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Gender Differences in the Perception of Pungency

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Abstract

Males and females judged the intensity of the typical pungent stimulus CO_2, presented by nose and by mouth, employing two scaling procedures: magnitude estimation and magnitude matching. The two groups differed in their perception of CO_2 pungency only when it was judged in the nose. Perceived nasal pungency grew as a power function of CO_2 concentration, with an exponent of 2.2 for females and 1.6 for males, and the magnitude matching test showed that, relative to their perception of sucrose sweetness, females perceived pungency more intense throughout the range studied. Perceived buccal pungency grew for both groups as the 1.1 power of CO_2 concentration, and the magnitude matching test, employing again sweetness as the reference modality, revealed no intensity differences in the perception of buccal pungency between the genders. It is suggested that the susceptibility of the nasal environment to hormonal and neural influences may account for the differences in perceived pungency between males and females.

Keywords: *Common Chemical Sense, Nasal Irritation, Buccal Irritation, Pungency and Gender, Carbon Dioxide, Trigeminal Nerve, Pungency Psychophysical Scaling*

Introduction

The common chemical sense (CCS) is a sensory modality, within the chemical senses, different from the classical modalities of olfaction and taste. The free nerve endings of the CCS mediate sensations that can be generically described as pungent. This term is used in a broad sense, and accounts for sensations such as stinging, cooling, irritating, burning, prickling, tingling, etc., which are mediated mainly by Cranial Nerve V (the trigeminal nerve).

A peculiar characteristic of the CCS is that its receptors are more widely distributed than the olfactory and gustatory ones, since they involve the conjunctiva as well as the entire nasal and oral mucosas.

A number of investigations compared the psychophysics of the CCS and the olfactory sense [4,5], as well as their interactions [3, 6, 30, 31]. Some of these papers discuss the similarities and differences between the two chemical senses in terms of their "in vivo" functioning in human beings, adding information to other physiological, anatomical and histological studies [1, 7, 21, 22, 23, 24, 34]. Unfortunately there are no such comparative psychophysical studies between the CCS and the gustatory sense.

A couple of previous studies [10,14] showed that cigarette smokers of both sexes were less sensitive than a comparable population of nonsmokers to the stinging sensation evoked in the nose by CO_2. This difference was seen both physiologically, in the threshold concentration of CO_2 necessary to elicit a reflex, transitory interruption of inhalation, and psychophysically, in magnitude matching.

García-Medina and Cain [16] found that males were less sensitive than females to the aforementioned interruption of inhalation, and Dunn, Cometto-Muñiz and Cain [14] confirmed these results and extended them to male and female smokers.

In the present study, we compare the perception of nasal and buccal pungency in male and female nonsmokers, in terms of two parameters: rate of growth of perceived pungency and comparative intensity of the sensation in both groups. For the latter, we decided to use the psychophysical method of magnitude matching [27]. With this procedure, participants judge stimuli of more than one sensory morality on a *common scale of perceived magnitude.* In the present case, our interest lies in judgments of pungency and judgments of sweetness. We anticipate no difference in sweetness perception between males and females, but we anticipate a possible difference in pungency perception. Hence, sweetness is our reference modality and pungency our test modality.

The election of the sweetness of sucrose as the reference modality is based on results of previous investigations which showed no differences between males and females in the perception of this stimulus [8, 12, 18, 26, 35].

Materials

Various concentrations of CO_2 in either air or water served as the pungent stimulus. In the nasal experiment, an air dilution olfactometer was employed to deliver concentrations of CO_2 to one nostril. The CO_2 (99.5% purity) cylinder was provided by La Oxígena S.A.C.I., Buenos Aires, Argentina (branch of L'Air Liquide, France). Breathing grade compressed air was used to dilute the CO_2 to appropriate concentrations. The final flowrate at each level of CO_2 always equalled 4 l/min.

In the buccal pungency experiment, an oversaturated solution of CO_2 in distilled and deionized water was diluted to different percentages to obtain the various pungency levels. The undiluted, oversaturated solution was prepared by filling a two liter aluminium bottle containing distilled and deionized water with a constant excess pressure of gaseous CO_2 until 4.7 volumes of carbonation were reached.

Commercial grade sucrose served as the comparison stimulus in the magnitude-matching tests for nasal and buccal pungency.

