypothesis Maddox and Bohil (2001) improved decision criterion learning when costs and benefits were manipulated by reducing the weight placed on accuracy through manipulation of the trial-by-trial feedback. They speculated that observers place importance on accuracy maximization, in part, because the most common type of feedback in decision criterion learning studies emphasizes accuracy.

All these considerations allow us to predict that by manipulating monetary rewards and penalties, possibly in conjunction with variations about the informational feedback received by participants may improve their decision performance. Additional research will be needed to explore these issues within the field of tasting, given its potential relevance for the design and modification of current tasters training programs. Future research is also needed to compare criterion location when base rates are manipulated to maximize the number of correct responses, evaluating whether criteria with this manipulation are closer to the optimal values prescribed by the model, or the results reported here are replicated there as well. Finally, exploring the interaction between base rates and payoffs, and potential effects on sensitivity (if any) and criterion will lead to an interesting developing from both, exploring further the suitability of SDT methodology applied to the field of food evaluation, and maximizing the effectiveness of training programs for tasters.

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$$\widehat{\lambda}_{OPT} = \frac{p(N)}{p(SN)} \bullet \frac{G_{CR} - G_{FA}}{G_H - G_M}; LOG = \log\left(\widehat{\lambda}_{OPT}\right)$$

Equation 1.

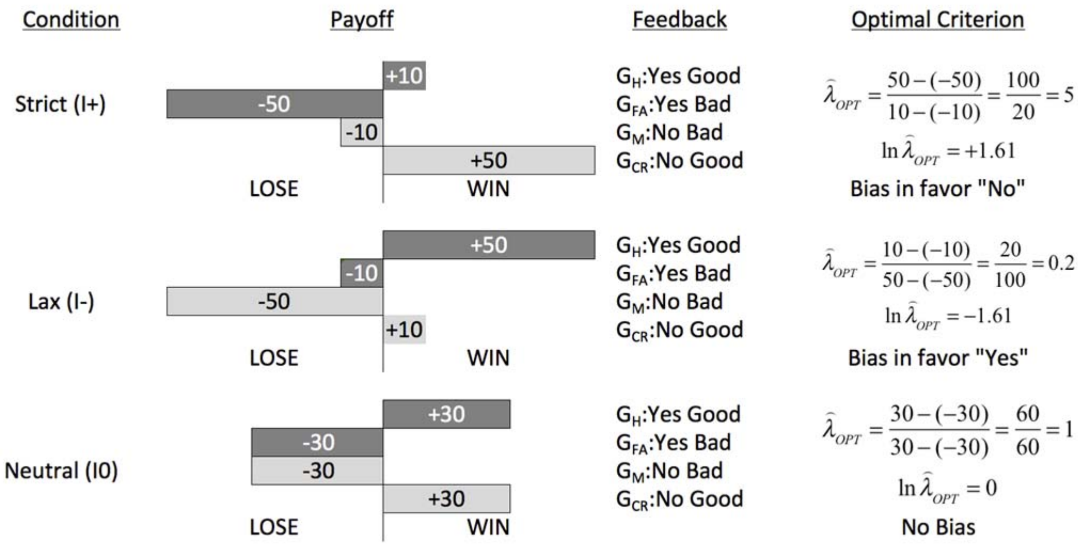


Figure 1. Normative computations. From left to right: Experimental Conditions, Payoff matrix detailing gains (G) associated to each of the 4 types of possible execution, the type of feedback, and details of the calculation of the Signal Detection Theory Optimal Criterion

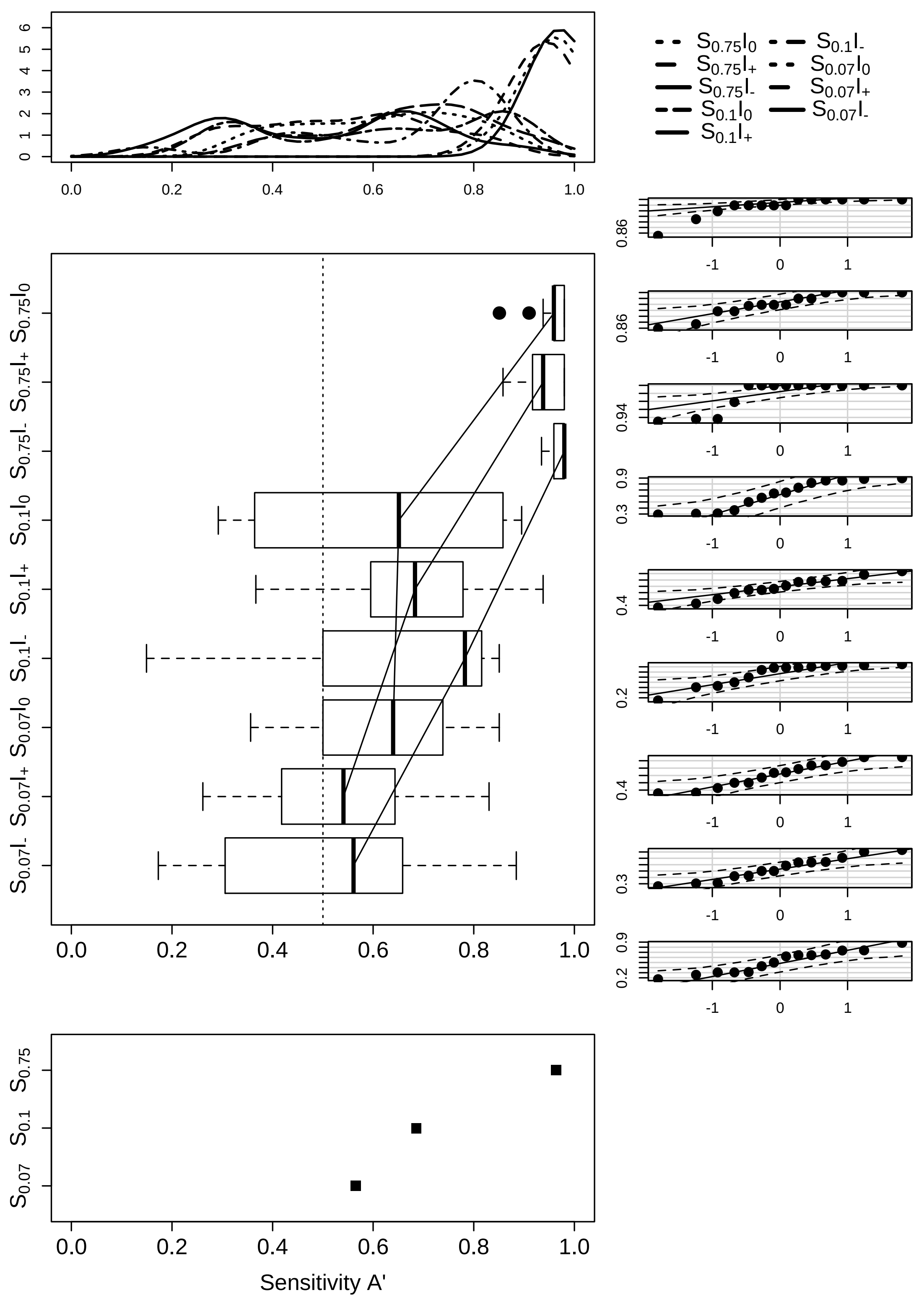


Figure 2. Descriptive-exploratory analysis for index A'. The top graph represents Kernel density functions, the center-left graph presents the Box-Plot, and the center-right graph presents the Normal Q-Q Plot functions. The bottom graph represents 20% trimmed means Dot-Plot of the only significant effect: main effect of concentration in A' index. The nine conditions reflect the complete factorial crossing of the 3 stimulus concentration levels ($S_{0.07}$, $S_{0.1}$, and $S_{0.75}$) with the 3 levels of induced bias (I_-, I_+, and I_0).

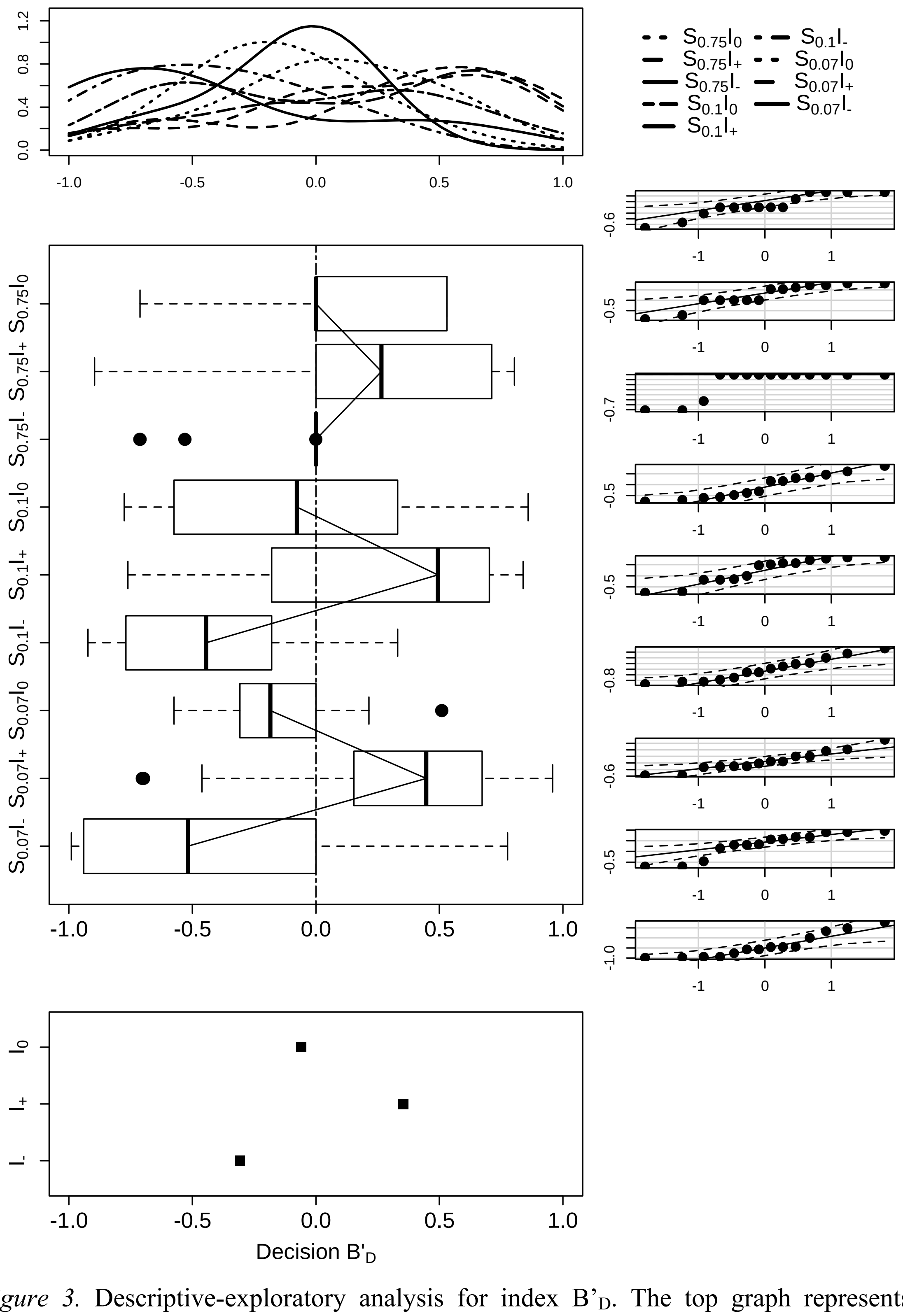
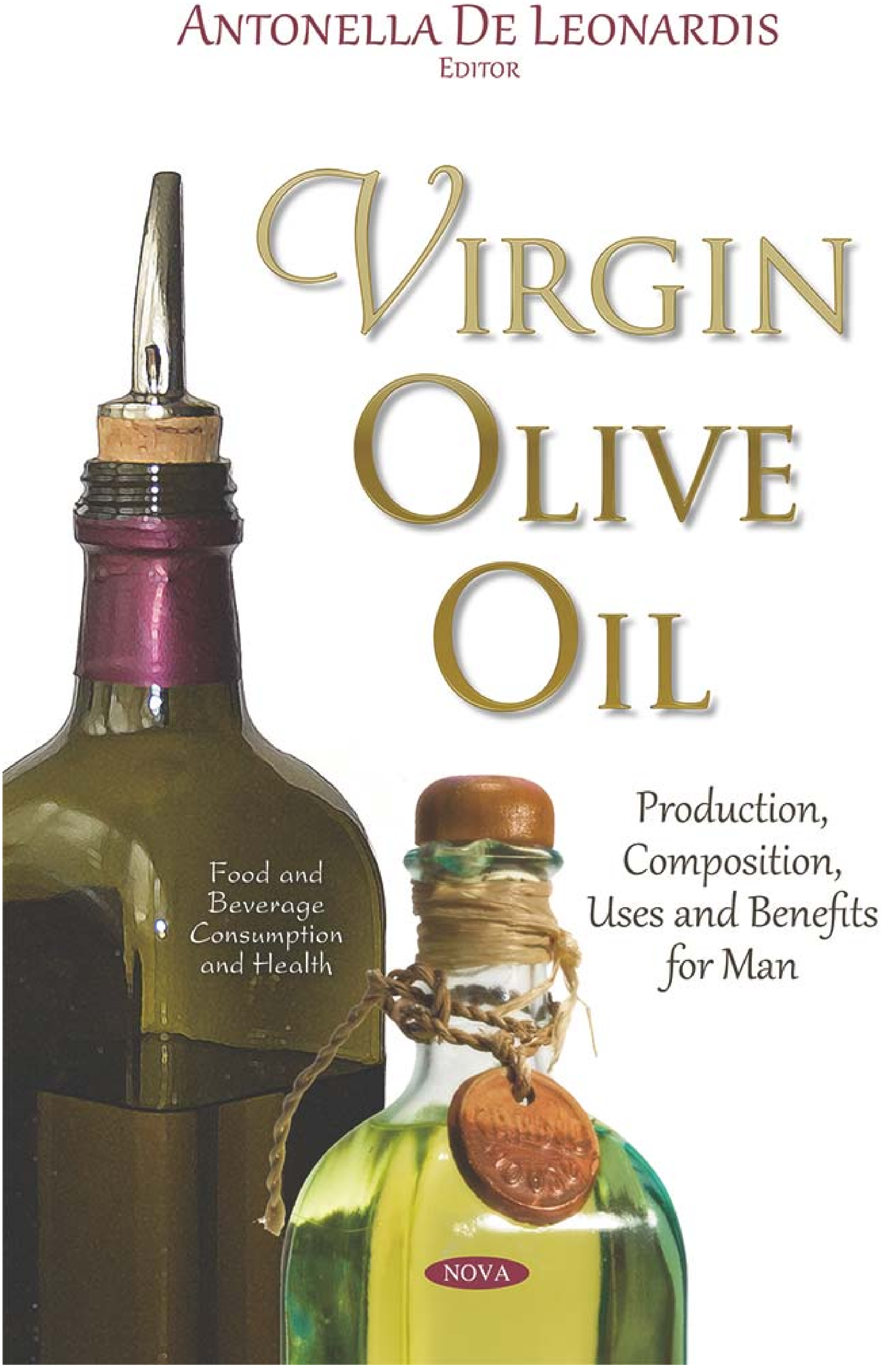


Figure 3. Descriptive-exploratory analysis for index B'$_D$. The top graph represents Kernel density functions, the center-left graph presents the Box-Plot, and the center-right graph presents the Normal Q-Q Plot functions. The bottom graph represents 20% trimmed means Dot-Plot of the only significant effect: main effect of Induced Bias in B'D index. The nine conditions reflect the complete factorial crossing of the 3 stimulus concentration levels ($S_{0.07}$, $S_{0.1}$, and $S_{0.75}$) with the 3 levels of induced bias (I_-, I_+, and I_0).

