

The influence of audiovisual stimuli cuing temperature, carbonation, and color on the categorization of beverage freshness

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Abstract

The study reported here investigated the influence of audiovisual stimuli signaling the likely temperature (the presence vs. absence of ice cubes), the likely level of carbonation (the presence vs. absence of bubbles), and the color of the liquid on the categorization of freshness in beverages. Participants made speeded categorization responses (“fresh” versus “not fresh”) concerning the bimodal stimuli. When the stimuli were categorized as fresh, visible ice cubes decreased the participants’ reaction times (RTs) the most, followed by the sound of ice cubes, and then the sound of carbonation. Overall, the participants were also more prone to categorize the stimuli as fresh, especially in the presence of ice cubes visible in the drink. When presented together, the targeted audiovisual perceptual features exerted an additive effect in both decreasing RTs and increasing the likelihood that a beverage would be categorized as fresh. No significant effect of beverage color (manipulated between-participants) was observed. These results are discussed in terms of the crossmodal interaction effects that might be expected to influence the multisensory experience of freshness in beverages.

Practical applications:

The current appeal of consumers for a global experience of freshness in the food and beverage domain constitutes a promising lever for strategic innovation. Thus, it appears timely to investigate how some sensory cues other than the chemosensory ones (i.e., taste and smell) involved in a multisensory drink experience, namely visual and auditory cues, interact and subsequently impact consumers’ perception and behavior. We believe that the triggering of specific cognitive mechanisms, which may occur during the multisensory integration processes associated with freshness perception could help to increase beverages’ attractiveness and appreciation. The present study thus has important implications for product formulation and marketing design purposes.

Keywords: Freshness perception, multisensory perception, audiovisual interactions, beverages, carbonation, temperature.

1. Introduction

1.1. Multisensory contributions to the perception of freshness

Over the past decade, the perception of freshness has received consideration in consumer studies since it is generally perceived as pleasurable by consumers and it thus may be expected to influence their purchase and consumption behavior (see Eccles *et al.* 2013; Labbe *et al.* 2009a; Roque *et al.* 2018, for reviews). Considering the particular case of beverages, it should be noted that the concept of freshness may convey different meanings because it can refer to: i) the overall multisensory experience during a drinking episode (involving for instance coldness, sourness, or a menthol odor that will contribute to an actual perception of freshness, but also some visual cues for instance, that may trigger freshness expectations); ii) the ageing of the organic ingredients contained in the drink (e.g. the age of the mint leaves in a mojito), or else iii) the time delay (informed and/or perceived) to which the drink has been prepared before being served. Hence, it is challenging to disentangle behaviorally the distinct, though likely related, meanings of freshness since the three meanings reported above may well overlap. Based on previous research (see Labbe *et al.* 2009a; Roque *et al.* 2018 for reviews), it appears that the multisensory experience of freshness is likely built from two fundamental cognitive mechanisms that include: i) expectations elicited by visual, auditory, and orthonasal olfactory cues for which a product can be perceived as fresh, before tasting, and ii) actual sensations elicited by gustatory and olfactory cues, as well as peripheral nervous systems including oral-somatosensory, nociceptive, and tactile cues contributing to the perception of freshness itself during tasting. As a first investigation of the crossmodal interaction effects that likely influence the categorization of particular beverages as being fresh, we chose to focus in this study on visual and auditory cues that may generate expectations of freshness.

The majority of previous studies that have investigated the multisensory perception of freshness have focused on the influence of gustatory, olfactory, and oral-somatosensory cues. Some of this research highlights different patterns of sensory dominance regarding the various sensory inputs contributing to freshness. For instance, Fenko *et al.* (2009) documented that for soft drinks and dishwashing liquids, olfactory cues dominated over visual color cues as far as freshness judgments were concerned. Labbe *et al.* (2009b), meanwhile, used edible gels, varying in their olfactory (mint and peach), trigeminal (coldness), taste (acidity), and texture (thickness) properties. The results of the latter study highlighted the fact that people differed in the main sensory modality that they associated with freshness, and that this appeared to be based on previously-learned associations. One cluster of consumers assessed the contribution of smell (i.e., mint) and trigeminal (i.e., coldness) sensations to freshness as being most important. A second cluster of consumers considered taste (i.e., acidity) most important, whereas a third cluster ranked oral-somatosensory (i.e., low thickness for liquids) as the most important.

