Taste and obesity

by

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Understanding the links between taste perception and obesity would help authorities cope with obesity, which diminishes the health of human populations. This has been highlighted by a study of the impact of programs intended to educate obese adolescents about healthy diets (Pasquet *et al.*, 2007)[1]. We present and discuss the results of this study in this chapter.

In order to analyze the relationships between taste perceptions and obesity, we will (I) present the main aspects of taste perception: psychophysical (mostly nerve impulses) and psychocultural dimensions, (II) specifically describe responses to sugars and fats, (III) explore the ethnic variability of taste responses, (IV) assess psychocultural dimensions of taste perception which would promote a loss of weight, and (V) show how psychophysical taste perceptions could interfere with the weight loss program throughout the psychocultural dimension.

Psychophysical and psychocultural dimensions of taste perception

The psychophysical dimension of taste perception has been studied in several human populations, using the method of measuring recognition thresholds proposed by Simmen, Pasquet & Hladik, (2004)[2] for solutions of sugars, salts, and various natural and pure synthesized compounds. These types of taste thresholds have individual characteristics which, like color vision, vary little, if at all, either with age or the degree of satiety, as shown by Pasquet *et al.*, (2006)[3]. They appear genetically determined, varying among different individuals and populations (Hladik and Pasquet, 1999)[4].

The differing resemblances among 412 individuals in taste recognition thresholds for various substances is expressed as an additive tree (Figure 1) showing the distance between the thresholds for different substances based on the correlations among them. For instance, most people who are able to detect sucrose at low concentration are also able to detect fructose at low concentration, whereas detection thresholds for citric acid or tannin are not significantly correlated with that of sugars. Similarly, detection thresholds for quinine is correlated with that of tannins, but not at all with that of sugars, and is partly linked to that of sodium chloride (Hladik *et al.*, 2003)[5].

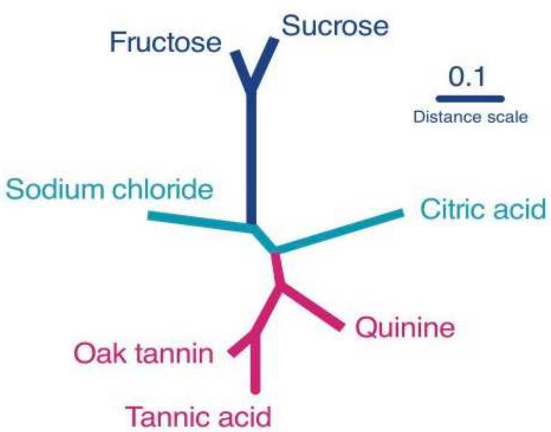

Figure 1. Additive tree showing the relationships between taste recognition thresholds for various compounds, constructed according to the pairwise Pearson correlation matrix calculated for the taste thresholds of 412 human adults.

These correlations reflect similarities and differences of initial signals in the taste nerve fibers arising from the taste buds of our tongue. Such a psychophysical dimension of taste perception has been explored in detail by the research team of Göran Hellekant at Wisconsin University (Hellekant and Danilova, 2004; Danilova and Hellekant, 2004)[6,7]. By recording directly the pulses on isolated fibers of the chorda tympani (the major taste nerve) of non human primates, the authors observed various responses according to various solutions used as stimuli and applied on the tongue (Figure 2). Each fiber generally responds to several stimuli, although some of them can be grouped as best responding to sugars or to bitter substances.

