

## Evidence of regional differences in chlorine perception by consumers: sensitivity differences or habituation?

P. Piriou, R. Devesa, S. Puget, T. Thomas-Danguin and F. Zraick

### ABSTRACT

Chlorinous flavors are a leading cause of customers' dissatisfaction with drinking water. Potential differences in chlorine perception were investigated by conducting sensory testing experiments in France and Spain to assess consumers' sensory sensitivity (chlorine flavor detection threshold and supra-threshold intensity) as well as their liking of and acceptability for chlorinated solutions. In both countries, two groups of panelists were constituted based on their water drinking habits (tap vs. bottled water). Chlorine flavor detection threshold was found to vary depending on countries (0.17 mg/L Cl<sub>2</sub> in France and 0.56 mg/L Cl<sub>2</sub> in Spain). Taking into account that mean flavor detection thresholds were found in agreement with chlorine residuals delivered at tap, it is likely that habituation may explain sensitivity differences between countries. This hypothesis is supported by results showing no significant sensitivity difference at detection threshold levels, but significant differences between tap water and bottled water consumers at supra-threshold levels (flavor intensity). In addition, consumers' liking and acceptability for chlorinated water was found to be in agreement with sensitivity: the higher the sensitivity the lower the acceptability for chlorinated waters. Thus, French consumers or bottled water drinkers showed a lower appreciation of chlorinated water solutions and were especially less inclined to accept chlorinated water as drinking water delivered at tap.

**Key words** | chlorine, consumer perception, drinking water

### INTRODUCTION

Consumers are increasingly concerned with tap water quality. The perception of water quality depends on several factors, but the appreciation of water quality and risks is mostly influenced by consumers' satisfaction with organoleptic properties (Dietrich 2006; Doria *et al.* 2009). As reported by Torobin *et al.* (1999), fair/poor esthetics were often associated with unsafe water.

The primary goal of water treatments is to provide a clean and safe product. The treatment complexity depends on the characteristics and the quality of raw water but also on compliance requirements for the finished water. In most cases, the last stage in drinking water treatment plants is a post-chlorination or the addition of another disinfectant with residual effect, such as chlorine dioxide or chloramines. Chlorine was the first disinfectant agent to be

used in drinking water a century ago and continues to be the most used worldwide.

Consumers immediately associate tap water with sensory descriptors such as 'chlorine', 'bleach', and 'swimming pool'. The 'chlorinous' descriptor is among the most frequently cited descriptors of the taste-and-odor wheel (Bruchet & Duguet 2004; APHA, AWWA, WEF 2005; Dietrich 2006; Ömür-Özbek 2012). In addition, chlorinous flavors are one of the leading causes of customers' complaints and dissatisfaction with drinking water. Indeed, Turgeon *et al.* (2004) and Kitazawa (2006) showed that consumer satisfaction with tap water quality is related to chlorine residuals and underlined the role of chlorine flavor in the lack of tap water acceptability by consumers. Proulx *et al.* (2012) indicated that residual

P. Piriou (corresponding author)

F. Zraick

Suez Environnement,  
38 rue du Président Wilson,  
Le Pecq 78230,  
France

E-mail: philippe.piriou@suez-env.com

R. Devesa

Aguas de Barcelona,  
C/General Batet,  
1-7,  
Barcelona 08028,  
Spain

S. Puget

T. Thomas-Danguin

Centre des Sciences du Goût et de l'Alimentation,  
INRA UMR1324, CNRS UMR6265, Université de  
Bourgogne,  
F-21000 Dijon,  
France

chlorine was one of the relevant factors contributing to the global flavor intensity of the distributed water assessed by a trained panel.

On the other hand, a recent paper by Platikanov *et al.* (2013) about tasting of tap and bottled waters showed that chlorination has a role in water flavor assessment, but mineral composition was the most important factor. In addition to the mineral content (total dissolved solids (TDS)), temperature has been pointed out as a key aspect (Whelton & Dietrich 2004; Gallagher & Dietrich 2010).

With regard to the sensory sensitivity toward a disinfection agent such as chlorine, Piriou *et al.* (2004) showed that chlorine detection thresholds in water vary according to subject experience (trained vs. untrained panel), the experienced panelist threshold being lower. In addition, Piriou *et al.* (2004) showed that French consumers' chlorine detection thresholds were lower than American ones, thus revealing sensitivity differences.