In another study, Westerink and Kozlov (2004) investigated what constitutes freshness for oral-care products by means of structured interviews with native English speakers. The results allowed for the identification of six main attributes as part of the concept of freshness: cleanness (related to mouth-cleaning activities), energy (related to energizing sensations experienced by the participants, e.g., texture or bubbles), “water-ness” (related to the multiple experiences of having water in the mouth, i.e., “after drinking water” feelings, or the natural level of salivation), coldness (related to temperature), taste, and smell. From these results, Westerink and Kozlov went on to argue that freshness is a dynamic concept that varies over time and individuals likely attribute different weights to the six attributes during product usage. Their results also highlight how people tend to value temporary perceptual features during the actual experience of freshness (e.g., temperature and energy), whereas they tend to

keep other sensory features related to the perception of freshness (e.g., particular compounds such as menthol) in long-term memory.

The complexity of freshness highlighted by these previous studies represents an additional argument to investigate first the influence of audiovisual perceptual features and their crossmodal interaction effects that may trigger freshness expectations before the actual consumption experience. When specifically focusing on the multisensory perception of freshness in beverages, there is a research gap with regard to the way audiovisual crossmodal interaction effects may facilitate the categorization of a particular beverage as being fresh or not. Some audiovisual features have nonetheless been highlighted as potential modulators of the multisensory drinking experience and they therefore represent good candidates to investigate further.

1.2. Audiovisual perceptual features involved in a multisensory drinking experience and their potential influence on freshness

According to consumers, coldness is one of the common sensory properties that enhances freshness perception, through different sensory cues (i.e., oral-somatosensory, tactile, trigeminal, as well as visual and olfactory cues), in food and beverages (Eccles *et al.* 2013; Labbe *et al.* 2009a; Zellner and Durlach 2002), water (Labbe *et al.* 2011), and soft drinks (McEwan and Colwill 1996; Saint-Eve *et al.* 2010; Zhang *et al.* 2016). Guinard *et al.* (1998) have also highlighted that the density of visual bubbles positively increases the perceived freshness in beers even though the foam created by bubbles on the top of the liquid can exert a negative impact on such judgments.

Regarding the influence of auditory cues, recent studies have highlighted the influence of sounds corresponding to the pouring of a beverage on the perception of its temperature (Velasco *et al.* 2013). The results of the latter study revealed the existence of a crossmodal correspondence (see Section 1.3) between the pouring sounds and a particular temperature:

the sonic properties of the sounds of hot and cold waters were respectively associated with congruent words attributes (i.e. “Hot Drink” and “Cold Drink”; see also Wang and Spence 2017). Another study conducted by Zampini and Spence (2005) highlighted that the perception of carbonation in a beverage may be influenced by the auditory cues provided by the bubbles (note that drinks packaging opening sounds may also be relevant here; see Spence and Wang 2015, 2017). Hence, the sound of carbonation is likely to influence people’s perception of freshness in beverages as well.

Finally, it is worth mentioning here the influence of color on the perception of freshness in beverages. To date, there is a lack of consensus in the literature concerning whether a particular color or group of colors are mainly associated to fresh beverages by consumers. Some studies have nonetheless reported a noticeable exception for clear beverages which are favored, in contrast to dark ones, when consumers have to characterize the appropriate color for fresh beverages (Clydesdale *et al.* 1992; Zellner and Durlach 2002, 2003). However, none of these studies detailed what consumers meant by “clear color” (for instance in terms of transparency or saturation). Additional early results obtained by Zellner and Durlach (2003) revealed that freshness ratings attributed to different colors of a vanilla-flavored beverage significantly differed for expected freshness ratings, whereas freshness ratings did not differ significantly from one another when the participants actually tasted the beverages.

Meanwhile, another study conducted by Clydesdale *et al.* (1992) revealed that American students most frequently associated clear (36%), followed by brown (24%), red (17%), and orange (12%) colors with the thirst-quenching character of fruit punch-flavored beverages. Importantly for present purposes, the thirst-quenching properties of beverages have been shown to correlate positively with the perception of freshness (e.g., Labbe *et al.* 2009b) and thereby they constitute a meaningful indicator of freshness. To summarize, it would appear

that various factors can modulate the influence of color on perceived freshness. For instance, the color of a beverage can set freshness expectations that will not necessarily impact freshness ratings during tasting (e.g., Carvalho *et al.* 2018). This discrepancy may be attributable to other sensory contributions (e.g., smell, taste, or flavor) and it likely depends on the past learned associations of consumers.