5.4 APPLICATIONS. MODERN PSYCHOPHYSICS AT WORK: DISOCCIATION BETWEEN SENSORY AND DECISION PROCESSES WITHIN THE QUALITY ASSESMENT OF OLIVE OIL

Finally, in the introduction above it was advanced the need of applying the methods of modern psychophysics to the field of sensory evaluation of natural foods. In this section we present a review conducted within the framework of this dissertation that shows that some of the psychophysical methods used and tested within the experimental work gathered above have started to be applied to the field of olive oil tasting. Within this review, description of the methods and main results has been intended to be easily understandable by any specialist in the broad field of the evaluation of the quality of olive oil. In fact, the review was published within a specialized monograph that was designed with the idea of giving a comprehensive overview of all the essential aspects related to olive oil.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VIRGIN OLIVE OIL

PRODUCTION, COMPOSITION, USES AND BENEFITS FOR MAN

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VIRGIN OLIVE OIL

PRODUCTION, COMPOSITION, USES AND BENEFITS FOR MAN

ANTONELLA DE LEONARDIS
EDITOR

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New York

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Chapter 13

MODERN PSYCHOPHYSICS AT WORK: DISSOCIATION BETWEEN SENSORY AND DECISION PROCESSES WITHIN THE QUALITY ASSESSMENT OF OLIVE OIL

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ABSTRACT

The analysis of the quality of olive oils is a complex task but highly relevant to achieve the transfer of the benefits associated to its consumption to the general population. Highly specialized tasting panels usually conduct measurement of its properties. However, traditional methods confound sensory precision with other aspects related to the taster's decision process, such as his/her beliefs, motivations, and preferences. We present and evaluate a new method of research in olive oil tasting based on Signal Detection Theory (SDT) that allows separating the evaluation of sensory and decision processes in a tasting situation. The proposed procedure, based on a dissociative model, allows for obtaining independent measures of sensory and cognitive factors, and also the calculation of the Receiver Operating Curves. The results of studies where this method was applied to olive oil tasting are presented and discussed here. This methodological proposal has also been proven to be useful to study psychological processes involved in tasting situations, including the evaluation of training programs conducted to improve tasters' discriminative abilities.

From a practical point of view, this dissociation between sensory and decision performance may contribute to an optimization of the evaluation of the quality of the olive oil, aiding its potential acceptation as a functional food, and facilitating the comparison between experts' and regular consumers' evaluations.

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Keywords: Olive oil tasting, sensory process, decision criterion, Signal Detection Theory, Receiver Operating Curves, training programs, functional foods, consumers' evaluations

1. INTRODUCTION

Some of the prevalent pathologies in modern societies are related to environmental factors including inappropriate food habits. The better known pathologies related to inadequate nutrition are cardiovascular diseases, diabetes, cancer, or the cognitive impairment associated to premature ageing. All of them are apparently related to the greater cell oxidization promoted by a diet high in saturated fat, e.g. [1-8]. In order to confront this problem, a new biopsychosocial approach to the health concept has changed the deterministic focus on the process of illness, giving the individual an active role in preventing and promoting his/her own health by adopting a healthy lifestyle. Contemporary research associates the prevention of psychological and physiological impairments, and fosters a good quality of life through a balanced diet. In that sense, the World Health Organization (WHO) published a document with the nutritional parameters recommended to prevent six food-related pathologies, highlighting the importance of the monounsaturated fat on health maintenance [9].

The Mediterranean diet has been proposed as one of the most suitable models to keep a correct nutritional status. Some of the foods used in this diet are currently aspiring to being classified as functional foods, see for instance [10]. Functional foods are those that have a beneficial effect for one or several functions in the organism, so that they provide a better state of health and sense of wellbeing. These foods may exert a preventive role, reducing the risk factors that lead to the occurrence of different diseases, or they may even act therapeutically on certain pathologies. Organisms such as the Food Information Council (FIC), the International Life Sciences Institute (ILSI), or its European section, the Functional Food Science in Europe (FUFOSE), define this type of foods as foods that provide benefits for health beyond their basic nutritional value [10].

The Mediterranean diet is defined with a pyramidal structure. On the base of this structure we find vegetables. Within those foods of vegetal origin, olive oil is probably the most common link across Mediterranean countries, being on the basis of every Mediterranean culture. Mediterranean people have used olive oil as food for several millennia. However, the scientific knowledge about its nutritional properties and health benefits is relatively new. Among those properties, we can enumerate benefits such as longevity, cardiovascular disease prevention, and protection against cancer, as qualities that are currently associated to regular consumption of olive oil as a source of monounsaturated fat, for a review, see [11]. The therapeutic value of olive oil is related to its chemical composition, formed by triglycerides in a 99%. The most representative component of this fraction is the oleic acid; an element that is considered to have protective properties against oxidative stress [12]. The 1% that is left is formed by components of high biological and nutritional value associated to virgin olive oils. The refining processes may alter these components, so that the refined oil usually loses vitamins, color, aroma, general flavor and nutritive quality.

These biologically and nutritionally relevant minor components add some supplemental positive effects in health, and provide qualitative and quantitative differences to diverse virgin varieties, e.g. [13], in press. Due to its high specificity, these minor components are used as quality and authenticity criteria when evaluating olive oils, e.g. [14].

In the last few decades it has been concluded that consumer's acceptance should be one of the key factors for the definition of the new categories of functional foods. Once that the features of functional foods have been established, and being olive oil a firm candidate to become one of them, an important issue is how to transmit the notion of functional food to the general population, given the influence of the diet for public health, and the essential role that consumer's acceptance has on the consumption of functional foods. As a matter of fact, this acceptance has been considered as the key factor for the definition of the new categories of functional foods since there has been verified that consumers do not accept easily a new food for the mere fact of which it has effects stated for the health until such food turns out to be agreeable to the palate [15]. This issue raises the importance of knowing the impact that different types of information may exert on the perception and acceptance of functional foods.

Not surprisingly, some researchers have identified food flavor as the key factor on consumers' choice, even in the case of functional foods. According to these researchers, taste beliefs and experiences have been reported as extremely critical factors when selecting this type of food, e.g. [16].

Thus, acceptance of healthy foods is not unconditional. Findings seem to relate consumption loyalty to consumers' hedonic evaluation, though consumption is also related to the specific benefits that provides for health, and to how reliable is the information about these benefits for the consumer, e.g. [15]. As a summary of these ideas, Hilliam [17] suggests that the food industry should focus on improving the flavor of functional foods so that they end reaching the consumer.

Some researchers have gone even further, suggesting that consumers are hardly ready to renounce to the appetitive quality of the flavor to increase the benefits of their diet, see [18, 19]. Twisting the issue a little more, recent studies that have examined the beliefs and attitudes individuals have towards food have found that they are strongly dependent on cultural traditions, education, cooking habits, hedonic appreciation, etc., though these attitudes are also susceptible of change [20]. Results in this area suggest that factors such as nutritional qualities, health benefits, ingredients and uses of foods, its price, brand or other purely contextual or social issues influence behavior, and they may also generate hedonic expectancies, e.g. [21-26]. Focusing on the case of olive oil, the study conducted by Caporale et al. [21] found that the information about the origin of the olive oil affects the perception of the sensory profile of this olive oil when provided by regular consumers, see also, [27-29]. Köster [24] goes even further, analyzing the different fallacies that are often accepted as true by professionals and consumers, such as the assumed uniformity and consistency in consumers' behavior, the idea that choice is based on conscious, rational thoughts, or the perceptual fallacy that sustains that only what is perceived may be remembered. Those fallacies have been dismounted by the scientific literature, drawing researchers' attention to the difficulty of the analyses of consumers' behavior, and emphasizing the need of restructuring the methods used in both, sensory and consumer's behavior research. The previous paragraphs raise the importance of considering multiple factors when promoting functional foods and its introduction as food habits for the population. Most of the research studies discussed in this section coincide on assuming the multiple determinants of choice behavior when it comes to select a food, including sensory qualities, and also some extrinsic and intrinsic factors that are interconnected in the consumers' evaluation of a product.

A precise methodology that would allow for isolating the role of the different psychological variables on choice would help the analysts in sorting out the role of the different factors within this complex situation. Advancing towards the development of such methodology has been the goal of our research efforts in the last few years. Our advances will be summarized in the following sections of the chapter.

1.1. Organoleptic Evaluation of Virgin Olive Oil: Quality Criteria

The classification of different oil types and the evaluation of their quality are complex and relevant processes, given that they determine commercialization of the product, consumers' preference and the eventual transfer of the benefits associated with its consumption to the general population. Oil quality and purity are established by evaluating positive and negative features of each variety. The evaluation process essentially involves the use of chemical analyses. Mainly attending to chemical parameters, olive oils are classified into three different categories: extra-virgin olive oil, virgin olive oil, and "lampante" olive oil. However, the complexity of olive oil and the variety of its components forces an organoleptic evaluation, or normalized analysis through the human senses. Sensory analysis is the mechanism used to evaluate the differences among varieties and to determine whether consumers like them, or even to establish consumers' preferences across varieties [30].

Given the importance of these sensory aspects, food industry in general, and olive oil industry in particular, has devoted a great effort to develop analytic methods in order to establish a correspondence between chemical components, such as volatile or phenolic compounds, and sensory analysis. In spite of these efforts, sensory analysis is still the most effective method to evaluate qualitative and quantitative differences in the sensations caused by the food.

The only way to know the final result of the product at the sensory level is by the evaluation of the food in highly specialized tasting panels [31]. A tasting panel consists of a group of judges trained to measure and describe the noticeable attributes of a given food. Their goal is to evaluate foods in an objective way, minimizing possible mistakes and estimation-measurement biases. The reliance on their decisions and thus, in the quality of the food depends on the accuracy of this process.

Evaluation methods are regulated by international organisms that unify and supervise the properness of the sensory practice. Specifically, the International Olive Council (IOC, formerly the International Olive Oil Council, IOOC), as the organization that protects developing and growing of the olive grove and its products, has established the general method for the organoleptic evaluation of oils, see [32].

Tasters' selection is conducted by using a highly structured process that determines potential tasters' sensibility thresholds to basic attributes of the oil (fusty, winey, burnt, and bitter), as well as the tasters' group mean threshold. The best candidates go through a training phase in which the coherence and reliability of their evaluations is tested.

In order to attain normalization in the evaluation process, the identity and singularity of olive oils has been acknowledged and measured. This has allowed professionals to find ways to improve their quality, and has also provided consumers reference patterns that help them to learn to distinguish this quality. The absence of homogeneity in panels' evaluations encouraged successive revisions of the sensory method so as to improve its efficacy.

Some of the control measures adopted by the revised norms were: the high level of training required for professionals, essay replications, parameters normalization (temperature, light, quantity, and sample presentation), adoption of a mean criterion, and the statistical treatment of the results [33]. However, these cautions have not quite completely solved the problem of the variability of the judgments. Sensory analysis of food is not an exact science: it presents a number of limitations that steam from the human nature of the measurement instruments, from the classical psychophysics methodology used, and from other factors related to each individual panel.

At the commercial level, sensory analysis may offer a way to discover whether consumers enjoy food sensory stimuli, as well as to identify the consumers' preferences. In this sense, the evolution of the consumers' preferences and their causes can be analyzed, explaining possible changes in the selection of oils. Organoleptic exploration becomes more complex, evaluating new and subtler attributes with the goal of improving the excellence and exclusivity of the olive oils. At the same time, the advances derived from the research about the connection between food and health may promote the consumption of olive oils of greater quality, with added health benefits, although the general population may not easily accept some attributes, such as high acidity. In this sense, a rigorous methodology that allows isolating the factors that influence experts' and consumers' judgments and that allows for a comparison between their estimations is required.

1.2. Classical Psychophysical Theories of Threshold

As mentioned above, the technical documents of the IOC show that the method for tasters' selection and training is conducted by a process that determines the potential tasters' sensitivity thresholds to basic attributes of the oil. For instance, determining the mean sensitivity threshold of aspirants for characteristic attributes will allow to eliminate less sensitive tasters, see [32]. This approach assumes that sensations directly depend on the intensity of the attributes of the olive oil, so that the stimulus is perceived only when its intensity is above some specific absolute level or threshold. Thus, as the IOC method is based on the tasters' sensibility thresholds, it shows its reliance on the principles of classical psychophysical theory.

Psychophysics has the merit of introducing the measurement in psychology, substituting the mere metaphysic speculation with the search of functional relationships between mind and body. The measurement of the sensory experience allowed establishing psychophysical laws. Weber and Fechner developed the classic psychophysics based on the concept of sensory threshold [34]. In their two-state theory (sensation versus no-sensation), the relevant concept was the absolute threshold. In the second half of the nineteenth century, Weber and Fechner accepted the idea that for any given attribute (e.g., sweetness) there is a stimulus value such that only greater intensities should produce the state of sensation (e.g., the degree of sugar concentration needed to detect sweetness). Fechner [35] devised three methods to measure the absolute threshold, all of them based in statistical-mathematical techniques: The limits, the adjustment, and the constant stimuli methods. Fechner also considered Weber's work, which some years earlier had measured a different threshold: the differential threshold, or the amount of stimulus increase that is needed to establish the difference between two stimuli of the same modality [36].

Given the sensory variation, both thresholds were established in probabilistic terms. Absolute threshold was defined as the stimulus that produces a 50% of "yes" responses in detection psychophysics tasks, and the differential threshold was defined as the stimulus increase that produces a 75% of responses "greater than" in discrimination tests.

Classical psychophysics opened the possibility of studying human perception through scientific methods, providing sensitivity indexes valid for the different sensory channels. However, classic psychophysics found a serious number of experimental limitations, such as the lack of universality of its principles for all the stimulus ranges or sensory modalities, see [34, 36, 37]. In the next section of the chapter we will focus on the limitations of classical psychophysical theory, and how these limitations affect olive oil tasting methods.

1.3. Limitations of Classical Psychophysics and Traditional Methods

Food industry has evolved quickly in the last fifty years. This development has been promoted by the research and innovation in food biotechnology, the engineering of the industrial processes and quality management, and also by people's focus on preventive health. Markets and consumers are nowadays establishing new requirements for the industry that should be met.

However, sensory analysis as the compendium of techniques for the evaluation of olive oil has changed insufficiently, carrying out the measurement of properties and attributes through traditional methods based on the threshold concept [32]. Classical psychophysics regarded the sensations experimented in front of a stimulus as directly reflecting the intensity of the properties of such a stimulus, so that those stimulus properties that are under a specific threshold are not perceived [36]. Evaluation in tasting panels has been developed following the classic idea that sensations are discrete elements, assigning panelists the function of evaluating the intensity of desirable and undesirable attributes, but without considering the subjective factors in the perceptual process that might affect the taster's criterion. These factors would go unnoticed in traditional methods of tasters' selection, and also on their evaluations.

Additionally, discrimination may be required in ambiguous situations, with concurrent or previous stimuli that show slight differences with the stimulus currently tested. Ambiguity favors the presence of biases and mistakes of different nature, such as biased evaluation responses. In these situations of maximum uncertainty or extreme similarity among attributes, the taster's internal aspects may become as relevant for the task as the physical features of the stimulus. Threshold psychophysics models cannot separate the measurement of attributes or properties from other effects that are not directly related with the stimuli, or with the sensory capacity for the evaluation.

However, modern psychophysics has adopted a different approach, changing the discrete conception of the sensations on which threshold theories were sustained. Sensations are currently understood as a continuum that depends on the stimulus properties and the perceiver's sensitivity, but also on other individual factors such as the taster's motivation, beliefs or interests.