Thus, evidence of chlorine flavor sensitivity differences are reported in the literature with potential impacts on tap water acceptability. However, these findings have to be confirmed and the reasons for these apparent sensitivity differences to be clarified.

For that purpose, sensory testing experiments were conducted in France (Puget *et al.* 2010) and in Spain to investigate consumers' sensory sensitivity by assessing their respective chlorine flavor detection threshold and supra-threshold sensitivity as well as their liking and acceptability for chlorinated water. In addition, as a follow-up study to Puget *et al.* (2010), the potential influence of the water drinking habits was investigated.

The aims of our experiments were to determine:

- first, whether the consumer sensitivity to chlorine flavor is the same in different countries;
- second, whether the chlorine flavor sensitivity impacts consumers' liking and acceptability of tap water;

- third, to what extent residual chlorine levels in tap water or water drinking habits affect chlorine perception.

## MATERIALS AND METHODS

### Chlorinated water samples

Chlorinated water samples were prepared by adding sodium hypochlorite solution (15% NaClO, RECTAPUR, VWR International, Briare, France) to bottled water: Evian (TDS = 262 mg/L) in France and Solan de Cabras (TDS = 326 mg/L) in Spain. These waters are usual references, used at CIRSEE and AGBAR, respectively, for their neutral taste. Their composition is quite similar and both have a moderate mineral content; these are rich in calcium and magnesium bicarbonate (Table 1).

For the chlorine flavor threshold concentration (FTC) assessment, eight chlorine concentrations (0, 0.01, 0.03, 0.06, 0.1, 0.17, 0.32, 1, and 3 mg/L as Cl<sub>2</sub>) were tested in France (Puget *et al.* 2010) and six (0, 0.1, 0.18, 0.32, 0.56, 1, and 1.78 mg/L as Cl<sub>2</sub>) were tested in Spain.

The concentrations were selected on the basis of previously published thresholds (0.16 (Bryan *et al.* 1973), 0.24 (Krasner & Barrett 1984), and 0.2 mg/L as Cl<sub>2</sub> (Piriou *et al.* 2004)) and based on the residuals delivered at tap, i.e., between 0.1 and 0.3 mg/L as Cl<sub>2</sub> in France and between 0.1 and 0.5 mg/L as Cl<sub>2</sub> in Spain. Hence in France, a dilution factor of 0.25 was used in logarithm of concentration between 0.32 and 0.06 mg/L as Cl<sub>2</sub> to cover precisely this range. Then, values were selected on each side of this range with a larger factor (0.48) to cover a larger concentration range between 0.01 and 3 mg/L as Cl<sub>2</sub>. In Spain, a constant factor for dilution (0.25 in logarithm of concentration) was selected to cover the concentration range between 0.1 and 1.78 mg/L as Cl<sub>2</sub>. In both countries, preliminary tests were performed with a small panel (around 10 tasters) to better estimate the

**Table 1** | Comparative chemical composition of Solan de Cabras and Evian bottled waters

Brand	TDS (mg/L)	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Bicarbonate (mg/L)	Silica (mg/L)
Solan de Cabras	262	5	1	57	25	8	22	285	7
Evian	326	6	1	76	26	6	12	357	16

expected threshold, prior to doing the experiments with the large panels.

For the chlorine flavor intensity, liking, and acceptability tests, a larger concentration range (supra-threshold concentrations) than the ones for detection was investigated. The same chlorine concentrations (0, 0.03, 0.1, 0.3, 1, 3, and 10 mg/L as Cl<sub>2</sub>) were used in both countries.

Chlorinated solutions were prepared daily and stored until tasting, i.e., for a maximum of 8 h, in brown glass 500 mL flasks. These solutions were used to prepare the samples delivered to tasters. Chlorine concentrations were controlled just after solution preparation and at the end of each sensory session, according to a procedure adapted from the DPD protocol for spectrophotometry (APHA, AWWA, WEF 2005).

### Participants

Consumers (subjects with no education in sensory analysis) were randomly selected, taking into account their gender, age, and drinking habit (tap water drinker or bottled water drinker), to be part of a panel both in France and in Spain. Preliminary sensory tests were performed in order to avoid highly sensory deprived subjects.