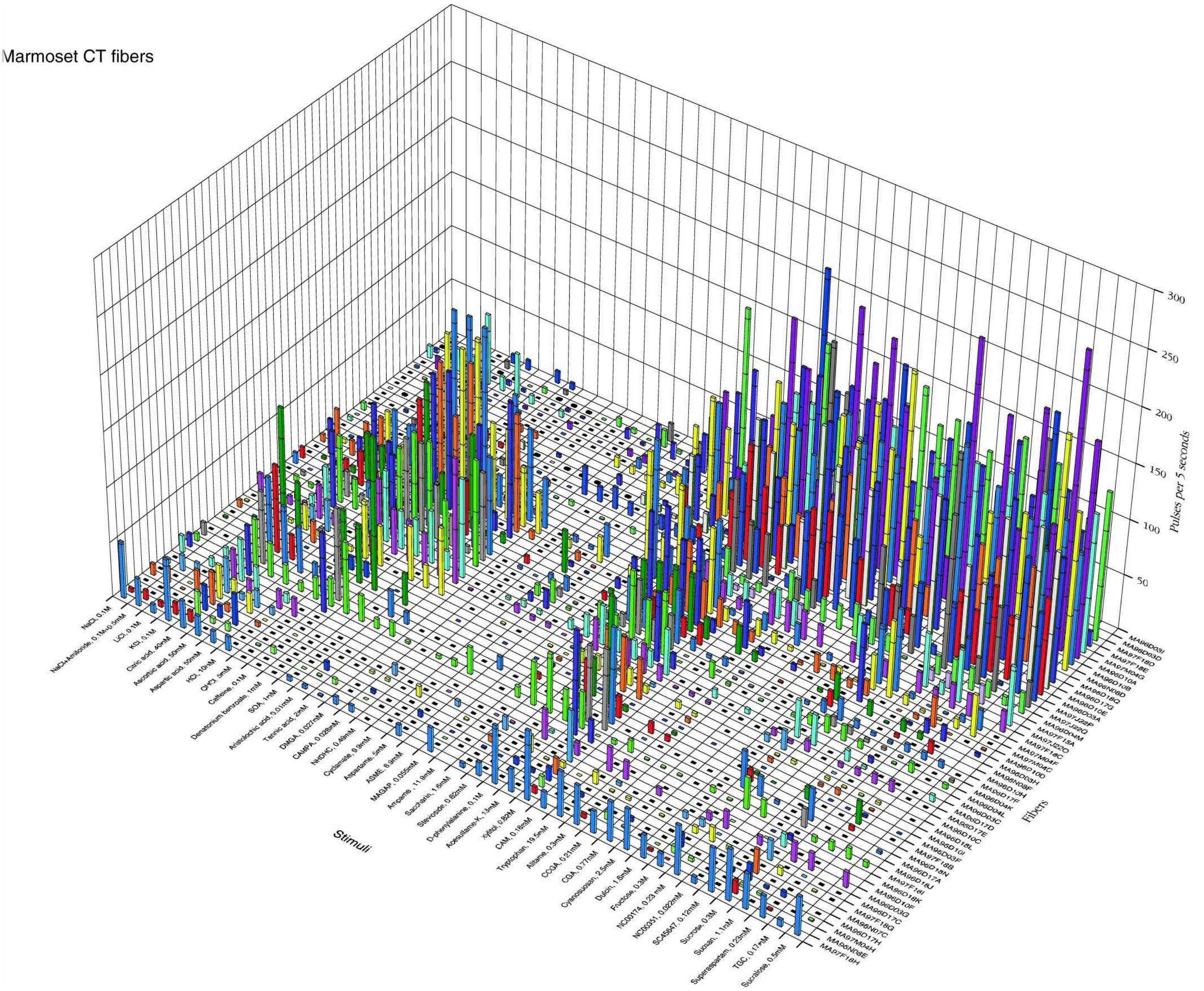

Figure 2. An overview of the responses of 49 chorda tympani taste fibers of the marmoset. The height of the column represents impulse frequency over the first 5 sec of stimulation. Absence of a mark shows that data are missing. The stimuli were arranged along the X axis in order of salt, sour, bitter and sweet. The fibers were arranged along the Y axis in groups: citric acid, quinine and sucrose best responding fibers (after Hellekant and Danilova, 2004)[6].

Interestingly, the study of taste recognition thresholds allowed the identification of some fiber categories that contribute differently to transmitting pulses triggered by stimuli of various compounds. These pulses progress along the taste nerve, and are relayed in the nucleus of the solitary tract and the thalamus, as Rolls (2004)[8] showed in a reconstructed schema (Figure 3) based on experiments on non-human primates.

The similarities and differences between responses of taste nerve fibers to various compounds, allowed the inference of trees for several non human primate species. The shapes of such trees are very similar to that of the tree expressing taste recognition correlations in humans. The example shown on Figure 2 for a limited number of taste nerve fibers shows that some categories of nerve fiber best respond to particular types of compounds (sugars, quinine, salts, acids...). However, most of the fibers may also respond to several other substances, hence the correlations comparable to those shown in Figure 1 for human recognition thresholds (Hladik *et al.*, 2003)[5].