The results of the studies described above stress the fact that different audiovisual perceptual features (e.g., perceptual cues linked to coldness, carbonation, and color) occurring prior to tasting influence freshness expectations and may thereafter, in some cases at least, be expected to influence the final perception of freshness as well. In terms of methodology, the majority of studies investigating the concept of freshness have focused on consumers' expectations by a collection of declarative data. Given the complexity of the cognitive mechanisms at hand in freshness perception, this approach needs to be completed by more objective measures of behavior such as categorization performance. A growing literature has highlighted the existence of specific cognitive mechanisms, namely crossmodal correspondences, which induce measureable crossmodal interaction effects. Thus, the next section is devoted to presenting why considering such mechanisms is relevant in the case of freshness in beverages.

1.3. Crossmodal correspondences and the measure of audiovisual crossmodal interaction effects

Audiovisual crossmodal interactions have been widely studied in research dealing with multisensory integration. In particular, the evidence that has been published to date points to the existence of numerous crossmodal correspondences. Crossmodal correspondences have been defined as the non-arbitrary associations that exist between different perceptual features belonging to various sensory modalities (see Spence, 2011, for a review). In a number of

cases, crossmodal correspondences have been shown to lead to perceptual consequences such as crossmodal enhancement at different stages of human information processing (e.g., Liang *et al.* 2013). Moreover, it has been shown that a number of crossmodal correspondences are shared across individuals and appear to be consistent over time (Spence 2011). The existence of specific crossmodal correspondences are often inferred from participants' reaction times (RTs) using speeded classification tasks, including variants of the Implicit Association Test to determine the strength of the association between two perceptual features (e.g., Deroy *et al.* 2016; Demattè *et al.* 2007; Parise and Spence 2012). This test is based on the rationale that when two stimuli share a strong association (i.e., congruent vs. incongruent associations, see Roque *et al.* 2018), participants' RTs are shorter and their responses tend to be more accurate. More straightforward speeded classification tasks are also often used to investigate interaction effects between different perceptual features (e.g., Evans and Treisman 2010; Marks 2004). A decrease in participants' RTs and a higher accuracy in their responses may reflect the triggering of participants' motor responses due to particular sensory inputs that belong to a category they are responding to (see Diederich and Colonius 2004). In the food and beverage domain, a large number of studies have been conducted to investigate the crossmodal interaction effects between various sensory modalities (e.g., see Knöferle and Spence 2012 for a review of crossmodal correspondences between musical sounds and basic tastes). However, there is still a lack of information on the interaction effects between visual and auditory cues that may occur before the actual consumption, but which still indirectly influence the subsequent consumers' experiences by triggering specific sensory expectations (see Piqueras-Fiszman and Spence 2015, for a review).

From an applied perspective, a better understanding of how to tap into the crossmodal correspondences regarding freshness would enable marketers, for instance, to facilitate

consumers' categorization of a given product as fresh. This might well be expected to have a positive impact on consumers' product experience since freshness features are part of consumers' sensory expectations and thereby they are likely to determine food and beverage attractiveness and appreciation. However, the crossmodal correspondences that can occur during the multisensory integration that leads to the perception of freshness, in the particular context of beverages, still remain to be explored.

The study reported here did not aim at highlighting proper crossmodal correspondences but rather to investigate whether some audiovisual perceptual features could induce crossmodal interaction effects and influence the categorization of freshness in beverages. We believe that it represents a promising step along the path to identifying the different perceptual features that could trigger crossmodal correspondences mechanisms.

The literature described above led us to formulate the following three hypotheses:

H1. Both visual and auditory perceptual features linked to temperature (presence vs. absence of ice cubes¹), and carbonation (presence vs. absence of bubbles²) would influence the categorization of freshness in beverages.

H2. Two main crossmodal interaction effects are expected: i) shorter RTs in the freshness categorization task for congruent combinations of auditory and visual stimuli that display the perceptual features of interest (e.g., presenting both the sight and sound of ice cubes) than for incongruent ones, and ii) a tendency to categorize these congruent stimuli as fresh.

H3. Even though there is no consensus in the literature, a significant influence of the color of the liquid on the categorization of freshness is also expected since different colors can lead to different expectations regarding the corresponding flavor of the liquid (at least when assessed in a within-participants experimental design), as well as different product categories to which the participants may associate a particular freshness intensity.

To investigate these three hypotheses, a speeded categorization task was conducted with audiovisual stimuli cuing the likely temperature (presence vs. absence of ice cubes), the likely level of carbonation (presence vs. absence of bubbles), and seven different colors of the liquid. The participants had to categorize the different bimodal stimuli corresponding to different beverages as “fresh” versus “not fresh”.