In Spain, 45 individuals, namely 21 tap water drinkers (13 women, eight men, mean age of 39 years) and 24 bottled water drinkers (13 women, 11 men, mean age of 43 years), took part in the first experiment (FTC). Again, 45 subjects, 23 tap water drinkers (12 women, 11 men, mean age of 38 years) and 22 bottled water consumers (13 women, nine men, mean age of 41 years) participated in the second experiment (intensity and hedonic tests). Most of them took part in the first experiment.

In France, 40 individuals, namely 20 tap water drinkers (nine women, 11 men, mean age of 38 years) and 20 bottled water consumers (14 women, six men, mean age of 43 years), participated in the first experiment. Thirty-five of the 40 previous consumers took part in the second experiment, 18 tap water consumers (eight women, 10 men, mean age of 38 years) and 17 bottled water consumers (11 women, six men, mean age of 41 years) (Puget *et al.* 2010).

### Tasting conditions

In France, all the experiments were performed in a room dedicated to sensory analysis. Consumers were placed in

separate booths and their responses were collected using software dedicated to sensory analysis (Puget *et al.* 2010).

In Spain, experiments took place in a comfortable room at 20 °C and free from interfering odors. Their responses were collected using a dedicated paper sheet. Owing to the size of the room, each tasting session was separated in four groups of 10–15 individuals.

For sensory tasting, samples of 10–20 mL were delivered in plastic cups and were prepared just before the tasting. The absence of off-flavor due to the bottled water and the cups was checked. All the water samples were tasted at 20 °C for all the experiments. All samples were duly codified with a three digit code. Tasters were asked not to eat or drink (except water) for 1 h before the session. Smokers were recommended not to smoke for 60 min before the experiment.

### Flavor threshold concentration

Flavor detection thresholds were measured according to the constant stimuli procedure (NF ISO 13301 2002). This procedure allows psychometric function modeling on the basis of detection probability measurement for increasing stimulus concentrations. In the experiments, the detection probability was measured using a three-alternative forced choice (3-AFC) discrimination test. For each level of chlorination, three samples were presented to the panelist two blanks (bottled water) and the sample containing the stimulus (chlorinated bottled water). Subjects were asked to identify the odd sample. Four repetitions were performed by each consumer at each concentration level (Puget *et al.* 2010).

In France, a total of 32 tests (3-AFC) were performed by each subject (eight concentrations and four repetitions), organized in two 1-h sessions (16 tests in a session). Four separate sessions were organized in Spain (six concentrations per session). In both cases, two sessions were spaced by a week.

The sample presentation order was the same for all tasters within a group. However, the location of the odd sample in one 3-AFC test was random for each trial. To avoid sensory adaptation and fatigue, tasters had to wait at least 2 min between each trial and were told to rinse their mouth with the reference water ('blank') during that period.

## Intensity, liking, and acceptability tests

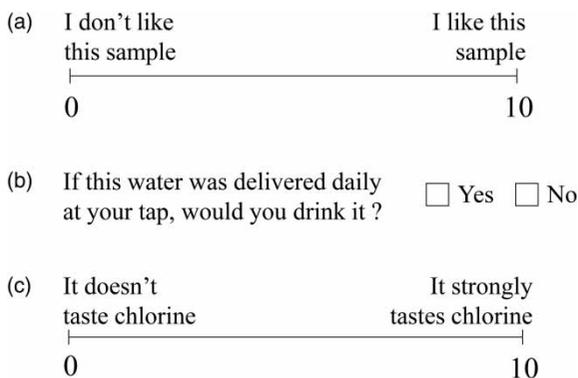
The session was divided into two blocks the first one was dedicated to liking and acceptability ratings and the second to intensity rating (Figure 1). The sample presentation order was randomized and different in each block. Four different presentation orders were used within a block (Puget *et al.* 2010).

Within the first block, liking for each sample was evaluated by the panelist on a non-graduated linear scale from 'I do not like this sample at all' to 'I like it a lot' (Figure 1(a)). Subjects had to mark their answer with an 'X' on the linear scale. Then, the distance between the scale origin and the mark was measured. Ratings on this scale were normalized to obtain a score between 0 and 10. For acceptability, consumers were asked 'If this water was delivered daily to your tap, would you drink it?' They were instructed to answer with 'yes' or 'no', codified '1' and '0', respectively (Figure 1(b)).