Stimuli

In the nasal pungency experiment, the concentrations of CO_2 in air were (%v/v): 21, 27, 35, 46 and 60. For the magnitude-matching test, these same levels of CO_2 were used, as were four concentrations of sucrose (%w/v): 3, 8, 20 and 50, (corresponding to 0.0876, 0.2337, 0.5843 and 1.4607 Molar, respectively).

In the buccal pungency experiment, the percentages of an oversaturated solution of CO_2 in distilled and deionized water were (%v/v): 20, 40, 60, 80 and 100. In the magnitude-matching test, these stimuli and the four concentrations of sucrose were used.

Method

Subjects

Nasal pungency. The experiment comprised two tests (see *Procedure).* In the first one, 22 males (average age ± S.D.: 22.6 ± 4.3 years) and 22 females (average age ± S.D.: 21.2 ± 3.2 years) participated. In the second test,
16 males (average age_+ S.D.: 23.4 ± 4.7 years) and 16 females (average age ± S.D.: 21.7 ± 3.5 years), all of whom took part in the first test, participated.

Buccal pungency. In the first test, 15 males (average age ± S.D.: 22.7 ± 3.9

years) and 15 females (average age ± S.D.: 21.9 ± 3.0 years) participated. In the second test, 14 males (average age_+ S.D.: 23.1 ± 4.8 years) and 14 females (average age ± S.D.: 21.7 ± 3.9 years), all of whom took part in the first test, participated.

All subjects were nonsmokers.

There were 25 participants (14 males and 11 females) common to both experiments (nasal and buccal).

Procedure

Nasal pungency. In the first test, subjects used the method of magnitude estimation without a prescribed modulus [28,29]. Participants were instructed to make numerical estimations of the perceived pungency of various concentrations of CO_2 presented in random order, using the first stimulus as the standard for comparison. Subjects chose one nostril (the more sensitive, or, if both were equally sensitive, the more comfortable to work with) and used that nostril throughout the experiment. They had to inhale on each trial for 2 to 3 sec (duration controlled by the experimenter), maintaining the inhalation (or sniffing) effort as constant as possible through the different trials. Each subject made four estimates per stimulus level.

The second test comprised the presentation of various levels of two types of stimuli: the pungent one: CO_2, tested in the nose, and a sweet one: sucrose. Subjects had to estimate numerically the perceived intensity of the sensation regardless of its quality, on a common scale of perceived magnitude [27]. Participants were told that the range from the lowest to the highest stimuli might be different in the two modalities. Subjects could assign to the first stimulus of the session any number deemed appropriate. Thereafter, they assigned numbers reflecting the perceived magnitude. The type of stimulus (sucrose or CO_2) varied irregularly from trial to trial. The procedure for the evaluation of nasal pungency was identical to the one used in the first session. As for the oral evaluation of sweetness, participants had to rinse their mouths with distilled and deionized water before starting the experiment and after each oral stimulus. On the trials involving sucrose, 5 ml of the solution were sipped, kept for 3 to 4 sec in the oral cavity, then expectorated. Each subject made four estimates per stimulus level.

Buccal pungency. In the first test, participants employed the method of magnitude estimation to judge the perceived pungency of various dilutions of an oversaturated solution of CO_2 in distilled and deionized water. They rinsed their mouths with water before starting the experiment and after each stimulus. Subjects had to sip the 25 ml stimulus, keep it in the mouth for 5 sec, then expectorate. The cups used to present the stimuli contained the appropriate amount of water for each dilution, and the corresponding volume of the oversaturated CO_2 solution was added a few seconds before the subject

sampled the stimulus. Each subject made four estimates per stimulus level. The second test consisted of a magnitude-matching experiment, identical to the one described for nasal pungency, except that, in this case, the pungent stimuli were taken in the mouth.

Results

Nasal Pungency

Magnitude estimation. Figure 1 shows the stimulus-response (psychophysical) functions for the nasal pungency of CO_2 in males and females. The results can be reasonably described by power functions though they show a characteristic upward concavity at low concentrations [6,10]. The exponent (slope in the log-log coordinates of Fig. 1) equals a value of 1.55 for males, and 2.22 for females.