2. Materials and Methods

2.1. Participants

Eighty-four French participants (50% female) took part in this study with a mean age of 29.8 ranging from 19 to 59 years old. They were recruited through the database of the Institut Paul Bocuse Research Center. All reported normal or corrected-to-normal vision and audition. None of the participants had any particular expertise in beverages in terms of leisure activities, education, or professional expertise. Each individual session lasted approximately 25 min and the participants received a 10€ voucher to complete the study. All of the participants provided written informed consent prior to taking part in the study. The experiment was approved by the local ethical committee.

2.2. Apparatus and stimuli

(i) Visual stimuli

Pictures of a 200 mL liquid served in a standard glass were created based on a full factorial design varying temperature (no ice cubes vs. 4 rectangular ones), carbonation (carbonated transparent lemonade 6.2 g/L CO₂ vs. still water), and colors (colorless, blue, green, yellow, orange, brown, and red, created using food-coloring). Pictures were taken in the same laboratory conditions in order to control for lighting, room temperature, liquid temperature

(i.e., ambient), size of ice cubes, CO₂ content, and color cues in the various different conditions (see Fig. 1 and supporting information for details).

Insert Fig. 1 here

(ii) Auditory stimuli

The sounds of 250 mL of liquid being poured into a glass were recorded for 2 sec across the factorial design giving rise to four different sounds: 1) still liquid without ice cubes, 2) carbonated liquid without ice cubes, 3) still liquid with 4 rectangular ice cubes, 4) carbonated liquid with 4 rectangular ice cubes. The liquids were the same as those used for the visual stimuli (i.e., still water and lemonade 6.2 g/L CO₂). The pitch of the sounds were normalized to 1,200 Hz in order to avoid different associations of the pitch with different liquid temperatures (see Velasco *et al.* 2013) and the background noise was reduced using Audacity 2.1.3 software³.

2.3. Design and procedure

The experiment was conducted in a controlled laboratory setting at Institut Paul Bocuse Research Center. The software E-prime[®] was used to record participants' RTs. All the visual and auditory stimuli were crossed based on a full factorial design giving rise to 16 different bimodal stimuli, of which 4 were congruent and 12 incongruent. Some bimodal stimuli displayed two perceptual features (i.e., one visual and one auditory, for instance, both the sight and sound of ice cubes for congruent interactions), others displayed three (i.e., one visual and two auditory or two visual and one auditory, for instance the sight of ice cubes and carbonation as well as the sound of ice cubes), and others displayed four perceptual features (i.e., two visual and two auditory). All of the bimodal stimuli were presented to the

participants 10 times in a random order, giving rise to a total of 160 trials. Hence, a repeated-measures design was adopted with the visual and auditory perceptual features signaling temperature and carbonation displayed as within-participants factors. Since the influence of color on flavor expectations in beverages has been widely reported in the literature (e.g., Carvalho *et al.* 2018), and also in order to avoid fatigue due to the duration of the experiment, the color variable in this study varied as a between-participants factor (N=12 participants per color, gender balanced). The alpha level was set at .05 for all statistical analyses. Statistical analyses were performed using R 3.4.1.

Before starting the experimental session, the participants were asked whether they were thirsty or not. In case they declared that they were thirsty, a 200 mL glass of still water was served. The participants sat on a chair 70 cm from the computer screen and wore headphones (Sony MDR-ZX110) for which the volume was adjusted during the training phase until each participant stated they reached a sufficiently audible level. In each trial, the participants started by looking at a fixation cross in the center of the screen for 1000 ms. Next, the bimodal stimulus was displayed for 2000 ms time-out, and the participants' task was to categorize as quickly as possible whether they perceived "the drink served in the glass as: Fresh or Not fresh" in terms of the expected freshness in mouth as if they would have to consume these drinks. To do so, they had to press one of two response keys (D or J) on the computer keyboard with their left and right index. Emphasis was placed on rapid responding (note that there were no correct responses in the task). The two response keys were counterbalanced across participants (see Fig. 2).

Insert Fig. 2 here

3. Results

3.1. The influence of audiovisual interactions on participants' RTs

Those trials in which the participants failed to make a response before the trial was terminated (less than 3.75% of trials overall) were not analyzed. Linear mixed-effects models were fitted to the data with participants as a random variable and the congruency variable as nested. A first model was conducted to test the overall effect of the congruency variable (i.e., congruent vs. incongruent stimuli) on participants' RTs. This model ($R^2_C=0.464$, see Nakagawa and Schielzeth 2013) revealed a significant main effect of congruency, $\chi^2(1) = 33.7$, $p<.0001$. Overall, the participants' RTs were significantly shorter for congruent stimuli ($m=1047$ ms $\pm$ 6.68 SEM) than for incongruent stimuli ($m=1081$ ms $\pm$ 3.96 SEM).