Within the second block, consumers rated chlorine flavor intensity on a non-graduated linear scale from 'It does not taste chlorine' (left) to 'It strongly tastes chlorine' (right) (Figure 1(c)). Marks on this scale were normalized to obtain a score between 0 and 10.

To avoid sensory adaptation and fatigue, tasters had to wait at least 2 min between each sample.

One session was done in France and two sessions (duplicate) in Spain (45 tasters/two different dates). However, it was decided to merge the data of the two sessions conducted in Spain because responses were not significantly different between repetitions ( $p > 0.05$ ).



**Figure 1** | Scales and questions for measuring liking, acceptability, and chlorine flavor intensity.

## Data analysis

SAS release 9.1.3 (SAS Institute, Inc., Cary, NC, USA) software was used for all the statistical analyses. Sensory data analyses were based on mixed modeling procedures which allow considering subjects as a random factor. This means that the participants were randomly selected within the population and could be considered as representative of the French or the Spanish consumer population, so that the statistical results are still valid at the population level (Pinheiro & Bates 2000; Puget *et al.* 2010).

## Flavor threshold concentration

In the 3-AFC tests, correct answers were coded with a 1 and incorrect with a 0. Each subject performed four repetitions ( $n = 4$ ) at each concentration. The number of correct answers  $Y$  is distributed as a binomial law  $[B(n,p)]$ , where the correct answer probability  $p$  combines correct answers occurring by chance (i.e., one-third) and correct answers due to real detection. By definition (NF ISO 13301 2002), the threshold is the concentration detected with a probability equal to 50%, which can be estimated for a group of consumers and for each subject, according to the procedure described in detail by Puget *et al.* (2010).

Flavor thresholds were first calculated and compared to assess the potential effect of drinking habits on consumer sensitivity of a given country, using a non-linear mixed model (NLMIXED procedure of SAS<sup>®</sup>), with 'water drinking habits' as fixed parameter, 'subjects' as random parameter, and 'chlorine concentration' in samples as covariate.

Owing to the absence of water drinking habits effects, as reported by Puget *et al.* (2010) for France and confirmed here for Spain, the data for both tap water and bottled water drinkers of a given country were merged. Then, the potential effect of consumers' living country on their sensitivity was assessed, according to the same procedure with 'country' as fixed parameter, 'subjects' as random parameter, and 'chlorine concentration' in samples as covariate.

In both cases (effect of water drinking habits or effect of consumers' living country), two models were compared ( $\chi^2$  nested model likelihood ratio test): a first one to estimate the mean threshold for the whole set of consumers and a

**Table 2** | Fixed factors tested in statistical models for intensity, liking, and acceptability data

Parameters	Level number	Levels
Country	2	France, Spain
Group	2	Bottled water, tap water
Chlorine concentration level	7	Z0 (0 mg/L Cl <sub>2</sub> ); E1 (0.03 mg/L Cl <sub>2</sub> ); E2 (0.1 mg/L Cl <sub>2</sub> ); E3 (0.3 mg/L Cl <sub>2</sub> ); E4 (1 mg/L Cl <sub>2</sub> ); E5 (3 mg/L Cl <sub>2</sub> ); E6 (10 mg/L Cl <sub>2</sub> )

second one that takes into account that chlorine flavor thresholds might differ depending on water drinking habit or consumers' living country, respectively (Puget *et al.* 2010).

### Intensity, liking, and acceptability

Intensity and liking scores were submitted to an analysis of variance (ANOVA, MIXED procedure of SAS<sup>®</sup>) with 'country', 'group', and 'chlorine concentration level' as fixed factors and 'subjects' as random factor (see Table 2). *Post hoc* tests consisted of least square means comparison with a Bonferroni correction for multiple testing.

Acceptability data ('yes' or 'no' answers) were analyzed owing to the generalized equation estimation (GEE) modeling for binary data (GENMOD procedure of SAS<sup>®</sup>) with 'subjects' as a repeated factor and 'country group' and 'chlorine concentration level' as fixed factors. Proportions of answers were further compared using chi-square tests (Zeger *et al.* 1988; Puget *et al.* 2010).