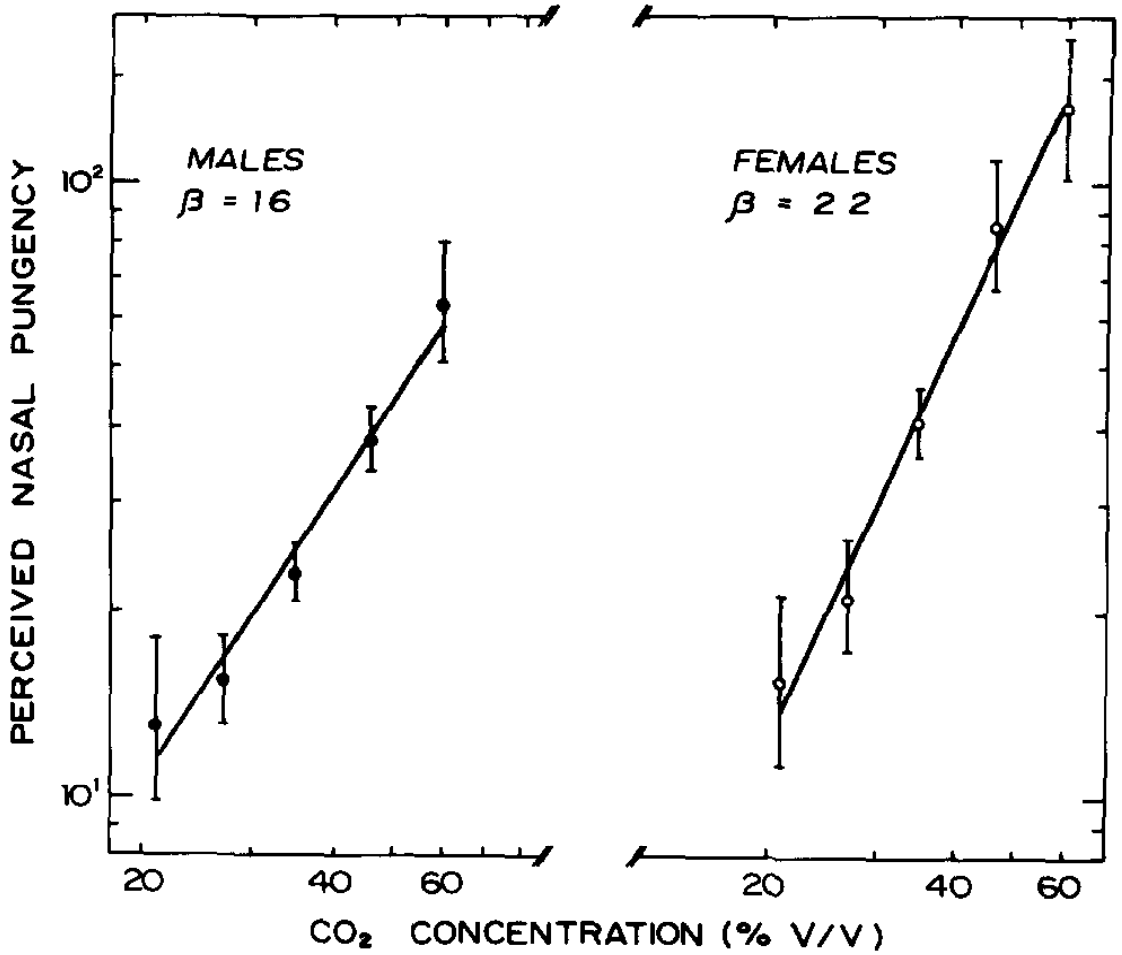

Figure 1. Psychophysical functions for CO_2 *nasal* pungency in males (filled circles) and females (empty circles). Each point represents the geometric mean of 88 estimates made by 22 subjects. The bars indicate standard errors. The slopes are shown. The relative position of the functions along the ordinate is arbitrary. Coordinates are logarithmic.

Magnitude-matching. This method was used to test possible differences in the perceived level of pungency between the two groups in the study. As mentioned in the Introduction, the technique requires the use of a reference or standard modality (here, sweetness), against which to compare numerical judgments of the target modality (here, pungency).

Figure 2 depicts the results of the magnitude-matching between nasal pungency and sweetness. The left part of the figure shows the raw data obtained. These functions have no significance in terms of relative perceived magnitude since participants could choose any number they wished at the onset of the scaling. For this reason the data were normalized in the following way: a factor was found which brought the average value of sweetness (across concentrations) for females into coincidence with the average value for males. Then, that same factor was applied to the pungency functions. This procedure allows a meaningful and immediate visual comparison between the genders (Fig. 2).