Decision-making processes take an essential role in sensory evaluation, and thus in the tasting process. The new methodology based in contemporary psychophysical models allows estimating the contribution of cognitive aspects to psychophysical performance.

In the middle of the twentieth century, research in human sensory discrimination focused its attention in a new model that allowed estimating the influence of non-sensory processes in the observers' response, the Signal Detection Theory, and this theory might be of straight-forward application to the field of olive oil tasting, see [34, 36, 37].

1.4. Modern Psychophysics: Signal Detection Theory

Signal detection theory (SDT) provided a general framework to describe the decisions adopted in situations of uncertainty or ambiguity [38]. The development of SDT as a direct translation of the theory of statistical decision to the explanation of the mental processes that underlie subjective judgments has produced a number of applications in experimental psychology, especially in areas in which discrimination is central, such as in research about perceptive processes [39] or in the area of recognition memory [40]. In applied sciences, a variety of diagnosis systems used this paradigm to measure its inherent precision [41]. The versatility of this model has favored its application in fields as different as weather forecast, clinical medicine, and survey research, staff selection or in sensory analysis of drinks and foods, e.g. [42-45].

Any situation of discrimination between two stimuli may be analyzed in SDT terms. In a typical experiment of signal detection, the observer should decide in each trial whether the experimented sensory effects are due to a background irrelevant activity, or to the superimposed signal. Through the analysis of the performance of the observer we may know the type of response given by him or her (correct/incorrect). If we consider a Yes/No classic task in which the participant should judge the presence or the absence of a small amount of olive oil in a stimulus compound, the taster may be understood as a detector of the presence of the component in the solution. Let us imagine that it is exposed to 10 samples randomly arranged, five with a small amount of olive oil diluted in other oil varieties (Signal+Noise stimulus for SDT model), and five without olive oil (Noise on SDT). This experimental situation allows for four different responses: Hits (the judge identifies the sample that contains olive oil, saying yes to a Signal+Noise trial); Misses (the judge does not identify the olive oil in a sample that contains olive oil, saying no to a Signal+Noise trial); False Alarms (the judge identifies olive oil in a sample that does not have it, saying yes to a Noise trial); and Correct Rejections (the judge does not identify the presence of olive oil in a sample that does not contain it, saying no to a Noise trial). Table 1 presents the confusion matrix with the four possible responses adapted to a classical experiment of flavor detection.

Following with our example, if our taster says "YES" to 4 of the 5 samples that actually contain olive oil and to 1 of the 5 Noise trials (saying "NO" to the other trials), taster's performance may be estimated by considering his or her Hits (4/5 or 0.8) and False Alarms (1/5 or 0.2) rates. These two results define the space of response, given that performance is redundant two by two once the amount of trials with Signal and Noise is fixed (the same result is obtained calculating the Rate of Hits together with the Rate of False Alarms, and the Rate of Correct Rejections together with that of Misses). Table 1 shows the confusion matrix with the four possible responses adapted to a classical experiment of flavor detection.

The most interesting feature of SDT's application to the field of olive oil tasting is that it allows for separating the sensory and decision processes. With respect to the sensory process, the threshold concept is discarded.

Table 1. Confusion matrix in a Tasting situation

		Stimulus		
		Flavor + Noise (FN)	Noise (N)	
Response	"Yes: Signal was present"	Hits (H) (4)	False Alarms (FA) (1)	Responses YES (5)
	"No: Signal was not present"	Misses (M) (1)	Correct Rejections (CR) (4)	Responses NO (5)
		Signal Trials (5)	Noise Trials (5)	

$$P(H) = \frac{H}{H+M} \qquad P(FA) = \frac{FA}{FA+CR}$$

Notes: The four possible responses are adapted to a classical experiment of flavor detection. The numbers within brackets represent the responses given by participants in the hypothetical experiment.

The result of the sensory process is a group of sensation values with a specific probability of appearing when the signal is presented with the noise, and with a different one when only the noise is presented.

Initial SDT approaches understood that the distribution of the density of probability associated to the Signal and the Noise may be adjusted to normal curves of equivalent variance [46].

This allows for a characterization of the sensitivity or detectability of a given observer in a test of sensory discrimination by the separation of Signal and Noise distributions.

If those stimuli are experienced as very different, sensory performance will be better and then there will be little overlapping between the functions, as they are more separated than when the stimuli are similar. The contrary is true when the stimuli are very alike, given that the noise and signal distributions will overlap significantly. This process depends on objective or external factors such as the degree of contrast between the signal and the noise, or the physiological state of the organism, being fairly stable across equivalent stimulus conditions.

Now let us imagine that the participant in our experiment is more willing to inform of the presence of olive oil throughout the session, either because of a bias that comes from his or her own experience, or because of a manipulation in the conditions introduced by the experimenter.

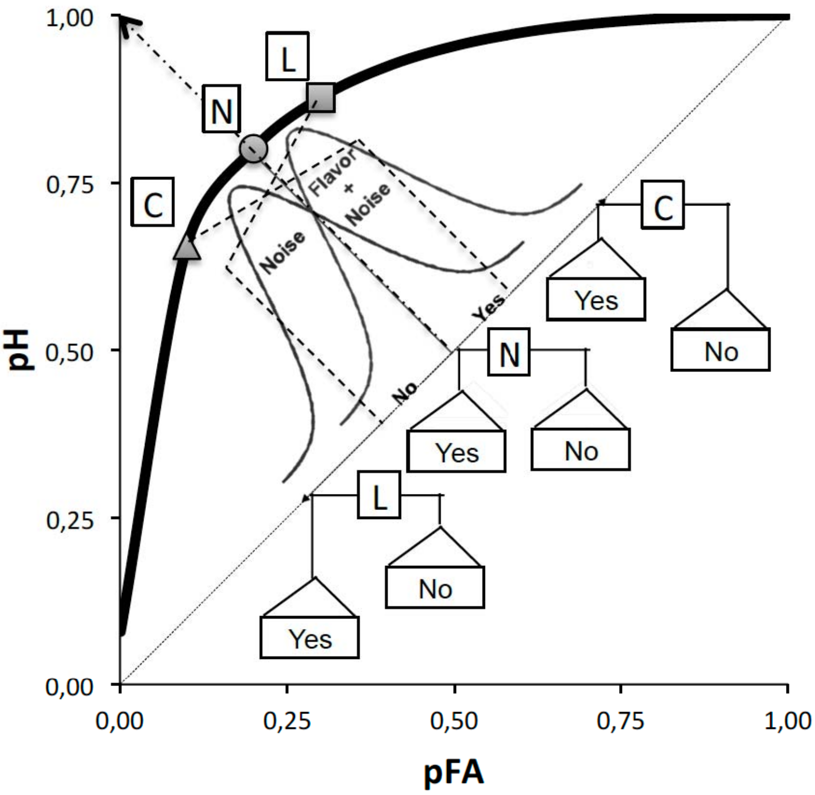
The tendency of response is likely to shift towards a more lenient criterion, saying yes more often, so that the obtained rates will change even though the presented samples are the same. From this perspective, performance in a perceptual learning task is partially determined by the criterion adopted to make decisions. Criterion is established in terms of the "perceptual evidence" needed by the observer to give a positive response to the signal presentation. So it may change or it might be manipulated by conditions that are not necessarily associated to the intensity of the stimulus or to the discriminative abilities of the observer. SDT allows separating this decision process from the purely sensory process.

SDT suggests that sensory processes are related to the stimulus physical properties (i.e., its intensity), and to the physiological status of the individual. Decision processes are assumed to be related to the knowledge about the situation that the observer has. This information is a source of theories and hypotheses about the nature of the sensory signals that the participant expects will occur. Thus, sensory and decision processes should be affected by the manipulation of different factors. The sensory process should be modified by changes in the contrast between the signal and the noise, or by the duration of the task. However, the decision process should be modified by instructions, payoff matrix (the relative cost of making the two types of errors, FA versus M on Table 1, and the relative benefit of the two types of correct responses, H versus CR on Table 1), or by changes in the probability of signal and noise (see [36], for an empirical review; and [38], for theoretical implications).

According to SDT, the proper combination of hits and false alarms rates allow for computing different indexes for sensory and decision processes. Receiver Operating Characteristic (ROC) curves represent the relationship between hits and false alarms rates when a stimulus is shown at a constant intensity. ROC curves are graphical representations of pairs of hit and false alarm rates when the factors affecting sensitivity are kept constant. They are also called isosensitivity curves, as all the dots in the curve represent the same level of sensitivity, or signal-noise discrimination. To build a ROC curve the same Yes/No task needs to be applied a number of times while keeping constant all the factors that are supposed to affect sensitivity (i.e., signal/noise contrast), changing only those factors that supposedly affect decision criterion. Each of the dots in the ROC curve represents participants' performance for a different decision criterion. This decision criterion may be manipulated through at least the three factors newly mentioned: signal-noise probability, payoff matrix, and instructions. Figure 1 presents an example of ROC curves.

The normal distributions with equal variance model predict a symmetrical ROC with respect to the diagonal that connect the coordinates (0, 1) and (1,0). As the curve gets closer to the superior left vortex from the ROC space (0, 1) the most sensitivity it reflects, and the closest it is to the diagonal, the lowest the sensitivity. Within each isosensitivity curve, the closer the dot from the upper right vortex (coordinates 1, 1), the more lenient/relaxed is the observer's criterion, and vice versa, the closer the dot to the lower left vortex (0,0) the stricter/conservative the observer's criterion (see L and C points on Figure 1, respectively for lenient and stricter cases).

Using the Hits and False Alarms rates a measure of the capacity of the individual to detect the signal may be estimated, as well as another measure of the decision criterion (or the sensation value that the taster needs to respond when he or she has tasted olive oil). The theoretical model allows computing two different indexes to dissociate those two processes. About 30 varieties have been proposed to quantify the sensory-decision performance, e.g. [47-49].



Notes: False Alarm probabilities (pFA) are presented as a function of the Hits probabilities (pH). The dashed line represents the isosensitivity curve. The three points in the line correspond to the variations in the response criteria: Neutral (N), Lenient (L), and Conservative (C). Within the chart the Normal SDT model, a conventional one, has been superimposed. According to this model the signal and the noise lead to distribution models based on the Gaussian distribution. The middle rectangles represent each of the decision criteria: The one that favors Yes answers (L), the second one favoring No answers (C), and the middle one favoring neither of the two answers (N).

Figure 1. ROC graph.

Classical indexes d’ and Beta have been the most commonly used in psychophysical tasks. Both are based on the assumption of normal distributions of equal variance associated to signal and noise [46].

Sensory index d’ represents the distance between the distributions associated to signal and noise, while the index associated to the decision process (Beta) represents the relative distance between the heights of the two distributions, e.g. [46]; but see [38].

The use of d’ and β is only justified when the mathematical assumptions of normality and homogeneity of the variances about the density and probability underlying functions have been confirmed, limiting its general use in situations in which the information is limited [36, 41].

Aside of the parametric approach associated to the normal distribution, different families of theoretical models that do not need the normality assumptions, such as models of thresholds, or nonparametric models based on geometric measures, have been proposed, see [36]. These models might be more appropriate for the limitations imposed by the tasting situation [50].

Once established an alternative method to classical psychophysics that may be appropriate in the field of olive oil tasting, the next step is to test the bonhomie of this method on tasting situations. In the following sections we will briefly present the results obtained in our research when using SDT in the field of olive oil tasting. The first section will be devoted to summarizing those studies that have addressed the improvement of the methods used to select tasters and test their performance. Subsequently we will summarize the research conducted to explore the effects of different training methods on olive oil discrimination.

2. Adapting SDT Methodology to the Study of Olive Oil Tasting

Our research aims at developing an experimental set up that would allow applying the SDT to the study of olive oil tasting under controlled conditions. This methodological approach fulfills the requirements of Signal Detection Theory, allowing for quantifying the sensory precision but dissociating it at the same time from other non-sensory aspects of performance. Below, we will describe the general features of the method and procedure used in all the studies, and then describe the results obtained [50-53].

Participants. Participants were undergraduate students of the University of Jaén. They were regular consumers of olive oil, with no explicit training in sensory evaluation.

Their participation was voluntary.

To avoid distortion of their discriminative ability, they were requested not to smoke, or ingest any food or beverages for 30 minutes before the experimental sessions. With the same goal, participation of individuals that were affected by cold, allergies or any other seasonal alteration of taste was declined. Assignation of participants to the different experimental conditions was done randomly, where needed.

Materials and Apparatus. Preliminary studies allowed to standardize both the facilities to implement sensory panels, and the protocol of the tasting process, such as reflected in Figure 2, see [53]. The tasting laboratory consisted of 8 individual cabins following the IOC guide for the installation of a test room [54]. Cabins were separated by mobile panels that precluded participants from seeing each other while performing the task. Each cubicle was equipped with a desk and a chair (Workstation), a Water bath, and a computer (PC- control). A numbered plastic sheet was placed at the table so that participants could leave the samples after tasting them (Sheet Coaster). A coaster to place the trial sample, a place mat in which a glass of water and a plate full of green apple chunks were located to wash the palate between tastings (Taste Wiping), a 17" TFT computer screen, a rubber keyboard and a mouse were also placed at the desk in front of the participant to interact with the PC Control.

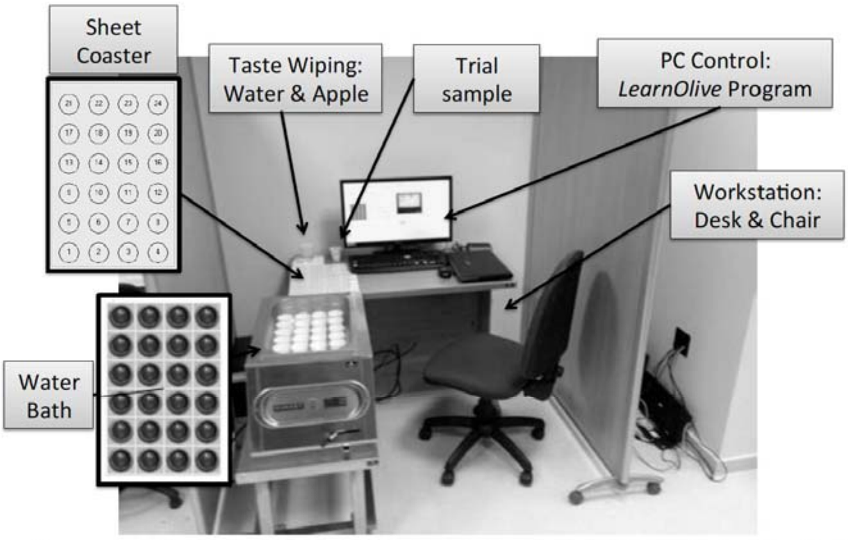
The final setting allowed presenting up to 24 samples of 5 ml each, and two different types of stimuli arrangements: Signal and noise.

Signal was arranged by including an amount of extra virgin olive oil diluted on a mixture of sunflower oil and food paraffin. The amount of olive oil depended on the design. *Noise* was identical to signal, with the exception that no olive oil was included in the mixture. In both cases, proportion of sunflower oil was kept constant (85%).

Samples were presented in blue tasting glasses covered with Watch-Glasses following the IOC guidelines for the standardized presentation of oil samples [55]. Samples were maintained between 27 and 29 degrees Celsius, IOC [54], by using industrial water-bath heaters that allowed keeping up to 28 samples at the same time for any given participant (see Water Bath on Figure 2). Water and apple chunks were provided to the participants between sample tastings, instructing them on how to cleanse their palate between trials.

Experiments were developed in individual cabins provided by a computer with *LearnOlive* software. This software was explicitly developed within our research team to conduct flavor experiments, and allows participants to easily follow the complete sequence of the task without intervention of the experimenter.