## RESULTS

### Chlorine flavor thresholds

The effect of water drinking habits on consumers' sensitivity was first assessed in both countries. As reported by Puget *et al.* (2010), bottled water drinkers were found more sensitive to chlorine flavor (lower detection threshold) than tap water drinkers. However, the difference between the two groups was not statically significant ( $p = 0.44$ ). Similar results were found for the Spanish consumers and the difference between bottle and tap water groups was not significant either ( $p > 0.1$ ).

The comparison of the French and Spanish consumers, whatever their water drinking habits, revealed a significant

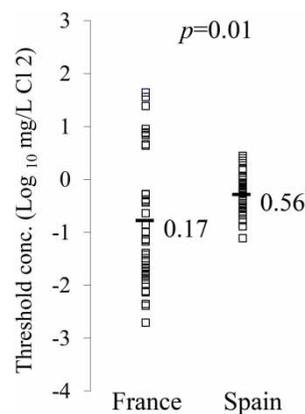
difference between chlorine flavor detection thresholds ( $p = 0.01$ ). Mean thresholds of 0.17 mg/L (standard error of the mean, SEM = 0.06) and 0.56 mg/L as Cl<sub>2</sub> (SEM = 0.17) were estimated, respectively, for the French and the Spanish consumers (Figure 2). Puget *et al.* (2010) reported a flavor detection threshold of 0.14 mg/L as Cl<sub>2</sub> (SEM = 0.08) for a group of French consumers, in agreement with the value obtained in the present study.

### Intensity, liking, and acceptability

#### Chlorine flavor intensity

To study the difference between France and Spain regarding supra-threshold perception of chlorine flavor in water, intensity ratings of 35 French panelists and 45 Spanish ones were submitted to an ANOVA. The factors 'group' (water drinking habits), 'country', 'chlorine concentration level' and their interactions were tested.

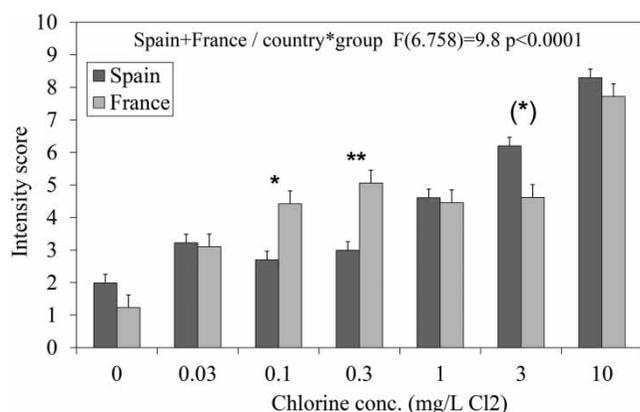
Results showed no main effect of 'country' ( $p = 0.75$ ; Table 3). Nevertheless, a highly significant interaction



**Figure 2** | Distribution of individual chlorine flavor detection thresholds in water for French and Spanish consumers.

**Table 3** | ANOVA results (fixed effects) for flavor intensity

Factor	Num df	DDL	F value	p value
Country	1	76	0.10	0.75
Group	1	76	6.21	0.015
Chlorine concentration level	6	758	91.0	<0.0001
Country*group	1	76	0.00	0.97
Group*chlorine concentration level	6	758	0.80	0.57
Country*chlorine concentration level	6	758	9.8	<0.0001

**Figure 3** | Comparison of chlorine flavor supra-threshold intensity scores for the French and the Spanish panels. (\*)  $p < 0.1$ , \* $p < 0.05$ , \*\* $p < 0.01$ , \*\*\* $p < 0.001$ .

between the factors ‘country’ and ‘chlorine concentration level’ ( $p < 0.0001$ ; Table 3) revealed that the intensity scores given for the different chlorine concentration levels was different depending on the country, as shown in Figure 3.

As shown in Figure 3, the mean intensity scores given by the two panels increased with increasing chlorine concentrations, as confirmed by the highly significant main effect of the factor ‘chlorine concentration level’ in ANOVA ( $p < 0.0001$ ). However, *post hoc* tests indicated that for 0.1 and 0.3 mg/L as Cl<sub>2</sub>, two concentrations commonly encountered at tap in France, the French panel perceived significantly higher flavor intensity compared to the Spanish panel. As a result, the two populations likely perceive chlorine flavor differently at these concentrations.