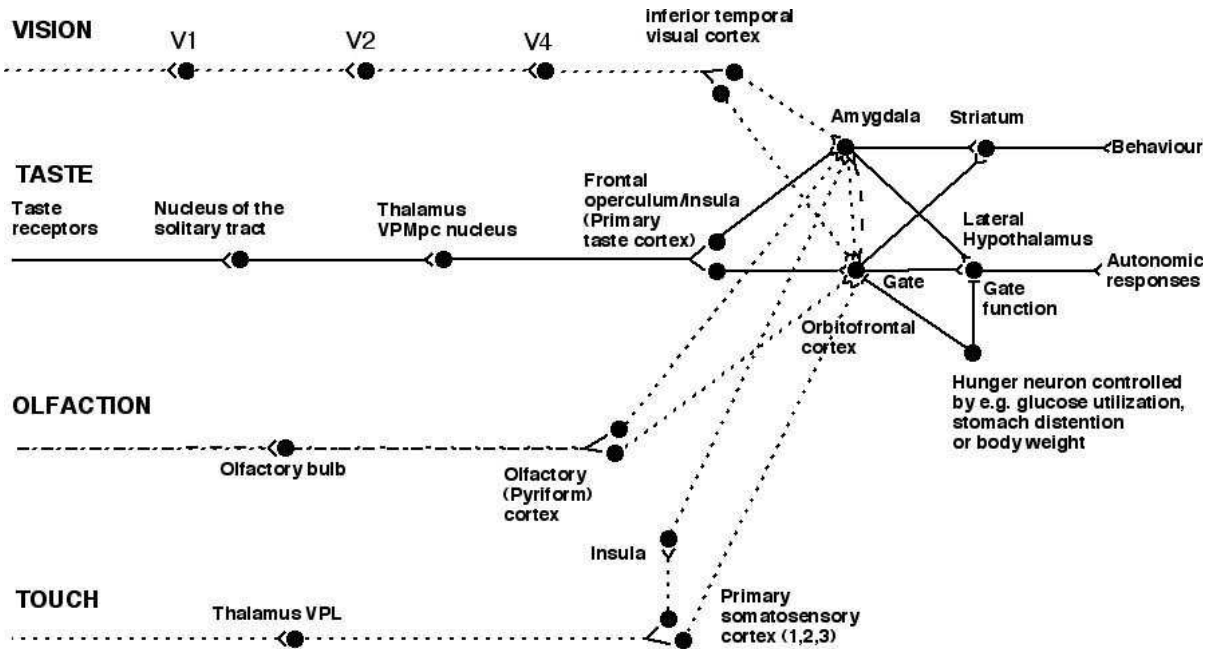

Figure 3. Schematic diagram of the taste and olfactory pathways in primates showing how they converge with each other and with visual pathways. The gate functions shown refer to the finding that the responses of taste neurons in the orbitofrontal cortex and the lateral hypothalamus are modulated by hunger. VPMpc - ventralposteromedial thalamic nucleus; V1, V2, V4 - visual cortical areas (after Rolls, 2004) [8].

In this schematic diagram (Figure 3), Rolls highlighted the convergence of pathways of sensory information (as pulses in nerve fibers), of taste, olfaction, touch and vision, toward the orbitofrontal cortex, where other types of fibers also converge. The association between responses to the four senses (e.g. color of a fruit + its odor + flesh texture feeling + sugary and acid taste recognition), that determines what is commonly called «taste», was clearly understood by Rolls[8] in terms of the various pathways inside the brain. The novel approach of Wedeen et al. (2012)[9], using diffusion magnetic resonance imaging, provides impressive images of the connective fibers inside the primate brain (including humans and non-human primates) and allows one to observe details of pathways. This approach complements the results obtained by Rolls for non-human primates, validating them for humans.

Other important fibers shown in Figure 3 also converge on the orbitofrontal cortex. These nerve fibers convey information about hunger and satiety (glycemia responses), as well as information from other areas of the brain implying unconscious and conscious perceptions of food such as liking and disliking. Accordingly, the convergence of all these nerve fibers in a unique area of the brain explains how and why food perception combines so many features, including cognitive aspects of taste. This last type of perception (the hedonistic dimension), depends on cultural and psychological factors and are generally measured in terms of psychocultural responses.