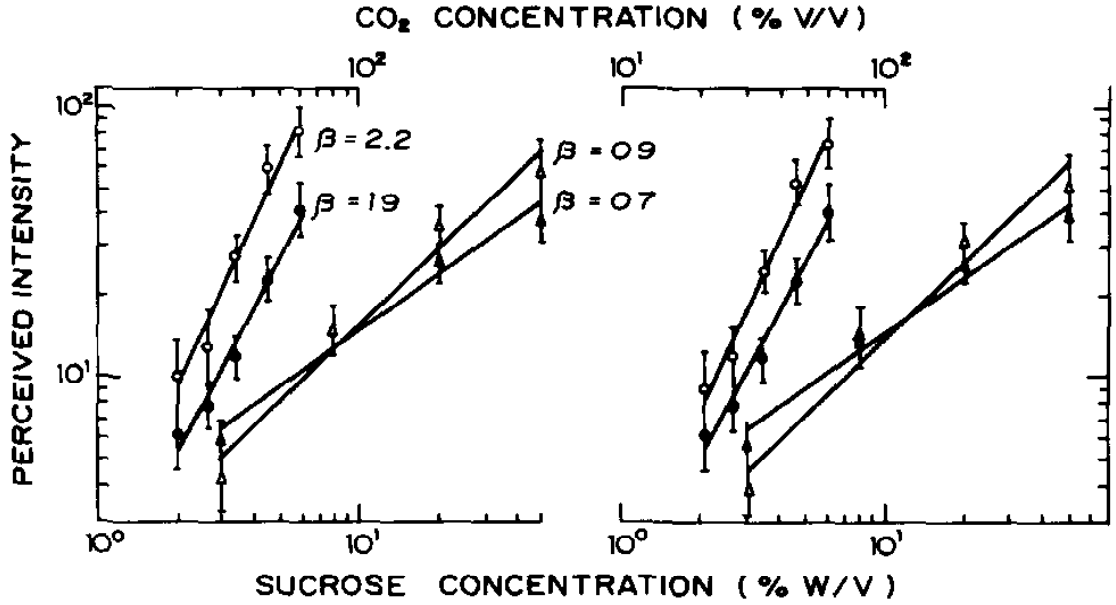

Figure 2. *Left part.* Psychophysical functions obtained by magnitude matching of CO_2 *nasal* pungency (circles) and sucrose sweetness (triangles) in males (filled symbols) and females (empty symbols). Comparison between genders is not appropriate without normalization since each subject was allowed to assign any number deemed appropriate to the first stimulus of the session. *Right part.* This portion shows the same functions as in the left part for males. The functions for females were multiplied by a factor that brought into coincidence the judgments of sweetness intensity from females with those of males. This normalization was performed under the assumption of no intensity differences in sweetness perception by males and females. The normalization was performed to allow a meaningful comparison of pungency intensity along the ordinate. In both parts of the figure, each symbol represents the geometric mean of 64 estimates made by 16 subjects, and the bars indicate standard errors. Coordinates are logarithmic.

The results indicate that, relative to perception of sweetness, males perceived nasally presented CO_2 less pungent than females. The difference is statistically significant, $F(1,30)=49.1$, $p<0.001$ for gender.

In terms of rate of growth, the nasal pungency function for females again showed a higher exponent (2.17) than that for males (1.87), although this difference is less distinct than that seen in the magnitude estimation test, mainly because of a steepening in the slope for males (from 1.55 to 1.87). It seems worthwhile to mention that females also gave a somewhat higher exponent than males for the sweetness function (0.94 vs. 0.68), where the values were expected to be the same.

Buccal Pungency

Magnitude estimation. The psychophysical functions for the buccal pungency of CO_2 appear in Fig. 3. As in Fig. 1, the results can be described by power functions, but, in contrast with what was found there for nasal pungency, here, for buccal pungency, the slope is almost the same for males and females (1.11 and 1.15, respectively). Note, also, that buccal pungency grows at a lower rate than nasal pungency (see Fig. 1).