The interactions between the factors ‘group’ and ‘chlorine concentration level’ and the factors ‘group’ and ‘country’

were not found significant (Table 3), but interestingly, a main effect of the factor ‘group’ was found ( $p = 0.015$ ; Table 3). This result demonstrates that, whatever the country and the chlorine concentrations, the bottled water drinkers perceived supra-threshold chlorine flavor as more intense compared to tap water drinkers (bottled: mean = 4.66, SEM = 0.19; tap: mean = 3.99; SEM = 0.19).

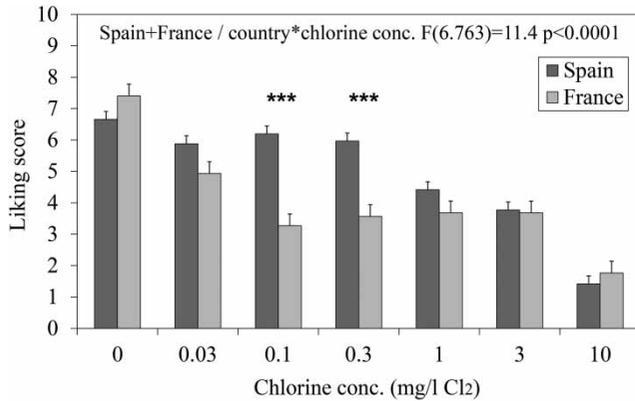
### Liking rating

Similarly to the intensity scores, liking scores of the French and Spanish groups were submitted to an ANOVA to evaluate the effect of the factors ‘group’ (water drinking habits), ‘country’, ‘chlorine concentration level’ and their interactions. Results showed a significant main effect of ‘country’, highlighting that French consumers liked chlorinated water less than Spanish consumers ( $p = 0.0012$ ; Table 4). However, the highly significant interaction between ‘country’ and ‘chlorine concentration level’ ( $p < 0.0001$ ; Table 4) indicates that the difference of liking between countries strongly depended on the chlorine concentration level (Figure 4). Hedonic scores were especially found to be lower for the French group at 0.1 and 0.3 mg/L as Cl<sub>2</sub> (Figure 4), that is those two concentrations perceived as significantly more intense by the French consumers (Figure 3).

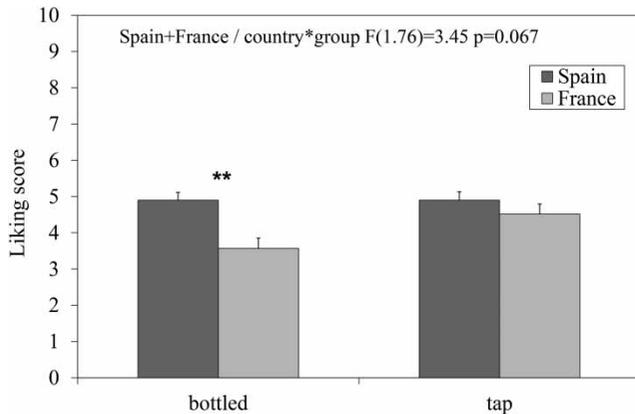
In addition, a trend was obtained for the factor ‘group’ and the interaction ‘group\*country’ (Table 4), suggesting that bottled water drinkers of the French panel liked the chlorine water samples less than the other groups (Figure 5).

**Table 4** | ANOVA results (fixed effects) for liking rating

Factor	Num df	DDL	F value	p value
Country	1	76	11.3	0.0012
Group	1	76	3.46	0.066
Chlorine concentration level	6	758	67.3	<0.0001
Country*group	1	76	3.45	0.067
Group*chlorine concentration level	6	758	0.89	0.50
Country*chlorine concentration level	6	758	11.4	<0.0001



**Figure 4** | Comparison of liking scores for the French and the Spanish panels (\*):  $p < 0.1$ ,  $*p < 0.05$ ,  $**p < 0.01$ ,  $***p < 0.001$ .