General Procedure. Experiments followed a 5-phase protocol: (1) Participants' recruiting and debriefing about the requirements to participate in the experiment, (2) Stimulus and taste sample preparation an hour before the experiment, (3) Cubicle preparation: Sample distribution according to the experimental setting and the randomizing provided by the software, and arranging of the setting for the participants including an arrangement of water, apple chunks, and cleansing elements, (4) Participants' reception, random assignation of the experimental location for each participant, and general instructions about how to perform the task, and (5) Performance of the experimental task.



Notes: The standard Tasting Cabin was equipped with a desk and a chair (Workstation), a Water Bath, a numbered plastic sheet (Sheet Coaster), a coaster to place the Trial Sample, a place mat to place the Taste Wiping, and a computer running LearnOlive software (PC- control).

Figure 2. The Tasting Cabin.

After signing the written consent, and filling a socio-demographic questionnaire, participants received general instructions about how to taste the olive oil samples (Turn-Smell-Taste-Clean procedure, see [51] for details).

The experimental session started immediately afterwards. Participants confronted a simple-detection task in which they should indicate whether each presented sample contained olive oil. The protocol followed by each participant was: (1) Picking the sample according to the established sequence, (2) tasting the sample, (3) giving the response about its content (Yes/No), (4) leaving the glass aside, and (5) cleansing her or his palate. Participants either received or did not receive feedback with respect to whether their response had been correct, depending on the design.

Dependent Variables and Statistical Analysis. Yes/No responses to each sample were recorded to compute Hits and False Alarms rates with the goal of computing the sensitivity and decision criterion indexes. The choice of the proper indexes should depend on the specific field of application. Sensory evaluation tests, and especially those using flavors, require the use of a limited number of trials so that saturation of the senses is avoided. This requirement does not favor the fulfillment of the mathematical assumptions in which classic measures are based: normality of the data and homogeneity of the variances. That is the reason why the choice of a nonparametric alternative is more appropriate within this field. In olive oil tasting tasks Non parametric Grier's A' [56], and Donaldson's B'_D [57] have been proposed as sensory and decision indexes, respectively [51]. Ramos-Álvarez et al. [53] performed a comparison between different indexes (d' and A' for sensitivity, and c, Logβ, B', and B'_D for decision criterion) with respect to the effect size of the factors manipulated in their study, finding that indexes A' and B'_D are at least as appropriate as classical parametric indexes to characterize performance in tasting situations. Figure 3 summarizes these results.

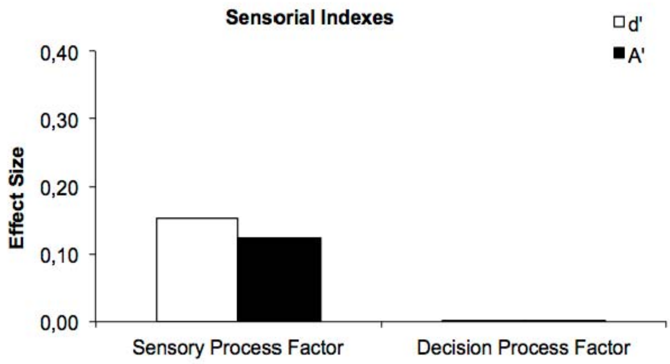
As shown, sensory indexes have a higher value when the sensory factor appears, whereas the same phenomenon happens with decision indexes. Moreover, sensory indexes d' and A' are very similar, and optimal values for decision indexes are C and B'_D Thus, the studies presented here have used those nonparametric indexes A' and $B'_{D,}$ see also [48].

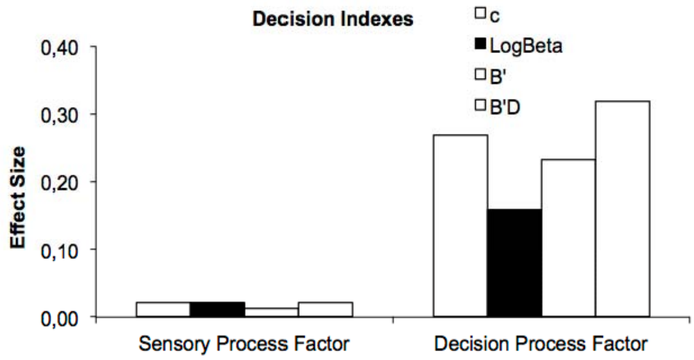
Under the same reasoning, parametric analyses of variance may not be most appropriate ones to be used in tasting situations, given the difficulties to verify Normality and Homoscedasticity assumptions because of the small number of data. Similarly, outliers are likely to appear in tasting tasks, according to our experience, invalidating the use of conventional statistics.

To explore these assumptions while summarizing the data, variability and central tendency indexes are presented in Box-Plot graphs according to robust statistics based on median [58]. Although this is not a requirement if the parametric assumptions are fulfilled by the data, our experience has inclined us to favor the use of robust statistics as a general analytic approach to tasting research, see [53].

2.1. Optimization of Olive Oil Sensory Analysis: Selection and Performance

Tasting situations are extraordinarily complex due to the confluence of physiological, psychological, social and even cultural factors and processes. These features make it difficult to analyze the tasting situation even under strictly controlled laboratory conditions.





Notes: Effect size was computed for an ANOVA where manipulated factors were the two variables affecting the Sensory or Decision process. On the top part computations for sensory indexes put forward for the SDT (d') are shown, together with its non-parametric alternative (A'). In the lower part the table shows the estimations for decision indexes, either using the SDT (c and LogBeta), or using the non-parametric alternative (Gief B' and Donaldson B'_D). Based on Ramos-Álvarez et al. [53].

Figure 3. Comparison of the different psychophysical indexes with respect to the Effect Size.

In a recent study by Jiménez and Carpio [59], they point out two different categories of variables that may affect the evaluation of the attributes in olive oil tasting: Factors that affect the sensory acuity of the taster (genetic factors, concentration ability, adaptation, saturation, sensory fatigue, physiology of the taster, and sample features among others), and other factors that are related to tendencies, response biases or task specific conditions that may affect judgments without affecting sensory acuity (motivation, test type, or quantity and quality of the information provided, among others). This idea is in agreement with the modern psychophysics that sustains performance is based on two different processes, the purely sensory one that derives from the combination of the physical qualities of the stimuli and the discriminative ability of the taster, and the decision process related to the cognitive aspects and the decision strategy of the observer, with his motivation, preferences, expectancies, and interests, see [41].

Considering a psychological perspective on the evaluation of olive oil may be of use to improve the internal processes of the panels, such as the selection of the components. Methods that would allow for quantifying separately the psychological processes involved in the tasting situation would imply an essential development on the optimization of the professional tasters' selection.

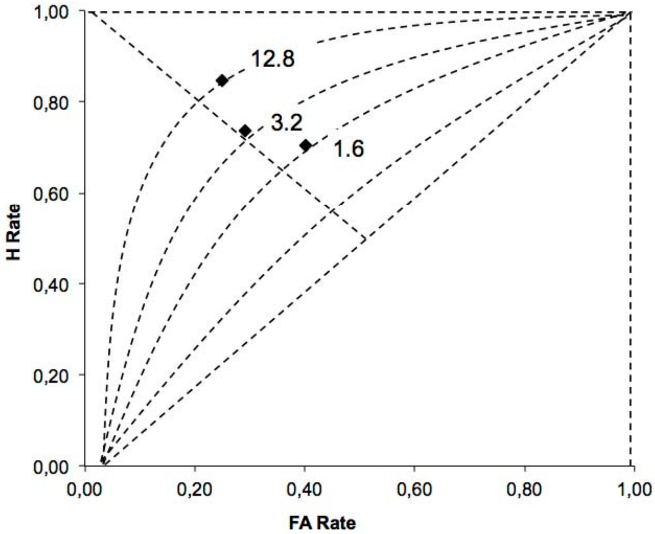
After all, the goal of such a selection process is to identify the individuals with a greater capacity to detect and discriminate among olive oil attributes, aside of the internal aspects that may bias their responses.

Human sensory mechanisms have a limited capacity and they are fairly imprecise. This imprecision of the mechanisms, as well as our own psychological nature makes us vulnerable to internal and external factors when living a sensory experience. It is in this limitation of the human mechanisms, in the adaptation capacity of psychophysical judgments, where our approach to sensory discrimination of olive oil as a decision-making process lays, a process in which the taster's response tendency may be guided to a goal, and changes in his or her strategy of behavior may be induced by experimental manipulations: Using rewards, instructions, or favoring expectancies about the presence of attributes and properties.

Paredes-Olay et al. [51] began the exploration of applying modern psychophysics to the study of olive oil tasting, searching for a separation of purely sensory processes from other factors that may affect performance, such as tasters' cognitive biases. These authors conducted a calibration experiment, based in classical psychophysics, using a task akin to the constant stimuli method adapted from the IOC normative [32], with the goal of selecting the concentrations of olive oil that would be used in subsequent experiments. The concentrations selected were 1.6%, 3.2% and 12.8%. The first two were detected by the 50-60% of participants, while the last one was detected by over 70% of participants. Thus, in the subsequent experiment there were two concentrations of some difficulty, and one that was easy to detect by most participants.

In their second experiment, Paredes-Olay et al. [51] implemented a detection task adapted to the specific methodology of Signal Detection Theory, allowing for a calculation of ROC curves and the separate calculation of sensory and decision indexes. The three levels of olive oil concentration were presented to three different groups. Each participant was exposed to 10 samples (5 Signal+Noise and 5 Noise). Participants did not receive feedback about their performance.

The results of this experiment are presented in Figures 4 and 5. Figure 4 presents a ROC graph of participants' mean performance. False Alarm rates and Hits rates are presented as a function of the three levels of olive oil concentration manipulated in this experiment: 1.6%, 3.2%, and 12.8%. The dashed lines represent the estimated isosensibility curve for each of the three points from SDT Model. The curves showed an increment in participant's sensitivity as the salience of the signal increased. With respect to the decision criterion, participants kept it basically neutral since the three points fall down closely together of the secondary diagonal (from the center towards the left vortex). Results obtained with indexes A' and B', which are presented in the left top and bottom charts of Figure 5, respectively, confirmed the impressions based on the ROC graph. Sensitivity criterion A' medians increased as olive oil concentration increased. Decision criterion B' was kept around zero (left bottom chart), an expected result given that no factors affecting decision criterion were manipulated in this experiment. These results are in agreement with dissociative predictions derived from SDT [36].



Notes: In this experiment, three olive oil concentrations (1.6%, 3.2% and 12.8%) were manipulated between groups, with a neutral situation regarding the sensory process. In the ROC graph, dashed lines represent isosensitivity curves for different sensitivity changes in the sensory process. Besides, points for the three manipulated conditions have been signaled. Based on Paredes-Olay et al. [51].

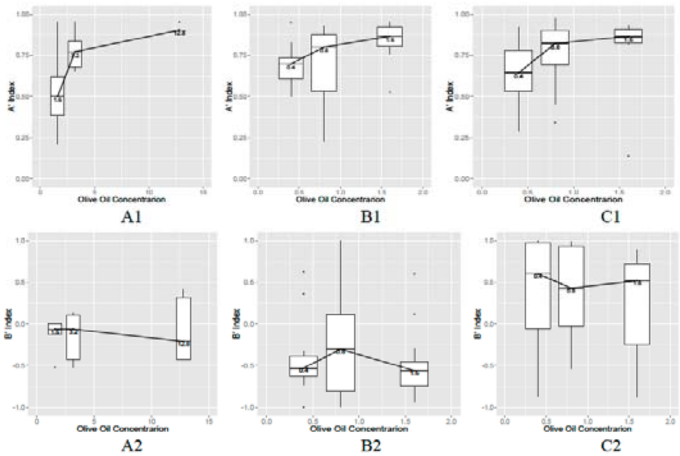
Figure 4. Olive Oil Tasting ROC.

This experimental series allowed for comparing two procedures based on two different psychophysics approaches.

The first one, regularly used in tasters' selection, allowed characterizing the discriminative capacity of participants with different olive oil concentrations. However, that methodology did not allow estimating whether tasters' performance was affected by any response bias that may or may not be playing a role in that situation. As it happens in other discriminative tasks, sensory evaluation of olive oil may be affected by cognitive biases that would go undetected when using these procedures.

In fact, undesirable deviations from a neutral criterion have been already found with other foods [44]. The second experiment applied a dissociative approach that allowed computing a pure measure of sensitivity, finding at the same time the lack of response biases in this situation by using an independent index. This methodological approach presents important advantages with respect to the traditional ones, allowing for a separate test of tasters' sensitivity and tasters' criterion biases.

After showing that Signal Detection Theory methods may be applied to olive oil tasting, Ramos-Álvarez et al. [53] conducted an experiment in which they applied the logic of the double dissociation additive test based on Sternberg additive factors method [60] that allows for assessing the interaction or independence of the sensory and criterion indexes within a single experimental situation.



A1) Selection Experiment. A'Index. A2) Selection Experiment. B' Index. B1) Dissociation Experiment. Lenient Condition. A'Index. B2) Dissociation Experiment. Lenient Condition. B'Index. C1) Dissociation Experiment. Conservative condition. A'Index. C2) Dissociation Experiment. Conservative condition. B'Index. Notes: Panel A (left) presents the charts corresponding to the Selection Experiment, based on Paredes-Olay et al. [51]; and Panels B and C, charts for Dissociative experiment adapted from Ramos-Álvarez et al. [53]. Panel B (middle) corresponds to the condition induced bias type "lenient", and Panel C (right) corresponds to the "conservative" condition. Top charts (A1, A2, and A3) show the nonparametric sensitivity index A', while bottom charts (B1, B2, and B3) present the nonparametric bias index B'. In all cases, three olive oil concentrations were manipulated between groups: 1.6%, 3.2%, and 12.8% on the Selection Experiment (left), and 0.4%, 0.8%, and 1.6% on the Dissociative Experiment (middle and right). In each of the box-plot graphs, straight lines represent the median, boxes represent variability, and outliers are represented by dots outside the boxes.

Figure 5. Olive Oil Tasting Statistical Analysis.

Two independent factors were simultaneously manipulated in a complete factorial design. Olive oil concentration was manipulated with three levels (0.4%, 0.8% and 1.6%).

Instructions were manipulated so that participants were induced to be either lenient or strict. Olive oil concentration was expected to affect only the detection process (A' type indexes), while instructions should affect only the decision processes (B'_D type indexes).

In this double dissociation test, the absence of interaction would point to the independence of the psychological processes associated to each factor.

The results of this experiment are summarized in the middle and right charts of Figure 5. Sensitivity index A' is represented in the top charts, while criterion index B'_D is represented in the bottom charts. Sensitivity increased with the concentration level, and this increase was not affected by the instructions, as shown by the two parallel lines that connect the median of each concentration level at each level of the instructions (compare top-middle and top-right charts).

The opposite result was found with the criterion index. Instructions that intended to induce a conservative bias did so regardless of the concentration level (see positive values for the median of the criterion index for every concentration level presented at the bottom-right chart of Figure 5).

Similarly, instructions that intended to induce a lenient bias did so regardless of the olive oil concentration (see negative values for the median of the criterion index at every level of oil concentration presented at the bottom-middle graph of Figure 5). Parallel lines connecting boxes at each concentration level suggest a lack of interaction that was confirmed by statistical analyses.

Manipulation of factors that theoretically should affect specifically either sensitivity or criterion decision did so without affecting the alternative index. These results confirm the usefulness of the SDT based methodology on the tasting situations, even using a small number of samples and a small number of participants.

In fact, these conditions were selected on purpose, with the idea of making the experimental situation as akin to the natural situation of a tasting panel as possible, so that the results of these experiments could be easily translated to applied settings.