Perceptions of fat and sugars

Nevertheless, mechanisms and pathways of stimuli from the tongue to the orbitofrontal cortex involved in perceiving fat differ from those perceiving sugars and other soluble compounds. Rolls et al. (1999)[10] found a population of neurons in the orbitofrontal cortex of primates that responds when fat is in the mouth. However, the responses to fat involve the sense of touch in the mouth more than stimulation through the chorda tympani, the proper taste nerve from the tongue. Indeed, the fat-related responses of these neurons are produced at least in part by the texture of the food (sense of touch) rather than by chemical receptors sensitive to certain fatty chemical compounds (sense of taste). In addition, the texture channel, through which these fat sensitive neurons are activated, is separated from the viscosity sensitive channel (Verhagen et al., 2003)[11], which jointly determine neuronal responses for fats (Figure 4).

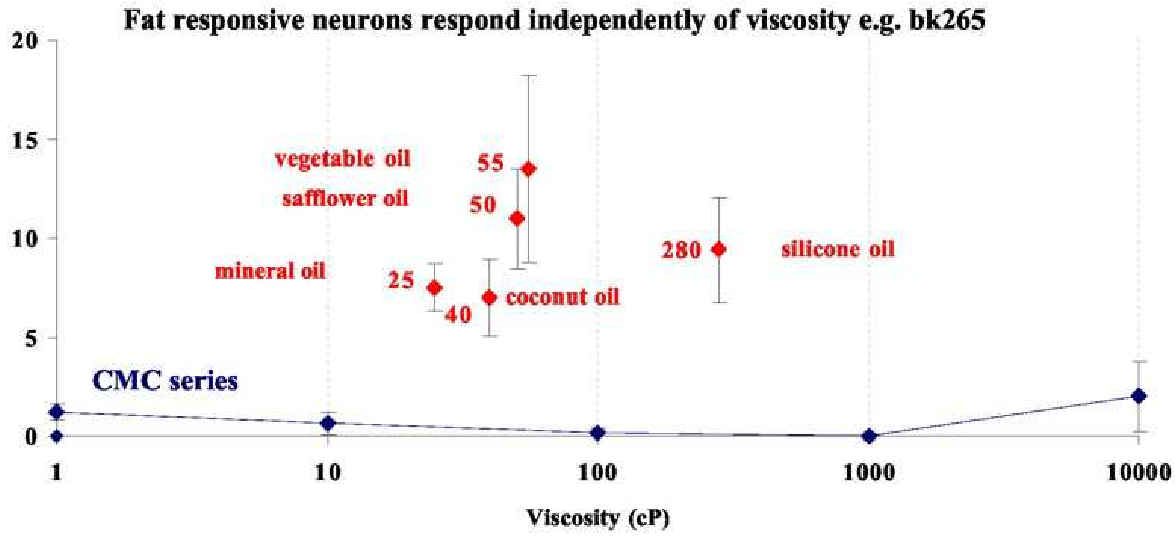

Figure 4. Responses of a neuron of the primate orbitofrontal cortex to the texture of fats in the mouth, independently of the viscosity .The cell (bk265) increased its firing rate to a range of fats and oils (the viscosity of which is shown in centipoises). The information that reaches this type of neuron is independent of a viscosity sensing channel. The neuron responded to the texture rather than the chemical structure of the fat in that it also responded to silicone oil ($(Si(CH_3)_2O)_n$) and paraffin (mineral) oil (hydrocarbon). Some of these neurons have taste inputs (after Rolls, Verhagen and Kadohisa, 2003)[12].

Perceptions related to fats or sugars are provoked by compounds that provide high energetic input. The abundance of these compounds in tropical forest fruit reflects the co-evolution of primates with angiosperms during the Cenozoic (Hladik et al., 2003)[13]. Plants provide high energy food for primates through their fruit's richness in sugars (and sometimes fat), and primates disperse seeds far enough to favor the reproduction of such plants. Thus, plants providing the sweetest fruits disperse their seeds most effectively, and primates with the best perception, and so recognition, of fats and sugars obtain the most energy. This coevolution between primates and the fruit they eat leads to a genetically determined aversion for bitter compounds and strong preference for sugars , as is expressed by the gusto-facial reflex identified by Steiner et al. (2001)[14].

The ability of primates to taste sugars and fats, their preference for them, and their aversion for bitter compounds, is shared by human beings. However, in today's world, with easier accessibility to energy-rich food in industrialized regions, this psychophysical trait can lead to obesity in humans (Pasquet et al., 2011)[15]. Moreover, the propensity for fats and sugars may have a psychocultural component (Cohen et al., 2013)[16]. For example, do obese persons have the greatest craving for fats and sugars? Craving can be considered a psychocultural response, even though the sensory responses (mostly involving the taste nerve) could remain a determining factor that can be studied through the ethnic variability responses of taste perception.