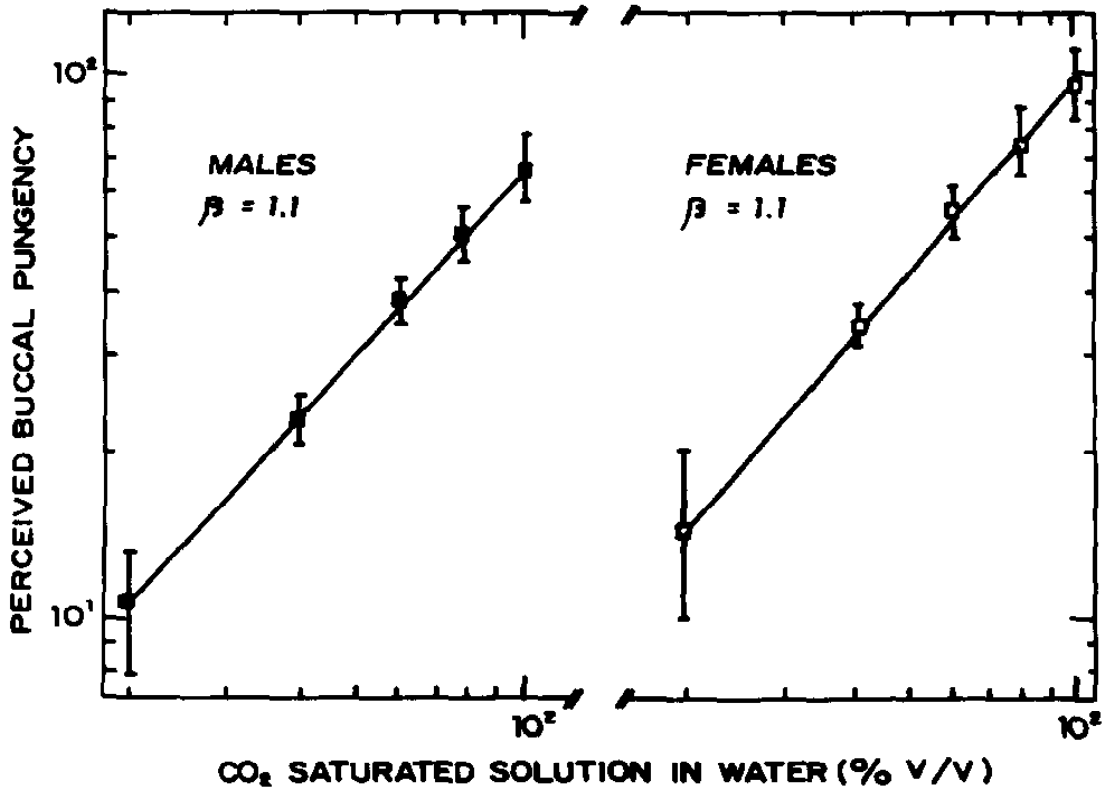

Figure 3. Psychophysical functions for CO_2 *buccal* pungency in males (filled squares) and females (empty squares). Each point represents the geometric mean of 60 estimates made by 15 subjects. The bars indicate standard errors. The slopes are

shown. The relative position of the functions along the ordinate is arbitrary. Coordinates are logarithmic.

Magnitude matching. Figure 4 presents the results of the magnitude-matching between buccal pungency and sweetness. The left side of the figure depicts the raw values obtained. As mentioned above, these raw values have no significance in terms of relative perceived intensity between gender since subjects were free to start with any number deemed appropriate for the first stimulus.

The functions were normalized as explained in the magnitude-matching test of the nasal pungency experiment and the results appear in the right side of Fig. 4. The outcome clearly shows that, unlike nasal pungency, buccal pungency is perceived in a very similar way between males and females when using sweetness as the standard modality to compare intensity of sensations (the difference is not significant).