2.2. Optimization of Olive Oil Sensory Analysis: Tasters' Training

Once the panelists are selected, the main goal of any training program within a sensory panel is to improve tasters' ability to detect and judge with precision the sensory properties of the food. In the context of olive oil tasting, achieving this goal involves an improvement of professionals' abilities to discriminate among the different olive oil varieties. Research in the field of perceptual learning may help to understand how those abilities are developed, contributing to the design of more efficient training programs, see for instance, [61, 62].

The concept of perceptual learning involves the effects of an increase in discriminability of the stimuli because of the experience with them [63]. One of those perceptual effects with potential implications for tasters' training is the transfer of discrimination along a continuum, e.g. [64, 65], or the easy-to-hard effect, e.g. [66]. It turns out that experiencing an easy discrimination makes it easier for subsequent learning of a difficult discrimination about stimuli that vary across the same dimension as compared to a group that is only trained with the difficult discrimination, e.g. [67].

This phenomenon has been studied in humans, and also with animals under different sensory modalities, including flavor discrimination, e.g. [66]. However, traditional approaches to the easy-to-hard effect have focused on the improvement of perceptual abilities. The use of the dissociative approach of SDT applied to the study of perceptual learning would allow for testing the potential participation of other strategic factor within the discriminative training procedure. This issue was approached by Moreno-Fernández et al. [52] in an experiment conducted within a situation akin to the ones described above.

Two groups of participants were exposed to a tasting situation in which they received one 45-minute session in each of four days in a row. In each session participants received 20 samples, 10 with the signal, and 10 with only the noise. Participants received feedback about the presence or the absence of olive oil in each sample. In the testing session participants were trained with a 0.5% olive oil concentration, a concentration that is difficult to discriminate by non-trained participants. Groups differed in the treatment received before the test. The Hard-to-hard group was trained with the same concentration throughout the 4 sessions. However, for the Easy-to-hard group, the difficulty of the discrimination increased from session to session, starting with a concentration easy to detect (2%) and decreasing progressively the concentration level of olive oil across sessions (1.5% and 1%) before being trained with the same concentration at testing.

Performance at testing was better in the Easy-to-Hard group (A' index of 0.76) than in the Hard-to-hard group (A' index of 0.62). Both groups of participants showed learning, but performance was clearly better for the group that received progressive training than for the group that was directly trained with the difficult discrimination. These results extend to the field of olive oil tasting results previously obtained with other discriminations in human and non-human animals, e.g. [66, 67], suggesting that the easy-to-hard training may be an useful training schedule for tasters. However, the use of the SDT methodology, aside of providing a sensitivity bias-free index, also allowed for detecting potential response biases that in any other way would have gone undetected.

In fact, this was the case with progressively trained participants. They became conservative as the training progressed, showing a significant tendency to categorize incorrectly signal samples as noise (B'_D index was 0.2 at the test session).

Thus, the easy-to-hard training schedule improves the ability for detecting an attribute, but it also produces a bias towards a more conservative non neutral strategy of response, suggesting that, when applied to tasters' training, this program should be combined with a corrective strategy, such as the use of specific instructions that may prevent trainees to be overly conservative, e.g. [53]. It should be as well obvious that the results of this experiment point towards the need to consider both, sensitivity improvements and the strategy used by participants, that is, the presence of responding biases on performance.

CONCLUSION

This chapter presents a new method of research and training for the sensory analysis of olive oil based in modern psychophysics theory that focuses on perceptive processes from the decision-making perspective. It is assumed that stimuli cannot be perceived in isolation from other psychological cognitive factors that are part of our human nature.

The proposed methodology based on a dissociative model, allows obtaining independent measures of the effects generated by purely sensitivity factors from purely decision factors that are present in all discriminations. The experiments used above to explain the dissociative SDT based dissociative model have been able to reveal the advantages of this methodology with respect to the one traditionally used in tasting panels, based on the threshold concept. Traditional methods do not allow separating the influence of factors related with tendencies, response biases, or task conditions that may affect tasters' judgments and are thus confounded with sensory acuity.

At face value, the use of an SDT based methodology applied to the olive oil tasting process will improve the quality of the sensory evaluation.

In addition, improving the quality of sensory evaluation including the evaluation of the cognitive aspects of the tasting process has a number of important implications. First, it will favor the approximation of experts' and consumers' criteria. This approach may be achieved by favoring the compatibility between their evaluations, something that can be accomplished by developing new advanced methods of analysis facilitating discrimination of variables in determination of quality criteria, acceptance and appetency.

Second, this approach may be beneficial for the research conducted in consumption and health. Given the complexity of organoleptic exploration, the quality of the evaluation will be improved by a precise measure of the sensory sensations that are part of the identity and singularity of the olive oils. These new method allows for the estimation of factors that are not necessarily attached to the perceptive experience, but that influence decisions of both, experts and consumers.

In the case of olive oil as a possible functional food, it is necessary to know what determines consumers' choice behavior, on which factors they base their choices, how they change their criterion, etc. so that processes to stimulate acceptance of the new functional foods may be developed.

Third, the SDT based method as has been exposed here has a direct translation to selection and training of tasters. The use of the dissociative method allows for an improvement of the selection of potential candidates for tasters, as measures of their acuity may be obtained free of biases.

As for its influence on tasters' training, the last experiment we summarized here not only shows that the gradual increase on the difficulty of the discrimination is a useful strategy to produce better training results; it also shows the importance of measuring the presence of strategic factors on the evaluation of any training program. And we should remember that the influence of those factors would go undetected in traditional selection and training methods based on classic psychophysics as in the case of olive oil tasting.

Finally, we should acknowledge that this line of research is just being born. The potential applications of dissociation methods based on Signal Detection Theory to olive oil tasting are yet to be fully determined.

Experimental psychology and olive oil tasting would benefit each other from an association that would not only allow for an improvement of the selection and formation of tasters, or for a detection of critical sensorial and criterion differences on consumers preferences, or on the differences between regular and potential consumers. It will also allow for a better understanding of the psychological processes involved in olive oil tasting and consumers' behavior, opening interesting, exciting and socially relevant perspectives on these fields.

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6 GENERAL DISCUSSION

The general goal of this dissertation was to provide a new characterization of the sensory analysis of flavors as the result of a decision-making process, taking an SDT-based methodological approach: The *Double Dissociation Additive Test,* that allows for differentiating between the sensory and decision processes involved in sensorial evaluation performance (Paredes-Olay et al., 2010; Ramos Álvarez et al., 2013). This research transferred organoleptic evaluation to the laboratory exploring the dynamics of the processes that underlie the taste experience. Experimental conditions were similar to the ecological situations in which tasting usually takes place, with the only exception that a mixture of basic flavors that allows for a greater experimental control was used instead of natural foods. This ecological point of view also involved the sample of participants, as they were selected from the general population, fulfilling the function of novice tasters.

The Double Dissociation Additive Test was developed by Ramos-Álvarez et al. (2013) and it allows for conducting a double check of the independence or the interaction of sensory and decision measures within the same experimental design. In the experiments gathered in this dissertation, the factor selected as sensorial should affect only the sensory index, keeping the decision index unaffected while, at the same time, factors selected as decision factors should affect only the decision index, leaving the sensorial index unaffected. Following this logic, factors that were expected to differentially affect sensory and decision criterion processes were manipulated in several full factorial designs: Signal salience, signal-noise base rates and payoffs matrices. An independent sensory index should be able to reflect changes in discriminability regardless of the specific signal-noise base rates or payoffs conditions. Statistically, this should be shown as a main effect of signal salience, no effect of base rates or payoffs matrices, and no interaction between factors. Alternatively, an independent decision index should be able to reflect variations in criterion regardless of the level of signal salience. In this case, statistics should reflect a main effect of base rates and payoffs, no effect for signal salience and no interaction between factors. In both cases, the presence of an interaction would imply an association between the induced criterion and the signal salience which, according to our hypothesis should not covary.

Obtained results suggest that the selected indexes to reflect sensory and decision processes in tasting worked independently from each other. A' index was affected only by changes in the intensity of the salt concentration. Conversely, stimuli probabilities and payoffs matrices only affected the criterion index B'_D, without affecting sensitivity. Moreover, all the statistical interactions were not significant. In agreement with the results reported by Ramos-Álvarez et al. (2013) when manipulated instructions and the intensity of olive oil within a mixture of other oils, the use of the Double Dissociation Additive Test together with nonparametric measurement parameters and robust statistics allowed for detecting independent variations in the sensory and decision criterion measures chosen. Obtained results confirmed the presence of outliers and a non-normal distribution of the data, the expected pattern of results associated to the specific features of the tasting process, such as the small number of trials and participants. This pattern of results invalidates the use of classical statistics, as it fails to fulfill their basic assumptions. This problem was overcome by the use of the more powerful robust estimators proposed by Ramos-Álvarez et al. (2013) as the most adequate to be applied to tasting research. The results found in these experiments allowed for extending the validation of the psychophysical methodology proposed for the analysis of psychophysical variables in the tasting procedure: The SDT based experimental tasting task, the use of the dissociative additive test, nonparametric indexes A' and B'_D, and statistical robust analysis of the data obtained with this procedure.

In the following sections we will present and discuss a general overview of the results of the different experiments gathered in this thesis with the goal of giving a better understanding of the overall results obtained in this research. As no interaction between factors that affected to sensory and decision processes was found in any of the experiments, the data for sensory and decision manipulations will be separately presented and discussed, before presenting the final remarks.

6.1 Analytic summary and discussion of the results concerning the sensory index

Figure D1 shows the comparison between the sensitivity values obtained along the different experimental series that shape this dissertation. As expected, sensitivity measures were very similar across the different experiments reported above. Only the values in the low range showed some variability given the rapid growth of the psychophysical function for salty flavor in the expansive phase. A' index showed to be a consistently sensitive parameter to detect differences in signal salience.

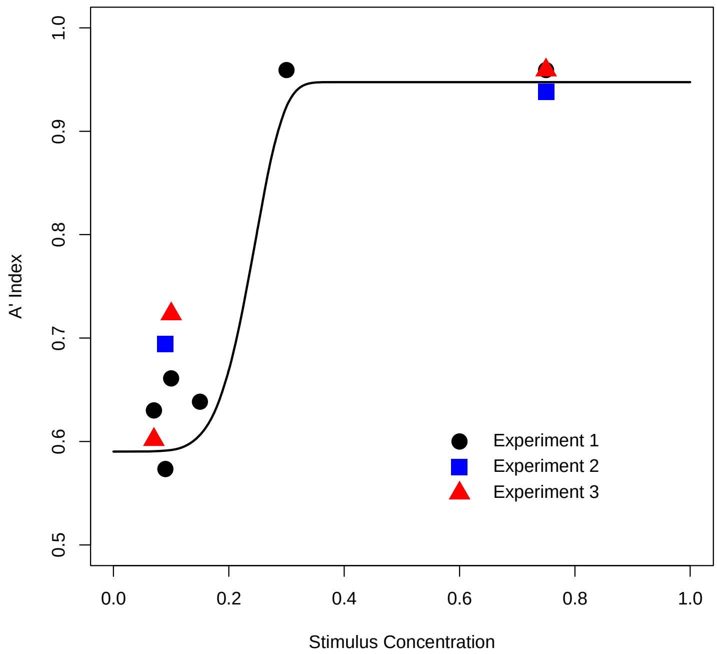

Figure D1: Charts corresponding to the Sigmoidal family models (i.e. Weibull) estimated from Experiment 1. The circles correspond to the A' medians on each of the six salt concentration levels manipulated on Experiment 1, the squares are the medians of the two concentrations used in Experiment 2, while triangles are the medians of the three concentrations used in Experiment 3.

Aside showing the effectiveness of the A' index to detect variations in sensitivity, Figure D1 shows that the range of concentrations chosen in these experiments needs to be completed so that the function of tasting may be completed as well. Although this issue do not affect the conclusions about the independence between sensory and decision processes reported above, additional data were gathered with the goal of extending the reach of the calibration study presented in Experiment 1. A quick inspection of the results reported in Figure D1 shows a jump in performance between concentrations of 0.15 and 0.30 of Experiment 1. A new condition using an intermediate value (0.25) with respect to those two concentrations was included. Additionally, original conditions of Study 3 were replicated using three intermediate concentrations (0.09, 0.15, and 0.30). Due to the complexity of Study 2 (remember the triple interaction Salience * Induced criterion * Feedback), it was not feasible to expand its scope to other salt concentration values. These new data were included together with the original values of the three studies reported here, and a new modelization analysis similar to the one conducted in Experiment 1 was conducted here. The results of that modelization study are presented in Figure D2. In this graph, the actual data are plotted against different types of models: Sigmoidal based psychophysical functions (Rouder et al., 2005) and other models that have been proposed in research about psychophysics curves of taste interactions, or Exponential-type, such as power, hyperbolic, and exponential (Keast & Breslin, 2003).

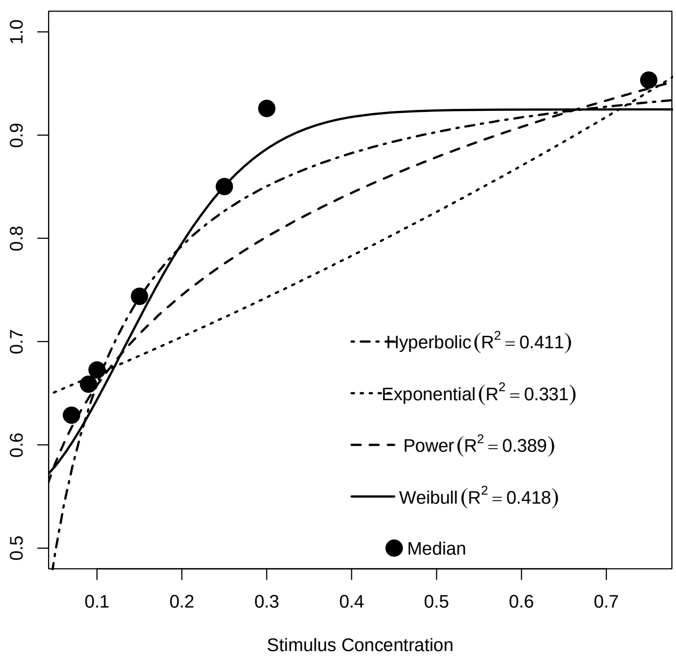

Figure D2: Global Function adjustment (i.e. Weibull). The circles correspond to the A' medians on each of the seven salt concentration levels manipulated across the three studies reported in this dissertation. The Models adjusted were of Sigmoidal (i.e. Weibull) and Exponential (i.e. Power, Hyperbolic, and Exponential) type.

Looking at Figure D2, the results reported in the first study of this dissertation are confirmed. Data from the three studies and from the concentrations added to complete the curve t are better adjusted to S-Type (Weibull) models than to E-Type (i.e. Exponential) models. Specifically, this distribution of data seems to be better represented as a Weibull model (R^2 of .42 versus .33-0.41 range for the alternative models). Again, as in Experiment 1, global data suggest some asymmetry on the curve, so that the initial expansive phase may be plainer than the compressive phase.

Research about psychophysical curves of taste stimuli shows accelerating concentration-response functions: At low concentrations of salt compound, the rise in sensitivity is proportional to the rise in concentration, while at high concentrations of the compound, no further increases in perceived intensity are attained (Bartoshuk, 1975; Holway & Hurvich, 1937; Meiselman, 1968). Conversely, data obtained throughout our experiments seem to fit better to the sigmoidal curves proposed for taste mixtures (Keast & Breslin, 2003) than to the exponential ones. The Weibull distribution has been used to represent the processing stages in different psychological models (Ratcliff, 1979, and see Rouder et al., 2005), and to fit different data related with biological processes (Lai, 2014). All models predict the three phases, expansive, linear and compressive at low, moderate, and high intensity, respectively, but the Weibull curve seems to better capture the asymmetry of growth.