Ethnic variability, taste perceptions and obesity

Studies conducted in populations of developing countries, in regions where access to food has been difficult, document different perceptions, knowledge and practices that promote fatty diet and value plumpness and stoutness (Brown and Konner, 1987)[17]. For example, in the Serere and Wolof districts of Senegal, populations originally presenting low Body Mass Index levels (Maire et al., 1992)[18], developed culinary practices promoting consumption of peanut oil, fatty meat, and sweet drinks (De Garine, 1962; Cohen et al., 2012)[19,20], symbols of urban lifestyle.

Similarly, the Bamileke of Western Cameroon, historically recognized as a wealthy ethnic group even after their migration towards the town, have now supplemented their traditional caloric dishes, which contain much palm oil, with foods containing large amounts of sugar and fat (e.g. seven lumps of sugar in a cup of coffee, extremely fatty doughnuts) emphasizing their wealthy status to surrounding peoples (Cohen et al., 2013)[16]. Even after migrating to industrialized western countries, people from these areas that live in poor neighborhoods of large cities, maintain these food habits (Wluczka and Debska, 2006; Kulkarni, 2004)[21,22] although other foods are much more accessible. Other richer, better educated, people living in the centers of these cities adopt a far healthier diet (Sobal and Stunkard, 1989)[23].

These psychocultural preferences, adaptive where shortages are frequent, can coexist with genetically determined adaptive preferences such as high taste sensitivity to energy-rich compounds. However, taste recognition thresholds of populations living in various environments throughout the world (Figure 5) differ significantly from each other, even though those differences are less pronounced than the large variation among individuals.

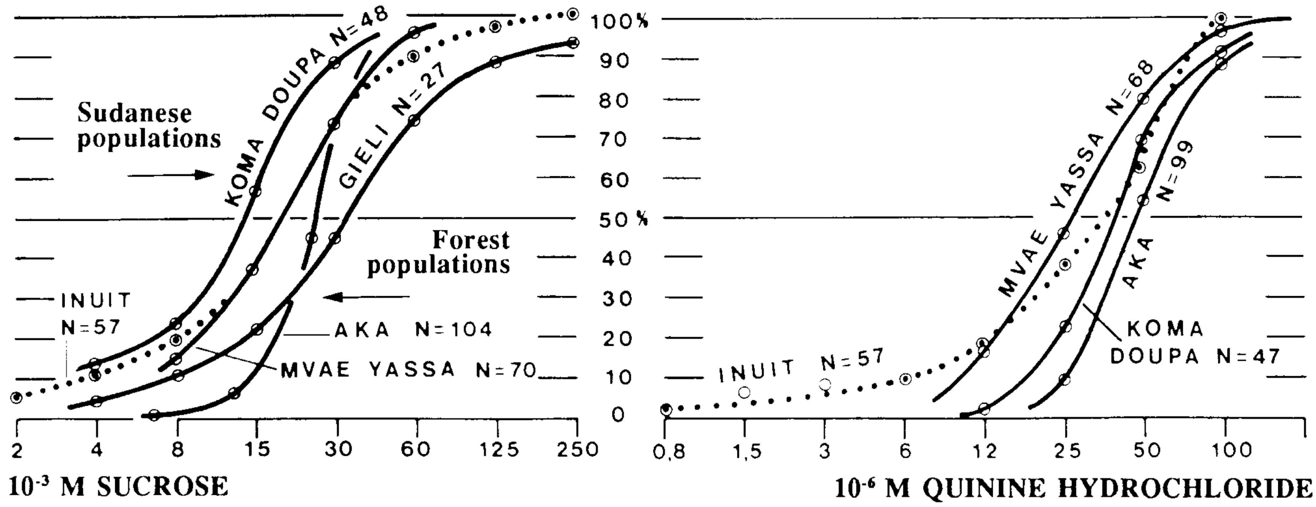

Figure 5. The curves show, for different populations, cumulative percentages of people able to discriminate the sweet taste of sucrose (left graph) and the bitter taste of quinine hydrochloride (right graph). Dilutions are indicated along the horizontal axis, respectively in millimoles (10^{-3} M) and in micromoles (10^{-6} M). Note that forest populations, especially Kola Pygmies (Gieli) have a lower sensitivity to sucrose than populations living in the Sudanese environment of northern Cameroon (Koma and Doupa). In contrast, the differences involving bitter substances are not significant (source: Hladik *et al.,* 1990)[24].