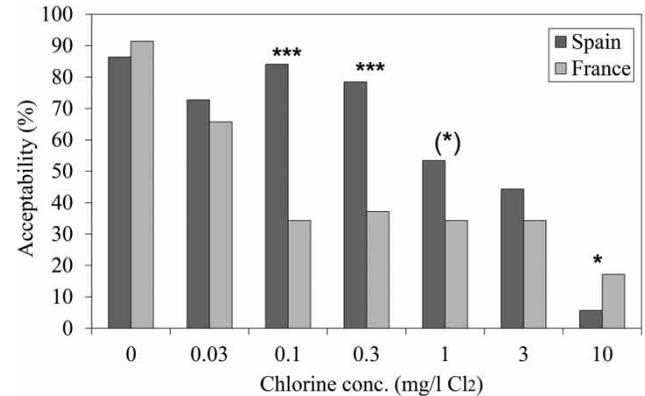


**Figure 5** | Difference of liking scores for tap water and bottled water consumers (\*):  $p < 0.1$ ,  $*p < 0.05$ ,  $**p < 0.01$ ,  $***p < 0.001$ .

## Acceptability

To study the difference between French and Spanish consumers for chlorinated water acceptability as a drinking water, acceptability scores of both panels were submitted to a GEE modeling in order to evaluate the effect of the factors 'group' (drinking habits), 'country', 'chlorine concentration level' and their interactions. Results revealed a significant effect of the 'chlorine concentration level' ( $p < 0.0001$ ) and 'country' ( $p < 0.0001$ ), but the interaction between 'country' and 'chlorine concentration level' ( $p < 0.0001$ ) indicates that the acceptability score for a given concentration of chlorine in water depended on the country, as shown in Figure 6.

At 0.03 mg/L Cl<sub>2</sub>, chlorinated water was accepted by the majority of the French panel (~65%), while less than 40%



**Figure 6** | Comparison of acceptability scores given by the French and Spanish panels (\*):  $p < 0.1$ ,  $*p < 0.05$ ,  $**p < 0.01$ ,  $***p < 0.001$ .

accepted higher chlorine concentrations as drinking water. In contrast, 80% of Spanish panelists accepted as drinking water a chlorine solution of 0.1 and 0.3 mg/L Cl<sub>2</sub> (Figure 6), and a majority (>50%) of Spanish panelists still accept chlorinated water at a concentration of 1 mg/L Cl<sub>2</sub> (Figure 6).

The factor 'group' was also found to be significant ( $p < 0.0015$ ), indicating that, even if low, the acceptability rate between tap and bottled water consumers was significantly different. As expected, tap water consumers accept chlorinated water more than bottled water consumers (50.53% vs. 49.47%, respectively).

## DISCUSSION

### Is the sensitivity to chlorine flavor the same in different countries?

Our results provided evidence that French and Spanish consumers have different sensitivities to chlorinated water. The French consumers were found to be more sensitive to chlorine flavor than the Spanish ones, since their mean detection threshold was significantly lower (0.17 vs. 0.56 mg/L as Cl<sub>2</sub>). The chlorine flavor threshold for French consumers confirmed previously published values (Puget *et al.* 2010). Moreover, this differentiated sensitivity at detection threshold was confirmed at supra-threshold level where French consumers rated chlorine flavor intensity as higher compared to Spanish consumers, especially at chlorine

concentration of 0.1 and 0.3 mg/L as Cl<sub>2</sub>, two concentration levels daily delivered at tap in France.

Our results confirmed the absence of sensitivity difference between bottled water and tap water consumers in France at detection threshold levels (Puget *et al.* 2010) and extended this finding to Spanish consumers. However, at supra-threshold levels, chlorine flavor intensity results showed that bottled water drinkers perceived chlorine flavor as more intense compared to tap water drinkers for both countries.

Regional differences in chlorine flavor perception in water were also reported by Piriou *et al.* (2004) showing a significant difference in chlorine flavor detection thresholds, by comparing results provided by French and American untrained panels. However, Piriou *et al.* (2009) reported also no difference in sensory sensitivity between French and Spanish consumers, for two other odorous compounds, methylisoborneol and geosmin.