Finally, modeling results collected in Figure D2 were obtained by using A' data for the conditions with and without feedback. Participants improved their performance when feedback was available but the effect of this variable on the parameters of the simulations was negligible. Again (remember discussion section of Study 2), results are in agreement with most studies that report a positive effect of feedback by improving overall accuracy of performance (e.g., Herzog & Fahle, 1997).

6.2 Analytic summary and discussion of the results concerning criterion index

Figure D3 shows the comparison among the criteria values obtained throughout the experimental studies conducted in this dissertation. B'_D index showed to be a sensitive measure to compute variations on response bias. Following SDT assumptions, payoffs and probabilities manipulations were effective to promote changes on the decision criterion. Induced bias for payoffs and stimuli probabilities under the feedback condition followed the same direction. That is, conservative when manipulations encouraged a conservative response, and lenient when a liberal strategy was promoted. In addition, positive and negative effects in both cases were symmetrical, as SDT predicts. However magnitude of bias differed across manipulations, so that criteria were less extreme when the payoffs were manipulated than when the manipulation affected the probability of the signal trials. The robust Effects Size statistics estimated for Studies 2 and 3 confirmed this general overview: A value of 0.758 for Experiment 2 and 0.513 for Experiment 3. Without feedback (excluding conditions in Figure D3, remember Figure 3b in section 5.2), pattern of results was very different and decision criteria were not adjusted to the probabilities a priori. Thus, feedback had a direct effect on adjusting the response criterion.

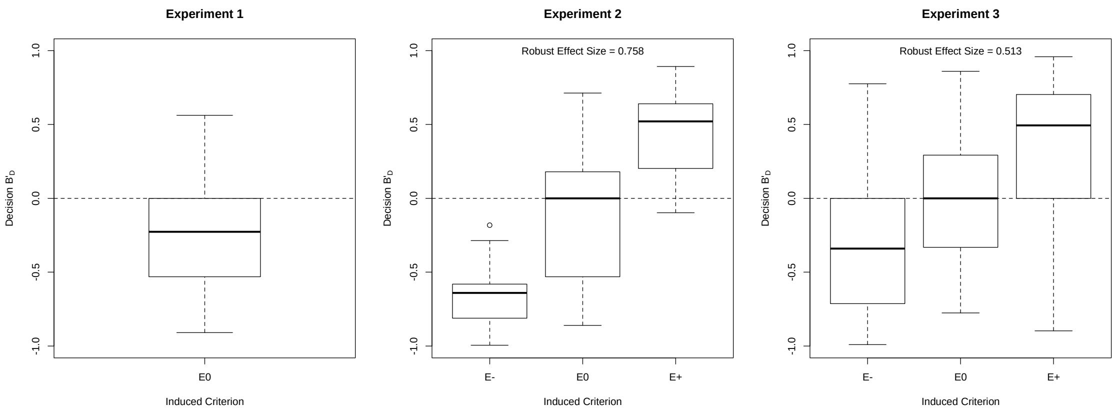

Figure D3. Comparative analysis for index B'_D. The graphs represents the Box-Plot of the main effect of Induced Criterion in B'D index. In Experiment 1, participants' treatment adjusted to E_0 condition of Experiments 2 and 3 (no criterion induced). In Experiments 2 and 3 participants received one of the 3 levels of induced criterion (E_-, E_+, and E_0 for lenient, conservative and neutral, respectively).

SDT presents a deterministic rule to compute the optimal performance on detection tasks that is determined by the payoff matrix and by the probabilities of the two stimulus distributions (see equation for Optimal Criterion in Figure D4). When the payoffs are symmetric (the rewards and penalties for correct and incorrect responses to the signal stimulus are the same as those for the noise stimulus) and the priors are equal [p(SN) = p(N)= .5], there is no bias in favor of either response and optimal beta is 1.0. The model assigns both variables, a similar role on decision performance when the relative ratios of priors and payoffs are equivalent. For example, if the payoff for a correct "signal" decision is 5 times the one for a correct "noise" decision, then it is assumed that the signal probability should need to be 5 times (more or less) the one of the noise probability to make the same "signal" response under both types of manipulations.

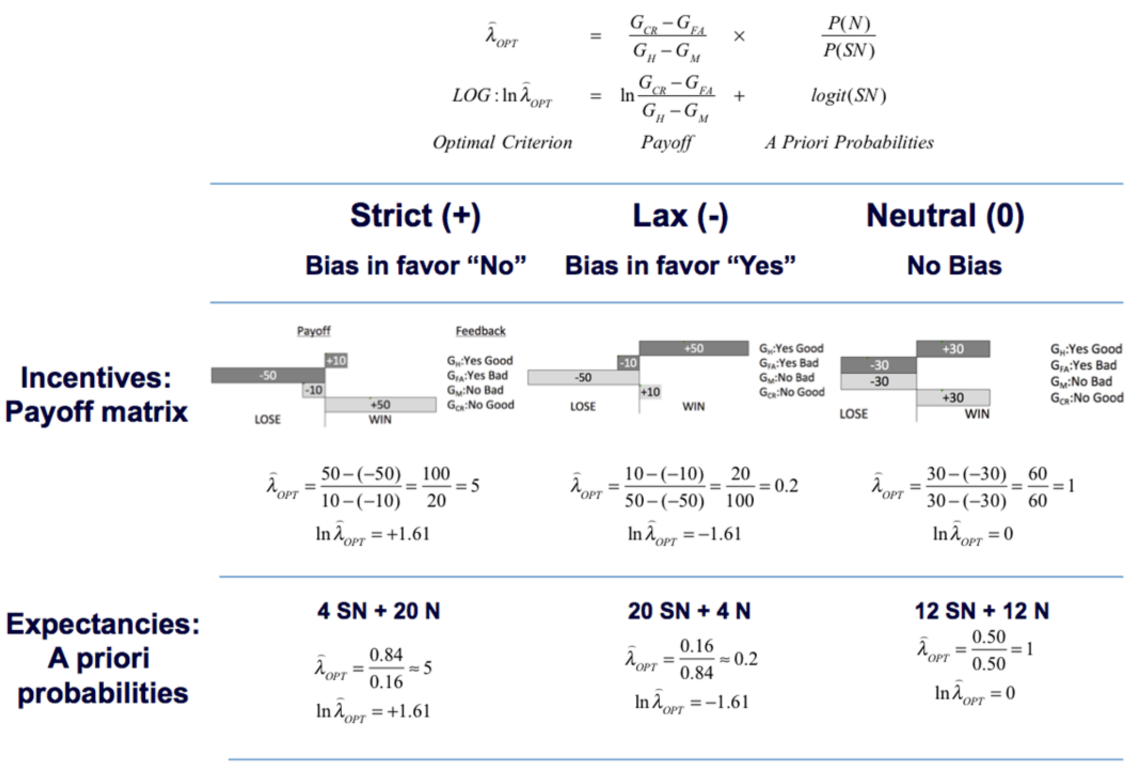

Figure D4. SDT Normative programming as a function of the expectancies (Study 2) and the incentives (Study 3). The top part of the figure shows the formal characterization of the expected optimal criterion according to SDT as a function of the payoff and a priori probabilities. The optimal criterion is computed as the product of the two factors, payoff (gains, pays or incentives matrix) and a priori probability of the stimuli. In every case the same computations are expressed in log terms.

Values of signal versus noise probabilities and payoffs matrices were computed to produce this equivalent effect on the decision index and thus, similar estimations could be expected. Figure D4 compares the extent of the induced bias in both cases. As can be seen there, induced bias was the same in both manipulations and thus, SDT predicts equivalent modifications in the placement of the criterion. Although Payoff matrices were effective to promote changes in decision, criteria were less extreme than those obtained with the Base rates manipulation, under feedback condition. While our data provide support for the hypotheses that decision performance varies under both, priors and payoffs manipulations, they seem inconsistent with the predictions of SDT for optimal criterion computation. This is not an unusual result. Many studies suggest that human observers fail to move their decision criterion to such an extreme position as the one required by SDT for optimal performance. This reduction in the range of criteria is called *"conservative cutoff placement"* and it has been reported in several research domains (Bohil & Maddox, 2003; Healy & Kubovy, 1981; Macmillan & Creelman, 2005).

Suboptimal decision criterion has been usually found under unbalanced payoffs. However, it has been also reported with unequal base rates in recognition memory tasks (e.g., Creelman & Donaldson, 1968; Han, 2008). When payoffs are symmetric and priors are equal, the observed beta used by participants is indeed 1.0., or equivalently, indices as LOG or B'_D are zero). However, when payoffs are asymmetric or priors are unequal (i.e., there is a bias in favor of one of the responses) participants use an observed beta that is closer to the neutral point than its optimal beta (Green & Swets, 1966, 1974). In agreement with the results observed here within a tasting situation, Healy and Kubovy (1981), in probabilistic categorization decisions, found that their participants tended to be more sensitive to the priors than to the payoff ratio even when the bias dictated by the payoffs was larger than the bias dictated by the base rates (see also Maddox & Dodd, 2001; Maddox, Bohil, & Dodd, 2003).

Two competing classes of explanations for this conservative cutoff placement of the criterion have been proposed (see Healy & Kubovy, 1981): (a) explanations that predict equal amounts of conservatism in response to the criterion change induced by payoffs and priors, and (b) explanations that predict unequal amounts of conservatism in response to the two types of criterion changes. Response persistence explanation is within the first group. According to this approach an extreme criterion needs of participants of making the same response on almost all the trials. However, providing participants with two response options creates a demand that induces them to use both responses with some frequency, leading to suboptimal performance (Green & Swets, 1966, 1974). The second approach that predicts equivalent effects of payoffs and priors on response bias is the "distribution misconception" (Kubovy, 1977). According to this hypothesis, participants' conception about the shape of the underlying stimulus distributions is distorted and they either overestimate or underestimate likelihood ratios. These two hypotheses have problems when explaining the results obtained in this experimental series, given that the conservative cutoff placement was greater for payoffs than it was for the a priori probability manipulation.

In the second group, two hypotheses have been proposed to explain different effects of payoffs and priors. The first hypothesis suggests that deviations from the normative prescriptions for asymmetrical payoff matrices occur when the utility of money is a negatively accelerated function of the monetary values included in the matrix (Ulehla, 1966). An alternative hypothesis is the one named as the "probability matching" rule, which specifies that over a series of trials, stimuli responses made by the subject are proportional to the base rates while the effects of payoffs are represented by a constant [According to the standard "multiplicative" probability matching, p(R) = minimum [kp(S), 1] where the constant "k" is a function of the payoffs; alternatively, Healy and Kubovy (1981) proposed a related "additive" probability matching rule to account for their general results, in which p(R) = minimum [p(S)+c, 1] where "c" depends on payoffs].

Two alternative mechanisms to explain the conservative cutoff placement have been discussed in the literature: The hypothesis of a competition between reward and accuracy maximization and the flat-maxima hypothesis (see Bohil & Maddox, 2003). According to the first one, observers attempt both, to maximize reward and to maximize accuracy. Because the observer must sacrifice some measure of accuracy to maximize reward when costs and benefits are manipulated, any weight placed on the accuracy will lead to the use of a suboptimal decision criterion. Alternatively, the flat-maxima hypothesis states that the observer's estimate of the reward-maximizing decision criterion is determined from the objective function of reward. To contrast the predictive value of these two mechanisms, Bohil and Maddox (2003) conducted two manipulations that did not affect the optimal criterion value. The first manipulation was a payoff matrix subtraction. Authors examined two levels of payoff matrices: Zero and negative cost associated to the incorrect responses. Results showed more suboptimal criterion learning in negative cost conditions than in zero-cost conditions. Authors argued that this finding could be due to an increased emphasis on accuracy maximization in negative cost conditions. The second manipulation they employed was a payoff matrix multiplication. Like the payoff matrix subtraction, the payoff matrix multiplication does not affect the value of the optimal decision criterion, but it does affect the steepness of the objective reward function. In this second manipulation, researchers included two additional matrices derived by multiplying each previous matrix by a factor of 6. Multiplication by a factor of 6 yields a steeper objective reward function. Authors found better decision criterion learning when values of matrix were multiplied by 6 than by a factor of 1 suggesting that both mechanisms are important for explaining deviations from optimal criterion.

As Healy and Kubovy (1981) reported in categorization judgments, we found that the induced bias magnitude due to variation in payoff matrices was lower than the one due to variation in prior probabilities, even though both manipulations prescribed an equivalent effect according to SDT. This finding suggests an unequal behavior of bias under signal probability and payoffs manipulations, and thus, hypotheses that predict equal amounts of conservatism in response to both manipulations have problems when explaining the results obtained in this experimental series. Although findings are in agreement with the second class of explanations, no conclusion about the underlying mechanism of this effect can be derived from the experimental designs presented in this dissertation. A complete design including both manipulations would be required to replicate findings and explore possible mechanisms of action. In addition, the proposed explanations are not specific enough and it is likely that several of them are related to the effect reported here. For instance, probability matching rule does not specify the value of the constant selected for a given asymmetrical payoff matrix. Healy and Kubovy (1981) suggest that this value will depend in large part on the specific experimental conditions, including the instructions given to the subjects and the extent of their training and it could account for the relatively large effects of payoffs obtained in other studies. In any case, further research will be needed to disentangle those issues, comparing for instance the effects that appear when other values are assigned to payoffs matrices and signal-noise base rates.

Separate discussion deserves the difference on the effects of signal probability on criteria placement as a consequence of manipulating the informative feedback about the correctness of responses. Specifically, participants were more likely to exhibit large differences in the estimated response criterion when feedback was provided. In this condition, available information seemed to have enabled participants to adjust their response biases so as to reflect actual base rates. When feedback was omitted, results revealed a pattern of bias that deviated from the one predicted by SDT. Participants' response did not reflect the actual probabilities distribution, and a reverse relationship between the induced bias and the decision index was found in some conditions, together with a general tendency to a more liberal criterion response. It should be obvious that for SDT principles to work, it is necessary that participants are somehow aware, either by instructions or by its own experience, of the actual distribution of the trials within the experiment. Although results are not in agreement with SDT predictions, these findings were in line with previous data reported in experiments conducted without feedback (e.g., Tanner, Rauk, & Atkinson, 1970). A reasonable interpretation of this result is that participants tend to believe that stimulus probabilities are identical in the absence of feedback, so that their responding does not reflect the actual asymmetric distribution of stimuli (Macmillan & Creelman, 2005). Complementarily, a tendency to equate the frequency of yes-no responses has been found in many judgments' tasks (e.g. Luce & Green, 1974). Luce and Green (1974) also suggest that this effect could be related with the degree of experience with the task. In any case, results suggest that feedback is important for criterion shifts to be observed and it seems to play a vital role in food analysis, a domain that requires unusual sensory abilities.