In these populations, the small but significant differences in perception of sucrose is explained by historical differences in their environments. In sudanese settings, the low biodiversity of plants entails a low sugar content in fruits, so Mvae and Yassa taste sugar content more accurately; whereas, in tropical forests, the biodiversity of fruits is far higher, so Aka Pygmies do not need to assess sugar content so accurately: during the Cenozoic, selective pressure for accurately recognizing sugars in fruits was presumably lower. In contrast, the selective pressure to avoid toxic bitter compounds such as quinine led to similarly accurate recognition thresholds for low concentrations of these compounds in different human populations.

Globally, the large variability of taste recognition thresholds in human beings does not imply significant inter-ethnic diversity of major genetic adaptations in food preferences, since this variability is mostly driven by various psychocultural factors.

Psychocultural dimensions of taste in relation to obesity

The measurement of taste perception in terms of hedonistic value (preferences and aversions) is based on tests which are a necessary complement of the evaluation of the psychosensory taste thresholds (shown above). Using similarly diluted solutions of various substances, such measurements of taste preferences and aversions, described in detail by Simmen, Pasquet and Hladik (2004)[2] can be made, either with solutions or with solid foods that are actually tasted, or by showing the picture of various foods and recording responses on a scale graduated from «the most delicious ever eaten» to «the worst ever tasted».

To complete the assessment of the psychocultural dimension, a major investigation of neophobia (the degree of aversion to a novel type of food) must be conducted. In this perspective, another scale for assessing neophobia was developed by Pliner (1994)[25]. This scale, called the Food Neophobia Scale (FNS), was translated into French by Rigal *et al.* (2006)[26] to obtain individual measurements of neophobia at the beginning and the end of nine-month educational sessions encouraging weight loss in massively obese adolescents. Each subject filled this 13 items/4 points (agree a lot, agree, disagree, disagree a lot, rated respectively from 1 to 4) scale questionnaire at the session's beginning and end. Individual FNS scores were calculated as a mean rating of the 13 questions arranged in terms of neophobia responses. In fact, neophobia is considered as a factor involved in disliking fruit and vegetables, which limits food choices largely to fast food types of carbohydrates, often leading to obesity (Monneuse *et al.*, 2004)[27].

Accordingly, the aim of the educational part of the weight loss session was to lead participants to reduce their neophobia levels in order to change their food habits.

In fact, food neophobia is one aspect of a general tendency to hyper-sensitivity, that also includes other psychocultural dimensions such as the extreme responses to sounds. In addition, this hyper-sensitivity of neophobic persons is correlated to a general hyper-sensitivity in taste perceptions (Monneuse *et al.*, 2004)[27], especially for PTC and PROP: phenylthiocarbamide and propylthiouracyl (the artificial chemicals for which a genetically determined sensitivity has been studied since the first discovery of Fox in 1931). Accordingly, the sensitivity to PTC and PROP can be used as indices of neophobia, as Sung Eun Choi (2014)[28] recently did. However, besides this genetic influence, knowledge of and education about foods also affect variation in neophobic responses.

Accordingly, the educational program of weight loss focused on acquiring a higher degree of acceptance of new foods, especially fruit and vegetables. The positive results obtained during the session (Monneuse et al. 2008)[29], with many obese adolescents partly or totally overcoming their obesity, depended on this focus.

Taste sensitivity and the weight loss program

Taste sensitivity, recognition taste thresholds — of solutions of fructose, sucrose, citric acid, sodium chloride, and PROP — was measured at the beginning of the weight loss session (Pasquet *et al.*, 2008)[1] in order to investigate relationships between those characteristics and possible changes of neophobia, which could accompany weight loss.

Among the adolescents in this weight loss program, we observed different levels of taste sensitivity reflecting the proportions generally observed in human populations by Simmen and Hladik (1993)[30]. Since it has been observed that the high sensitivity to PROP reflects a high, genetically determined, global sensitivity linked to neophobia, it is pertinent to use the various responses to PROP to identify hyper-sensitive subjects, and adapt the weight loss program to their peculiar needs.

In fact, when separating the subjects into three groups according to PROP sensitivity, low, medium and high (Figure 6), we observed that the variation of neophobia (measured by the FNS scale) during the weight reduction session was significant for tasters of low and medium concentrations, whereas there was no significant variation for third group that could perceive the lowest levels of PROP (high PROP perception).