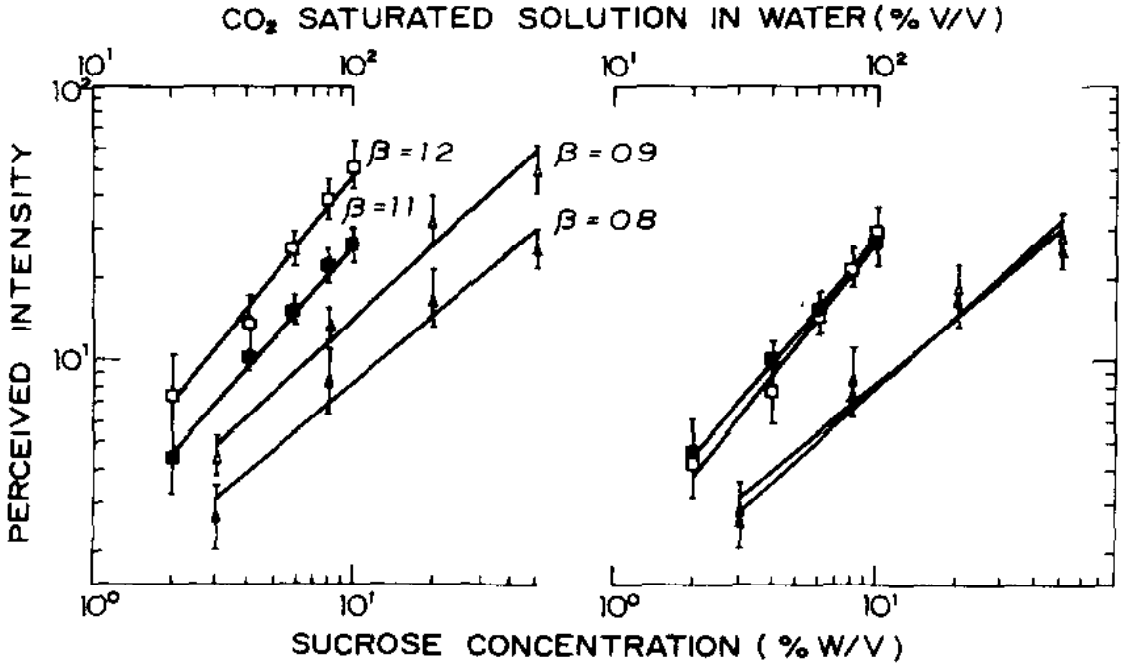

Figure 4. *Left part.* Psychophysical functions obtained by magnitude matching of CO_2 *buccal* pungency (squares) and sucrose sweetness (triangles) in males (filled symbols) and females (empty symbols). Comparison between genders is not appropriate without normalization since each subject was allowed to assign any number deemed appropriate to the first stimulus of the session. *Right part.* This portion shows the same functions as in the left for males. The functions for females were multiplied by a factor that brought into coincidence the judgments of sweetness intensity from females with those of males. This normalization was performed under the assumption of no intensity differences in sweetness perception by males and females. The normalization allowed meaningful comparison of relative pungency between genders. In both parts of the figure, each symbol represents the geometric mean of 56 estimates made by 14 subjects, and the bars indicate the standard errors. Coordinates are logarithmic.

In relation to the exponents (or slopes when plotting in log-log coordinates) for buccal pungency in males and females, the values obtained confirm the outcome of the magnitude estimation test, showing no difference between the two groups (1.13 for males and 1.22 for females). Furthermore, the absolute values of the exponents lie very close to those obtained by magnitude estimation. These similarities encouraged us to take an average of the exponent for buccal pungency evoked by CO_2, including all subjects and both psychophysical methods. It equals 1.15.

For the sweetness functions, the average exponent of 0.84 obtained in this test (0.80 for males and 0.88 for females), agrees with the value of 0.81 obtained in the equivalent magnitude-matching test between sweetness and nasal pungency (where the exponents for sweetness by gender were 0.68 for males and 0.94 for females).

Discussion

A previous study [16] explored spatial integration of common chemical sensations across the two nasal cavities and in the course of that investigation found that females were more sensitive than males to a reflex, transitory interruption of inhalation provoked by the irritation of CO_2. Another investigation [14] confirmed this gender difference and extended it to male and female smokers. It seemed an interesting possibility to test whether this physiological difference could be confirmed psychophysically at the suprathreshold level, particularly since the reflex data have fallen into register with psychophysical data in a couple of other studies [10,11]. Since our interest was centered in gender differences, we decided to test only nonsmokers, avoiding any blurring of the outcome resulting from different smoking patterns in the group of subjects.

The magnitude estimation procedure used for both nasal and buccal pungency addressed the question of whether the rate of growth of the psychophysical functions was the same for both sexes. Figures 1 and 3 reveal that the results are different depending on the stimulation site. When CO_2 was tested in the nose, females showed a higher exponent than males (2.22 vs. 1.55), whereas when it was tested in the mouth, the exponents were almost the same (1.11 for males and 1.15 for females).