The particular complexity of taste sensory evaluation could be on the basis of the slight but reliable lenient response bias that was detected regardless of the salt concentration in the parametric study of the salty quality that is reported in Study 1 of this dissertation, as well as when base rates were manipulated without feedback in Study 2. In the psychophysical curve, bias was similarly found across different physical intensities. In fact, this experiment was conducted to detect the possible emergence of strategies and/or response biases that may occur when complex sapid stimuli are evaluated. In these situations, the difficulty of discrimination may be increased by qualitative changes that occur in more complex mixtures (Moskowitz, 1972). A possible explanation for this phenomenon is that tasters may adopt different cognitive strategies depending on the complexity of gustatory stimuli and the available information. Difficult decision environments may result from many aspects as low stimuli salience, poor observer's sensibility, absence of feedback or lack of experience with the task. This factors may affect response bias in different directions, even opposite (e.g., Brown, Steyvers, & Hemmer, 2007; Estes & Maddox, 1995; See, Warm, Dember, & Howe, 1997; Stillman, Brown, & Troscianko, 2000; Swets, Tanner, & Birdsall, 1961; Wenger, Copeland, Bittner, & Thomas, 2008). Only tentative hypotheses may be formulated to explain this finding at this point. See et al., (1997) reported a trend to liberality of responding in absence of an externally imposed bias, as decision become easier the greater the stimuli salience (see also Brown et al., 2007). Stillman et al. (2000), using the same-different procedure and basic flavors, also found a general tendency towards more conservative response biases as sensitivity declines (the less sensitive participants were the ones that were more strongly inclined towards giving "same" responses). In the same line, Wenger et al. (2008) reported that perceptual practice can produce an increase in the false alarm rate and reliable liberal shifts in detection responses. However, Estes and Maddox (1995) showed that higher interitem similarities produce more false alarms. Finally, Swets et al. (1961) found a frequent strict criterion employed by the observers under the yes-no procedure (see also Friedman, Carterette, Nakatani, & Ahumada, 1968). They suggested that participants attempted to avoid making false alarms responses even in the absence of an explicit caution against this incorrect response.

In summary, the results reported here show that, aside tasters' sensitivity, decision processes play an important role on organoleptic evaluations. Taking decision processes into account becomes essential for sensory evaluation of foods, given that alterations in response biases may be expected depending, for instance, on the distribution of the signals, the differential costs of performing each response, or the feedback provided by the situation.

6.3 Final Remarks and Applications

The results reported in this dissertation were found in a situation in which flavors' tasting research was approached from an ecological point of view. Methods, materials and settings were created to reproduce a real tasting environment. Stimuli were two artificially arranged compounds, but components were in fact human basic tastes. The choice of these specific stimuli had the advantage of increasing the experimental control by simplifying its manipulation with respect to manipulation of real foods. However, mixtures were complex enough as to approach to a standard tasting situation. Traditional sensory research, when trying to increase control, has chosen to use extremely simple stimuli, usually basic tastes. However, this lack of control was gained by sacrificing the complexity of standard foods. An excess of simplification of designs and stimuli leads to a decrease on the generalizability of the obtained findings to more complex, natural stimuli, so that ecological validity is sacrificed in these simple designs (see Meiselman, 1992, 1993). As we report, the choice of complex matrices is an appropriate approach, but research in this topic is still scarce. More research is needed exploring other complex matrices of compounds in a wide range of intensities (beyond threshold level). How two or more perceptually distinct components are combined by the taster should be analyzed, as well as the effects that may occur if the nature of the combination changes. As we have showed, one approach that allows for assessing mixture interactions over a range of concentrations is to develop psychophysical functions for the compounds of interest. Parametric analysis and psychophysical functions have important implications for the area of perceptual research since they allow to make predictions about the interaction between the studied components in complex stimuli. Our methodological approach allows for providing sensitivity's profiles to different taste qualities while controlling possible response biases that could distort sensitivity measures. Additionally, the Weibull model may be a useful tool for characterizing sensory performance and represent the data trend obtained from other flavors mixtures or other sensory manipulations as for instance, the stimulus temperature.

The choice of participants selected from the general population, without experience, or formal training with the tasting process was also part of this ecological approach.

Using naïve participants allows for testing how the tasting process works in the absence of specific training, extending the results of this research to applied fields such as consumers' perceptions, and allowing for counting with a basic characterization of common performance that can be later used as a benchmark with which comparing experts behavior, as their specific training may affect how cognitive variables operate on them. For instance, the effects of several manipulations such as feedback variables would probably be different when using trained tasters. In this sense, several studies suggest that feedback affects differently to naïve participants and participants with formal training (e.g., Liu, 2011; Luce and Green, 1974; See, et al., 1997; Tanner et al., 1970). From an applied perspective, exploring sensory and decision performance using expert tasters when this and other cognitive factors are manipulated may be relevant to detect whether different strategies may emerge with practice. Biases are always a deviation from the optimal strategy and it should be a goal for any sensorial evaluation to prevent, or at least control, biased strategies in any sensorial test.

In summary, the results obtained in the experiments that define this dissertation suggest that sensory and decision processes may be separately evaluated and controlled within a laboratory setting that was established to replicate the conditions in which natural tasting tasks are conducted. Under these constrains, the experiments conducted here produced results that are in agreement with those reported within other experimental research paradigms such as vigilance, memory, taste, diagnostic, etc. (see Swets, 1998 for a review). Given this, a reasonable assumption will be that the proposed methodology may be used for conducting laboratory experiments oriented to explore the psychological processes underlying food tasting as well as for controlling the presence of factors affecting decision processes within natural tasting situations.

With respect to the basic research, the work that we report in this dissertation has allowed establishing several variables that selectively affect different processes through the convergent dissociation test as signal salience, probabilities a priori, and payoffs matrices. Following the factorial logic, in a second phase new variables that may or not interact with the factors established should be mixed with the old ones, so that the model could be enriched. Exploration of the multiple variables that could selectively affect sensory and decision indexes will allow for a future optimization of experimental designs. Thus, this model shows a very high heuristic potential and will surely be used in other applied contexts. In this sense, two directions for future research emerge from these findings. First, further research is needed to determine whether cutoff locations for changing priors and changing payoffs differ when a larger range of priors and payoffs are considered. Second, examining human decision criterion learning when base rates and payoffs are manipulated separately is needed to compare performance with cases in which base rates and payoffs are manipulated simultaneously. Base rates and payoffs vary widely in real-world situations, and in many cases, both differ simultaneously within the same discrimination problem. Despite this fact, few empirical studies of decision criterion learning under simultaneous base-rate / payoff conditions have been undertaken within the same experimental context (e.g., Healy & Kubovy, 1981; Maddox & Bohil, 2003). More work is clearly needed including several discriminability categories and conflicting conditions, in which the base rates and payoffs bias the taster toward different responses.

Taking apart cognitive and sensory components is central to uncovering small differences in sensory qualities and developing accurate models of perception. But applications of SDT are evident not only in basic science, but also in applied research and food industry. Specifically this proposal could be of special interest to the evaluation of training programs conducted to improve tasters' discriminative abilities and consumers' perceptions. Both applications are widely discussed in Section 5.4 , in which a review of several studies in which the psychophysical methods used and tested within the experimental work gathered above have already been applied to the field of olive oil tasting. Moreno-Fernández et al., (2012) conducted an experiment exploring a perceptual learning phenomenon with potential implications for tasters' training: The easy-to-hard effect (e.g., Scahill & Mackintosh, 2004). In the easy-to-hard effect, experiencing an easy discrimination makes subsequent learning of a difficult discrimination about stimuli that vary across the same dimension easier as compared to a group that it is only trained with the difficult discrimination from the start (e.g., Liu, Mercado, Church, & Orduña, 2008). Authors found that the easy-to-hard training schedule improves the ability for detecting an attribute, but it also produces a bias towards a more conservative strategy of response, suggesting that, when applied to tasters' training, this program should be combined with a corrective strategy, such as the use of specific instructions that may prevent trainees to be overly conservative. Results of this experiment point again towards the need to consider both, sensitivity improvements and the strategy used by participants, that is, the presence of responding biases on performance. Practical implications to optimize both the selection and training of tasters are immediate. The use of the dissociative method could allow for an improvement of the selection of potential candidates for tasters, as measures of their acuity may be obtained free of biases. In training procedures, both sensory and decision measurements could be useful to assess tasters' performance from a more complete perspective, introducing appropriate actions to improve the discrimination or to keep a neutral response strategy.

Dissociation between sensory and decision processes may also contribute to an optimization of the evaluation of the food quality, facilitating comparisons between experts' and regular consumers' evaluations. Many studies coincide on assuming the multiple determinants of choice behavior when it comes to select a food, including sensory qualities, and also some extrinsic and intrinsic factors that are interconnected in the consumers' evaluation of a product. For instance, there are many examples of changes in the perception of a product due to purely contextual or cognitive factors (e.g., Caporale, Policastro, Carlucci, & Monteleone, 2006; Siret & Issanchou, 2000; Stefani, Romano, & Cavicchi, 2006; Tuorila, Meiselman, Cardello, & Lesher, 1998). A precise methodology that allows for isolating the role of the different psychological variables on choice would help the analysts to sort out the role of the different factors within this complex situation. All this can be applied to the consumers' decision-making field. For instance, designing programs to analyze and change the subjective perception about food quality (O' Mahony & Hautus, 2008).

Finally, we should acknowledge that this line of research is just being born. The potential applications of dissociation methods based to sensory evaluation of food are yet to be fully determined. To finish, we raise a variety of open questions that need to be addressed in the future within this field of research. First, there is a need of more methodological research. Aspects as choice of organoleptic characteristics, type of task and other procedural issues should be based on the specific food chosen to be rated. Second, conceptual aspects of sensory evaluation must be considered. Most sensory evaluation work has had a practical orientation, and there is a lack of real theory that sustains the data. And finally, there is also a need for integration of basic sensory research, food science, and consumer's preferences dimensions with the goal of reaching a full understanding of how tasting processes work.

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7 CONCLUSIONS

1. The research reported in this dissertation shows the suitability of an SDT based approach to optimally describe the dynamics of human behavior on sensory evaluation of food. Within that approach, the *Double Dissociation Additive Test* shows to be a suitable methodological model for analyzing the perceptual abilities and cognitive factors involved in difficult discriminations of flavors, providing independent measurements of both sensory and decision processes.

2. Sensory and decision processes were separately evaluated and controlled within a laboratory setting that was arranged in such a way that reproduced the real life situation of organoleptic evaluations. Methods, materials, setting of the study, and even the sample of participants, were designed to approach the process of sensory evaluation within laboratory requirements, but keeping a high ecological validity.

3. From a methodological perspective, the obtained results endorse the need of using Non-parametric indexes and Robust type statistical analysis for tasting research, as this situation does not usually fulfill the assumptions of the parametric model, and commonly involves the presence of outliers in the data.

4. A sensory profile to the salty quality across a wide range of concentrations in novice tasters was obtained using the A' index. Not surprisingly, discriminability improved as salt concentration increased, and these results did not interact with factors affecting decision processes in the Double Dissociation Additive Test, supporting the independence between sensory and decision processes.

5. Decision processes were shown to play an important role in organoleptic evaluations. Factors that were expected to modify criterion placement induced neutral, conservative, and lenient response patterns. Signal-noise probabilities and payoffs matrices manipulations affected selectively B'_D criterion index, without altering sensitivity measures, supporting again SDT assumption of independence between sensory and decision processes.

6. A symmetrical induced criterion (positive-strict and negative-liberal) was found for probabilities and payoffs, as predicted by the SDT model. Contrarily to what it is expected from the SDT approach, the effect size of changing the probabilities and

payoffs differed. Similarly, criterion placement fell short from what it was expected from the optimal normative criterion computed through SDT. While the general result validates the use of the SDT approach to sensory evaluation, there are some constrains on the application of the model that should be taken into account.

7. Feedback plays a vital role in food analysis. Feedback had a net benefit in sensory performance, with no interaction with salt concentration. That is, the effect of feedback appears to be additive on the sensory process. Also, feedback allowed criterion to be set according to the stimuli probabilities presented: A neutral, positive or negative response pattern was obtained when induced bias was neutral, conservative or lenient, respectively, and continuous feedback was provided. However, when feedback was omitted, results revealed a pattern of bias that deviated from the one predicted by SDT. Participants' response did not reflect the actual probabilities distribution, and a reverse relationship between the induced bias and the decision index was found in some conditions.

8. The methodology developed and tested within this dissertation has started to shown its power as an analytic tool to be used in applied fields. This innovative approach allowed for obtaining a basic characterization of common performance in novice tasters. Obtained results are encouraging as they already have been applied to basic sensory research and olive oil tasting, suggesting that they may be similarly applied to related domains such as natural tasting situations, food science, and to the study of consumers' perceptions.

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8 RESUMEN EXTENDIDO

El análisis sensorial es una disciplina de importancia en la investigación y desarrollo de los alimentos, sobre todo en los procesos de control de calidad. Se ha definido como un método científico para evocar, medir, analizar e interpretar las respuestas a los alimentos o atributos percibidos a través de los sentidos (Stone y Sidel, 2004). Para la evaluación sensorial se utilizan métodos normados y rigurosos pero basados habitualmente en los desarrollos metodológicos de umbral. A un nivel elemental, la cata obedece a una situación psicofísica en la que la medición de propiedades se establece por referencia a las variaciones en un continuo físico, como la intensidad del atributo o su concentración, pero la situación de cata presenta una extraordinaria complejidad por la confluencia de procesos y factores fisiológicos, psicológicos, sociales o incluso culturales. Además, como estímulos complejos, las interacciones entre los componentes de un alimento dificultan la capacidad del catador para la discriminación. Aunque los jueces son entrenados para desarrollar sus habilidades organolépticas en condiciones de extrema dificultad, aprendiendo a identificar, medir y describir los atributos separadamente, el análisis resulta extraordinariamente complejo, incluso en condiciones de laboratorio, lo que propicia la aparición de sesgos y errores de diferente naturaleza. La evaluación sensorial por consiguiente presenta limitaciones derivadas de la propia naturaleza de los instrumentos de medición, de la complejidad de los alimentos y de la metodología empleada, basada en los métodos psicofísicos clásicos, que confunde la precisión sensorial con otros aspectos relacionados con la toma de decisiones del catador, como sus expectativas o motivaciones.

La serie experimental que presentamos a continuación, examina los procesos psicológicos implicados en la discriminación de sabores apoyándose en un modelo psicofísico contemporáneo: la Teoría de Detección de Señales (TDS). Desde el punto de vista metodológico, la TDS proporciona un paradigma de trabajo óptimo para el análisis de los procesos perceptivos y de aprendizaje implicados en la cata, ya que permite aislar los efectos puramente sensoriales de aquellos influidos por funciones superiores. El modelo proporciona además un marco general para describir las decisiones adoptadas en situaciones de incertidumbre o ambigüedad (Wickens, 2002). Como teoría multiestado, prescinde del concepto de umbral y asume que un mismo estímulo puede producir diferentes efectos sensoriales, caracterizando la experiencia perceptiva de manera variable. El supuesto central establece que tales juicios se encuentran mediatizados por dos grupos de factores independientes y caracteriza la respuesta de los observadores como el resultado de un *proceso sensorial* más uno *decisorio.* El proceso sensorial depende de la agudeza del observador y de las características físicas estimulares, como la intensidad del estímulo o concentración. Por su parte, el proceso decisorio depende de las características de la tarea o de aspectos subjetivos como las expectativas sobre la presentación estimular, las instrucciones o los incentivos asociados a las respuestas (Macmillan y Creelman, 2005; Swets, 1996; Wickens, 2002). Estas condiciones se pueden manipular experimentalmente para inducir cambios en el criterio de respuesta. Por ejemplo, un experimentador puede aumentar la frecuencia de un estímulo para inducir un criterio relajado de respuesta, es decir, un aumento en las respuestas afirmativas (Sí se presentó el estímulo), o por el contrario reducir proporcionalmente el número de ensayos con la presentación estimular, fomentando una estrategia conservadora (un incremento en las respuestas negativas). La TDS permite separar el proceso decisorio del puramente sensorial mediante la manipulación de ensayos con *Señal + Ruido (SN)* y *Ruido (N)*, el cómputo de las *Tasas de Aciertos* (probabilidad de responder Sí a un ensayo Señal) y de *Falsas Alarmas* (probabilidad de responder Sí a un ensayo de Ruido) y el cálculo de dos índices independientes. El perceptor responderá en función del criterio de decisión adoptado, lo que puede representarse como un punto localizado a lo largo de una dimensión, cuyos extremos son *relajado y estricto*. Si el valor de sensación experimentado rebasa ese criterio de decisión, el participante responderá "Sí"; y responderá con un "No" en caso contrario. En ambos casos es posible que el observador haya errado, ya que los efectos sensoriales de ambas distribuciones se superponen. La TDS permite también caracterizar el funcionamiento del criterio de respuesta óptimo ajustado de manera que se consigan objetivos comportamentales concretos. Este valor óptimo se deduce a partir del producto de dos factores: las expectativas y los incentivos. El primer factor corresponde al cociente de las probabilidades a priori o desproporción de ensayos de ruido respecto a los de señal. El factor de los incentivos relaciona las ganancias y costes asociados a los posibles resultados de la matriz de confusión, es decir a los diferentes tipos de aciertos o errores posibles (McNicol, 2005; Swets, Tunner & Birdsall, 1961; Wickens, 2002).