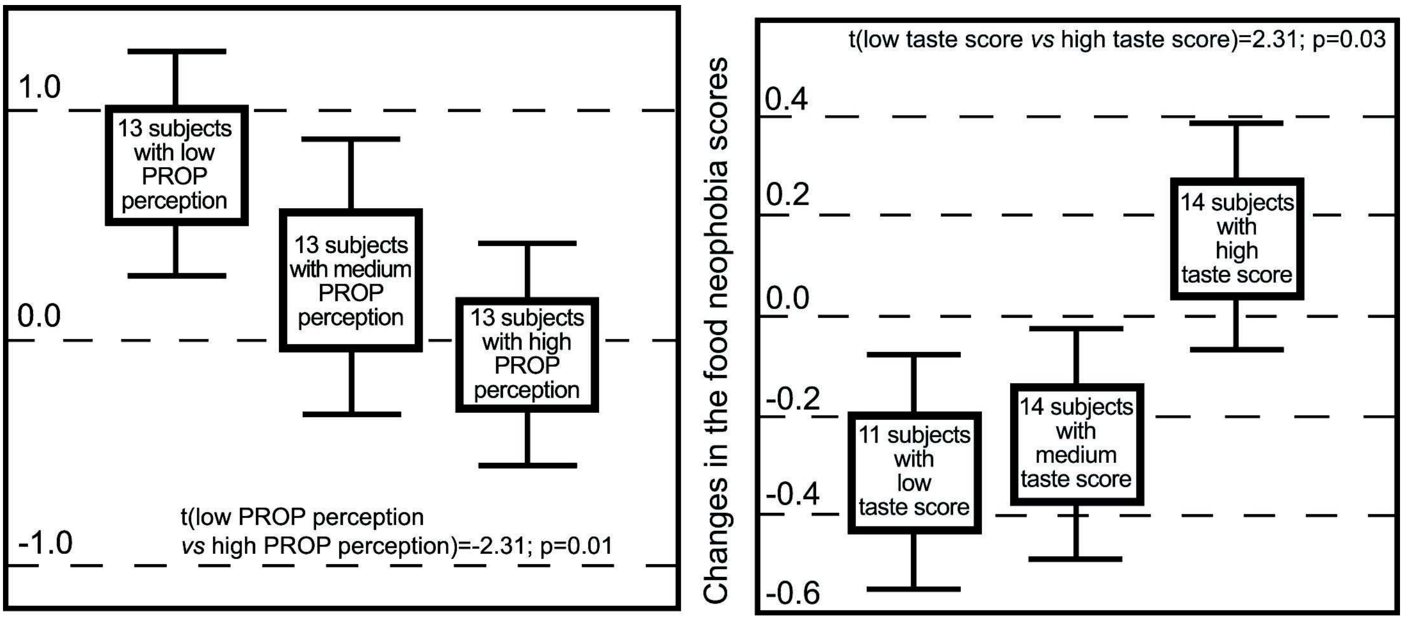

Figure 6. At the end of a nine months session of weight reduction, when grouping the subjects according to taste sensitivity, a significant difference was found in the variation of taste neophobia. A similar discrepancy appears either considering sensitivity to PROP (left graph) or according to a taste score (calculated from sensitivity to sugar, salt, and citric acid), with an absence of variation among the most sensitive subjects (after Monneuse *et al.*, 2008)[29].

In addition, when grouping the subjects according to other taste recognition thresholds (for sugars, citric acid and sodium chloride), a similar significant correlation with the variation of neophobia was observed (Figure 6). Since variation in neophobia during the weight loss session was significantly correlated to actual weight loss, we can conclude that subjects with a high taste sensitivity cannot easily overcome their neophobia or lose weight.

Finally, variation in neophobia level might depend largely on the psychocultural dimension of taste perception. However, the convergence of several signals (Figure 3) determining taste perception implies that the psychocultural dimension is not independent of the psychophysical dimension. Accordingly, a weight loss session must be adapted to take into consideration the subjects with the higher genetically determined taste sensitivity. Considering the present trend for reducing sugar in most food products, following the new guidelines of the WHO, which is discussed in the press (i.e. Sifferlin, 2014)[31], introducing information about added sugar on food containers, would improve the psychocultural perceived dimension of foods, and thus contribute to lower the risks of obesity, even for the most vulnerable subjects with genetically determined extreme taste sensitivity.

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