Taking into account chlorination practices in the different countries (France:  $\leq 0.3$  mg/L and Spain:  $\leq 0.5$ – $0.7$  mg/L), it is noticeable that the mean flavor detection thresholds obtained, as part of this work, in the different countries (France: 0.17 mg/L and Spain: 0.56 mg/L as Cl<sub>2</sub>) are in agreement with the regional chlorine residuals in the supplied drinking waters; the higher the chlorine residuals, the lower the sensitivity to chlorine flavor (higher detection threshold).

In addition information reported by Piriou *et al.* (2004) allowed estimation of a chlorine flavor threshold of 1.1 mg/L for American consumers for chlorine residuals  $\leq 4$ – $5$  mg/L as Cl<sub>2</sub> in the United States.

These results, combined with those previously mentioned, suggest that habituation to the level of chlorine delivered at tap may have an impact in chlorine flavor perception. This hypothesis is also supported by the results reported here showing no significant sensitivity difference at threshold concentration levels, but significant differences observed between tap water and bottled water consumers at supra-threshold levels (flavor intensity scores).

Sensory habituation is generally thought to reflect the involvement of central processes and can be associated with the decrease of the perceived intensity of stimuli as a function of exposure time. Sensory adaptation, on the

other hand, reflects more peripheral processes (Dalton 2000). However, these distinctions are rarely clear-cut since a change in perceived intensity can imply both processes. Nevertheless, it has been consistently suggested that habituation and/or adaptation is context dependent. For instance, the belief that an odor stimulus is harmful influences the perceived intensity of the odor and its adaptation/habituation pattern (Kobayashi *et al.* 2008).

### **Does sensitivity toward chlorine flavor impact consumers' liking and acceptability of chlorinated water?**

Our results indicate that chlorine flavor liking and acceptability in a water intake context decreases when chlorine concentration increases in both Spanish and French populations. However, the evolution patterns were different, depending on the country. For the French panel, a decrease of the liking and the acceptability scores was observed between 0 and 0.3 mg/L before reaching a plateau. These hedonic patterns seemed to be mapped to flavor intensity. For the Spanish panel, the decrease of liking and acceptability scores was noticeable between 0.3 and 10 mg/L after a first plateau of rather high levels of liking and acceptability. Again, hedonic scores seemed to be mapped to flavor intensity.

As highlighted by hedonic scores, Spanish consumers are likely to be more inclined than French consumers to drink chlorinated waters, in agreement with their respective sensory sensitivity (flavor intensity and flavor threshold). Taking into account that pleasantness and to a higher degree acceptability judgments imply a putative intake decision, it appears clear that chlorine flavor is a negative marker of water acceptability, as suggested by previous studies (Torobin *et al.* 1999; Dietrich 2006; Doria *et al.* 2009).

In agreement with the results obtained for chlorine flavor perception, differences in chlorine flavor liking and acceptability were found to depend on water drinking habits. Indeed, French tap water consumers gave significant higher liking scores than bottled water drinkers. For acceptability, tap water consumers were found to give higher acceptability scores, whatever the country. These results are in agreement with those of Hudon *et al.* (1991), investigating consumer water consumption habits. Those

consumers who drank tap water had a quite positive representation of the tap water with no indication of any health risk and found tap water to be of good organoleptic, chemical, and bacteriological quality. Conversely, consumers with a poor or negative representation of the tap water indicated that they preferred to drink bottled water. [Torobin \*et al.\* \(1999\)](#) also noticed a correlation between perceived safety and actual water taste and suggested that taste does shape safety perception. This was also reported by [Mackey \*et al.\* \(2004\)](#). As a result, chlorine flavor seems to play ultimately against tap water acceptability, as a marker of safety representation ([Puget \*et al.\* 2010](#)).

## CONCLUSION

The in-water chlorine flavor detection threshold and supra-threshold sensitivity were found to vary depending on countries. According to the relationship found between chlorine practices and sensitivity, it is likely that habituation may explain perception differences. This hypothesis is also supported by results showing no significant sensitivity difference at detection threshold concentration level but significant differences between tap water and bottled water consumers at supra-threshold levels (flavor intensity).

In addition, consumers' liking and acceptability for chlorinated water was found to be in agreement with sensitivity; the higher the sensitivity, the lower the liking and acceptability for chlorinated waters. Thus, French consumers or bottled water drinkers showed a lower appreciation of chlorinated water solutions and were especially less inclined to accept chlorinated water as drinking water delivered at the tap.

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