El objetivo general de esta tesis doctoral fue el análisis coordinado de los factores implicados en los procesos sensoriales y de toma de decisiones en situaciones de análisis sensorial, utilizando catadores noveles, como forma de mejorar la comprensión de los procesos perceptivos básicos, de aprendizaje y de la propia situación de cata. Como objetivo complementario, se examinó la adecuación para esta línea investigación de una nueva aproximación metodológica basada en la TDS, de la tarea experimental aplicada a la investigación con sabores, del uso de medidas no paramétricas para la cuantificación de los procesos implicados y del análisis estadístico basado en una aproximación robusta. Como objetivos específicos se establecieron los siguientes: (1) explorar la sensibilidad al sabor salado en un amplio rango de concentraciones describiendo la función psicofísica para esta cualidad, (2) evaluar tres factores propuestos por la TDS como determinantes de las fluctuaciones asociadas al cambio en el criterio de los observadores, concretamente, los incentivos contingentes a la ejecución, la densidad estimular y la retroalimentación de la respuesta. Con estas manipulaciones se predice la disociación procesual en situaciones de discriminación de sabores.

Con esos objetivos, comenzamos la serie experimental que se recoge en esta tesis doctoral. Diferentes factores que podían afectar los procesos sensorial y decisorio en el contexto de la evaluación de sabores se exploraron a través una aproximación metodológica novedosa: *el Modelo de Disociación Convergente Aditiva* (Ramos-Álvarez, Moreno-Fernández, Paredes-Olay, & Rosas et al., 2013), que permite aislar los efectos sobre la sensibilidad y el criterio de respuesta realizando una estimación directa de la dinámica de procesos, dado que las inferencias se efectúan de manera convergente para los índices que cuantifican a sendos procesos. La lógica consiste básicamente en localizar los procesos implicados en la realización de la tarea y a continuación seleccionar una variable independiente para cada proceso. Se introducen entonces los factores en el contexto de un diseño factorial completo, de forma que las variables se manipulan simultáneamente permitiendo comparar las medidas de los índices y observar su independencia o interacción. La ausencia de interacción nos permitiría confirmar la predicción de que los procesos psicológicos asociados a ambos factores discurren disociados, previa justificación teórica de tal independencia. Concretamente, se realizaron tres experimentos de evaluación sensorial para manipular la saliencia de la señal, la frecuencia de los estímulos, las matrices de pagos y la retroalimentación de la respuesta sobre la ejecución de los participantes. Se utilizó una tarea de detección simple con dos tipos estimulares: Señal + Ruido (SN) vs Ruido (N). La señal consistió en un compuesto binario salado /ácido en solución acuosa, toda vez que la preparación del ruido se hizo eliminando la sal en la misma solución acuosa. El uso de una combinación de sabores básicos permite reducir los atributos a los que se expone el catador ante estímulos más complejos, favoreciendo al mismo tiempo el control experimental y la validez ecológica. En cada experimento se incluyeron aproximadamente 15 participantes por condición experimental.

Siguiendo las prescripciones del modelo de detección, se registraron las respuestas Sí/No ante cada tipo estimular, para computar las Tasas de Aciertos y Falsas Alarmas, con el objetivo último de calcular los índices sensorial y decisorio. La elección de los índices apropiados depende del campo específico de aplicación. Las pruebas de evaluación sensorial y de manera más restrictiva las realizadas con sabores, exigen una extensión muy limitada de ensayos para evitar la saturación de los sentidos. Este requerimiento hace improbable el ajuste a los supuestos estadísticos en los que se fundamentan las medidas clásicas: el de normalidad de los datos y homogeneidad de varianzas, por lo que resulta más adecuada una alternativa no paramétrica basada en la estimación del área bajo la curva ROC. Concretamente optamos por las medidas A', desarrollada computacionalmente por Grier (1971), y B'_D, índice derivado por Donaldson (1992) a partir del índice B' propuesto inicialmente por Grier (1971). Estos desarrollos formales resultan menos restrictivos que los tradicionales y se han propuesto en tareas de cata de aceite (Paredes-Olay, Moreno-Fernández, Rosas, & Ramos-Álvarez, 2010), habiendo recibido apoyo, tanto metodológico como experimental, en los últimos años. En cuanto al análisis estadístico, se utilizó un análisis robusto de varianza basado en los desarrollos de Wilcox sobre las medias recortadas (Wilcox, 2005) por similares razones a las expuestas para la decisión de los índices de medición: el uso del análisis estadístico estándar de varianza resulta poco viable dada la limitada cantidad de puntos de datos prevista en una situación de cata (para su justificación véase Paredes-Olay et al., 2010).

El primer experimento de esta serie fue un estudio paramétrico de la sensibilidad humana al sabor salado. La intensidad del estímulo salino se manipuló a través de un rango de concentraciones de dificultad creciente (entre 0.07% y 0.75%). Dichos valores permiten una adecuada caracterización del rendimiento sensorial, desde una discriminabilidad en torno al azar hasta una ejecución máxima. Los valores intermedios se seleccionaron en un rango relativamente bajo de valores de concentración, dado el rápido crecimiento de la función psicofísica para esta cualidad. Los datos obtenidos se ajustaron óptimamente a una función Weibull. Este modelo describe adecuadamente las interacciones binarias entre los compuestos, toda vez que predice la tendencia de crecimiento mejor que otros modelos. Un hallazgo inesperado, fue la tendencia general hacia un criterio de respuesta relajada, independiente del nivel de concentración, a pesar de que la situación mantuvo en valores neutrales todas aquellas variables (i.e. expectativas, incentivos e instrucciones) que podrían afectar al mismo.

En el segundo experimento que da cuerpo a esta tesis se manipularon tres factores simultáneamente: la saliencia de los estímulos, la densidad estimular y la retroalimentación de la respuesta. Para la manipulación del proceso sensorial se utilizaron dos niveles de concentración salina: 0.09% y 0.75%. Por su parte, para inducir cambios en el criterio de respuesta, se manipuló la frecuencia de ensayos con señal a través de tres probabilidades a priori: 0.50, 0.16 y 0.84. En la condición neutral la distribución de estímulos fue uniforme mientras que en las condiciones estricta y relajada las probabilidades se calcularon para inducir un efecto simétrico (positivo y negativo) respectivamente. Por último, la retroalimentación de respuesta adoptó dos niveles: ensayo a ensayo o ausencia del mismo. Como se esperaba, la intensidad de la concentración únicamente afectó al índice sensorial, mejorando la discriminabilidad con el aumento de la concentración de sal. Al mismo tiempo, la presencia de retroalimentación mejoró el rendimiento sensorial de los participantes en comparación a la condición sin retroalimentación. Por su parte los cambios en la densidad estimular y la retroalimentación tuvieron un efecto directo sobre el criterio de respuesta. La presencia de retroalimentación permitió el ajuste del criterio a las probabilidades de presentación estimular según las tres condiciones de variaciones del criterio inducidas. El efecto observado en las condiciones extremas fue simétrico y de dirección contrapuesta. Sin embargo, en la condición sin retroalimentación se observó un patrón independiente de las tasas y el criterio de respuesta adoptó una tendencia opuesta a la inducida. Retroalimentación y tasas base interactuaron, sugiriendo que la retroalimentación de la respuesta modula el tipo de criterio inducido.

En el tercer se examinó el rendimiento de los catadores en un experimento con matrices de pagos. Para analizar la sensibilidad se manipuló la intensidad estimular según tres niveles de concentración de sal (0.07%, 0.1%, y 0.75%). Por su parte, para promover los cambios en el criterio de respuesta, se asociaron tres matrices de pagos al rendimiento de los participantes, que inducían patrones de respuesta neutral, conservador o relajado. Los valores de las matrices de pagos asimétricas se calcularon para inducir un efecto equivalente pero de signo contrario. Como se esperaba, el índice de sensibilidad solo se vio afectado por los cambios en la saliencia de los estímulos, mejorando la ejecución con el aumento de la concentración. En cuanto al criterio, se observaron las tres tendencias de respuesta conforme se había previsto: una tendencia de respuesta neutral con la matriz simétrica (iguales ganancias y pérdidas con ambas respuestas), un patrón conservador con la matriz que optimizaba el No como respuesta (menos pérdidas asociadas a los fallos y mayores ganancias asociadas a los rechazos correctos) y un patrón relajado con la matriz hacia el Sí (mayores ganancias para los aciertos y menos pérdidas con las Falsas Alarmas). Se observó asimismo un efecto simétrico pero de signo contrario para las condiciones estricta y relajada.

Los resultados de la serie experimental mostraron influencias selectivas sobre la dinámica de procesos apoyando la hipótesis de independencia sensorial-decisoria, el uso del test disociativo y la aproximación ecológica al análisis sensorial de sabores. En el estudio paramétrico conducido en el primer estudio, se encontró una cierta tendencia a relajar el criterio, un hallazgo inesperado dado que las variables decisorias fueron expresamente controladas. Sin embargo estos resultados vinieron a respaldar la necesidad de un análisis convergente entre procesos, dada la posibilidad de aparición de sesgos que podrían contaminar las medidas sensoriales. Atendiendo al proceso de adopción de decisiones, tanto las expectativas inducidas como los incentivos promovieron cambios significativos en el criterio de respuesta, aunque el efecto tuvo mayor alcance con la manipulación de la frecuencia de los estímulos. Los catadores en general parecen adaptar dinámicamente sus criterios de respuesta cuando las contingencias así lo requieren, aunque la retroalimentación juega un papel fundamental en la optimización del rendimiento. En definitiva, este trabajo pone de manifiesto que los procesos de decisión juegan un papel relevante en situaciones de cata. Desde el punto de vista de la investigación básica, el modelo de disociación propuesto puede ser enriquecido en el futuro con la exploración de nuevas variables y sus interacciones (p.e., la interacción entre las probabilidades y los incentivos), o aplicado al análisis de la sensibilidad a distintos compuestos de sabor u otras variables sensoriales (p.e., la temperatura de las muestras), utilizando el modelo Weibull, otra de las aportaciones relevantes que hemos desarrollado en esta tesis.

Finalmente, dedicamos un último capítulo a una serie de estudios que muestran el trasvase de la investigación básica al análisis sensorial de un alimento de gran trascendencia para el consumo: el aceite de oliva. La misma aproximación metodológica permite realizar aportaciones desde el punto de vista aplicado, como por ejemplo, para el análisis de la calidad de los aceites, la aceptación de alimentos funcionales, la selección y entrenamiento de catadores y en definitiva para la optimización de la evaluación sensorial. Estos y otros aspectos se tratan con detalle en este capítulo, que pretende mostrar la idoneidad de la aproximación metodológica y la viabilidad de su aplicación en contextos aplicados.

En la siguiente sección resumimos las principales conclusiones alcanzadas en el trabajo realizado en esta tesis doctoral.

8.1 CONCLUSIONES

1. La investigación presentada en esta tesis puso de manifiesto la adecuación de una aproximación basada en la TDS para describir de manera óptima la dinámica del comportamiento humano en la evaluación sensorial de los alimentos. Dentro de este enfoque, el *Test de Disociación Convergente Aditiva* mostró ser un modelo metodológico adecuado para analizar las capacidades perceptivas y los factores cognitivos implicados en las discriminaciones difíciles de sabores, proporcionando mediciones independientes de los procesos sensorial y decisorio.

2. Los procesos sensorial y decisorio fueron evaluados separadamente y controlados en un entorno de laboratorio dispuesto de tal forma que reproducía la situación real de la evaluación organoléptica. Los métodos, materiales, instalaciones, e incluso la muestra de participantes se diseñaron para abordar el proceso de evaluación sensorial dentro de los requerimientos propios del laboratorio, pero manteniendo una alta validez ecológica.

3. Desde un punto de vista metodológico, los resultados obtenidos avalan la necesidad de utilizar índices no paramétricos y un análisis estadístico de tipo robusto para la investigación en cata, ya que en esta situación no suelen cumplirse los supuestos del modelo paramétrico y es común la presencia de valores atípicos en los datos.

4. Se obtuvo un perfil sensorial de la cualidad salada a través de una amplia gama de concentraciones en catadores noveles, utilizando el índice A'. Como era de esperar, la discriminabilidad mejoró con el aumento de la concentración de sal. Estos resultados no interaccionan con factores que afectan a los procesos de decisión en el Test de Disociación Convergente Aditiva apoyando la independencia entre los procesos sensorial y decisorio.

5. Los procesos de decisión mostraron jugar un papel importante en las evaluaciones organolépticas. Los factores que se esperaba podían modificar el emplazamiento del criterio promovieron patrones de respuesta neutrales, conservadores y relajados. Las manipulaciones de las probabilidades y las matrices de pagos afectaron selectivamente al índice del criterio B'_{D}, sin alterar las medidas de sensibilidad, apoyando de nuevo la asunción de independencia entre los procesos sensorial y decisorio.

6. Conforme predice el modelo de la TDS, se encontró un criterio inducido simétrico (positivo-estricto y negativo-relajado) con la manipulación de las probabilidades y los pagos. Sin embargo, contrariamente a lo esperado, el tamaño del efecto para ambas manipulaciones fue diferente. Del mismo modo, el desplazamiento del criterio fue menor del esperado según el criterio normativo óptimo computado a partir de la TDS. Mientras que el resultado general valida el uso del enfoque de la TDS para la evaluación sensorial, hay algunas limitaciones en la aplicación del modelo que deben ser tenidas en cuenta.

7. El feedback juega un papel vital en el análisis de los alimentos. La retroalimentación de la respuesta tuvo un beneficio neto sobre el rendimiento sensorial sin interacción con la concentración de sal. Es decir, el efecto del feedback parece ser aditivo sobre el proceso sensorial. Además, el feedback permitió el ajuste del criterio conforme a las probabilidades de los estímulos presentadas. Se obtuvo un patrón de respuesta neutral, positivo o negativo cuando el sesgo inducido fue neutral, conservador o relajado respectivamente y se facilitó retroalimentación. Sin embargo, cuando se omitió el feedback, los resultados revelaron un patrón de sesgo diferente al que predice la TDS. La respuesta de los participantes no reflejó la distribución real de las probabilidades y en algunas condiciones se encontró una relación inversa entre el sesgo inducido y el índice de decisión.

8. La metodología desarrollada y probada dentro de esta tesis ha comenzado a mostrar su poder como una herramienta analítica para utilizarse en campos aplicados. Esta aproximación innovadora permitió obtener una caracterización básica del rendimiento común en catadores noveles. Los resultados obtenidos son alentadores dado que ya se han aplicado a la investigación sensorial básica y a la cata de aceite de oliva, lo que sugiere que podrían aplicarse de manera similar a otros dominios relacionados como situaciones de cata naturales, ciencia de los alimentos y al estudio de las percepciones de los consumidores.

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