It is worthwhile noting the very high exponents obtained for CO_2 nasal pungency in both groups, since generally, exponents for odorivectors are typically less than 1.0 [2, 9, 25]. Cain [3] showed that the presence of a common chemical (trigeminal) attribute in an odorant increases the rate of growth of its psychophysical function. All these data might support the notion that, at least perceptually, CO_2 could be considered an almost pure common chemical sense stimulant [6].

Although chemical stimuli delivered to the mouth (tastants) have generally higher exponents than those delivered to the nose (odorants) [9] this was not the case for CO_2, since buccal pungency grew less rapidly than nasal pungency. Nevertheless, the exponent for CO_2 buccal pungency may be considered within the range of values obtained for tastants with the sip and spit procedure [15,20]. It would be of interest to test other typically pungent stimuli in the mouth, and compare the exponents obtained with the ones reported here.

Results of the magnitude-matching experiments revealed that females actually perceived the pungency of CO_2 more intense than males only when tested in the nose, not when tested in the mouth (Figs. 2 and 4).

It is interesting to note that the change in psychophysical procedure from magnitude estimation to magnitude matching altered the nasal pungency exponent for males but not for females, although this alteration was not drastic. The exponents for buccal pungency were not altered by the procedural change for either males or females. Magnitude estimation concerns itself exclusively with the rate of growth of one sensory modality, while magnitude matching, besides the rate of growth, deals mainly with the relative intensities of stimuli from various sensory modalities, judged on a common scale of perceived magnitude. Thus, the higher complexity of the magnitude matching procedure, and its main emphasis on relative intensities of stimuli from different modalities, rather than on rate of growth of one modality, suggest that exponents obtained by the two methods, for the same modality and subjects, do not need to be exactly coincident.

We can, then, state as a general conclusion that males and females differ in their perception of the intensity of the typically pungent stimulus CO_2 whenever it is presented to the nose, whereas such difference does not show when it is presented by mouth.

It would be of great interest to continue studying the comparative behavior of males and females regarding the perception of the intensity of other pungent substances, in order to see if the observed results can be generalized. Care should be taken to eliminate, or at least minimize, the olfactory component that the majority of irritants have. In this sense, CO_2 seemed a very appropriate stimulus, since, perceptually, its irritating pungency is virtually devoid of odor [6].

Up to the moment, we simply do not know why females are more sensitive to nasal pungency. Results found in the literature about sex differences in odor sensitivity are conflicting, and they deal almost exclusively with threshold measurements. Some authors found no differences, while others found females to be more sensitive (see [19]). The reasons for the latter are not clear, but they could have a hormonal basis (see [19]). On the other hand, there have been reports showing that sex differences exist even before puberty, at least for some

odors, making a strict gonadal hormone explanation of these differences unlikely [19,33].

At this point, it seems worthwhile mentioning that all those data involve testing of the olfactory sense mainly, more so when working at the threshold or near threshold levels of the stimuli employed, and it has previously been suggested that the free nerve endings that mediate common chemical sensitivity might have a different pharmacological reactivity than olfactory receptors [10].

Various investigations have found that olfactory sensitivity in women varies through their menstrual cycle [13,17], though the reasons are obscure. Such fluctuations in olfactory sensitivity seem to be present even in women taking oral contraceptives which attenuate the circulating gonadal hormone levels [13]. It would be of interest to study whether irritation sensitivity varies through the cycle. Autoradiographic studies of the trigeminal pathway of rodents demonstrated the presence of various estrogen target cells, concluding that "estrogen-related modulation of trigeminal perception may occur at different anatomical levels" [32]. Finally, why should this difference in pungency sensitivity reveal itself when stimulating the nose and not when stimulating the mouth? At this point we can only speculate. It is generally true that women have smaller noses than men; also, small noses may well absorb more molecules per unit area than large noses. If saturation of free nerve endings receptors is not complete, as it might have been the case here, this would lead to relatively more stimulation in women. We have no reason to suspect anatomical or morphological differences between the free nerve endings present in the mouth as compared to those present in the nose. We are inclined to think that the difference might lay in factors affecting the nasal environment (e.g., mucus quantity and composition, epithelial engorgement) which might be more susceptible of hormonal and neural influences than the oral environment.

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