When considering the variables linked to the stimuli as independent variables and the participants' RTs as the outcome variable, the final model considered ($R^2_C = 0.495$) revealed a significant three-way interaction effect between the sight of ice cubes and the different carbonation conditions, $\chi^2(9) = 18.51$, $p<.0001$. Another three-way interaction effect between the sound of ice cubes and the different carbonation conditions was revealed by the model, $\chi^2(12) = 280.94$, $p<.0001$. The color of the stimuli did not significantly influence RTs ($F = 1.09$, $p = 0.38$). These results are presented in Fig. 3 below.

Insert Fig. 3 here

The interaction between the sight of ice cubes and the different carbonation conditions appeared to have a significant influence on the participants' RTs: a Tukey post-hoc analysis revealed that the sight of ice cubes in a drink always induced significantly faster RTs, as

compared to the absence of ice cubes visually, whatever the interaction with carbonation, $p < .01$ ($b = -74.11$, $t(5) = -6.13$, effect size: $r = 0.94$). When there was no carbonation, only a non-significant numerical tendency was observed ($p = 0.99$).

Another significant influence on the participants' RTs was revealed for the interaction between the sound of ice cubes and the different carbonation conditions: a Tukey post-hoc analysis revealed that the sound of ice cubes only induced shorter RTs when interacting with the sound or both the sight and sound of carbonation, $p < .01$ ($b = -149.7$, $t(7) = -12.46$, effect size: $r = 0.98$).

An additional result can be highlighted from these two graphs: the sight of carbonation always induced significantly longer RTs, $p < .01$ ($b = 96.42$, $t(6) = 7.41$, effect size: $r = 0.949$; $p < .05$ in the 'No sound of ice cubes' condition) whatever the interaction with ice cubes whereas the sound of carbonation induced shorter RTs when interacting with the sight or the sound of ice cubes, $p < .01$ ($b = -51.77$, $t(8) = 4.30$, effect size: $r = 0.84$).

3.2. The influence of both audiovisual interactions and participants' responses on participants' RTs

Other linear mixed-effects models were fitted considering the variables linked to the stimuli as well as the participants' responses as independent variables and the participants' RTs as the outcome variable. The final model considered ($R^2_C = 0.487$) revealed a significant three-way interaction between the different ice cubes conditions and the participants' responses, $\chi^2(11) = 18.85$, $p < .0001$. When the participants categorized the stimuli as fresh, a Tukey post-hoc analysis revealed that both the sight ($b = -102.72$, $t(10) = -6.72$, effect size: $r = 0.91$), and the sound of ice cubes ($b = -72.9$, $t(12) = -4.52$, effect size: $r = 0.79$) significantly decreased the participants' RTs, $p < .001$. Moreover, this effect was additive when the two cues were presented simultaneously.

When the participants categorized the stimuli as not fresh, a Tukey post-hoc analysis revealed that their RTs were significantly longer in the ‘Sight of ice cubes’ or both Sight and sound of ice cubes conditions ($p < .001$), as compared to the ‘No ice cubes’ or ‘Sound of ice cubes’ only conditions.

Another three-way interaction between the different carbonation conditions and the participants’ responses was revealed by the model, $\chi^2(13) = 7.04$, $p = 0.03$. A Tukey post-hoc analysis revealed that the sight of carbonation always induced significantly longer RTs, $p < .001$ ($b = 66.9$, $t(6) = 6.4$, effect size: $r = 0.93$), regardless of whether the participants categorized the stimuli as fresh or not fresh. However, the sound of carbonation induced significantly shorter RTs when the participants categorized the stimuli as fresh, $p < .001$ ($b = -58.2$, $t(13) = -4.12$, effect size: $r = 0.75$). Due to these opposite effects of the sight and sound of carbonation on RTs, no additive effect of carbonation on the participants’ RTs was obtained.

3.3. The influence of audiovisual interactions on participants’ responses

Generalized linear mixed-effects models were fitted to the data as binary logistic regressions with the participants’ responses as the outcome variable, participants as random variable and the congruency variable as nested. When considering the variables linked to the stimuli as independent variables, the final model considered (Tjur’s coefficient of discrimination: $D = 0.39$, see Tjur 2009) revealed a significant three-way interaction effect between the different carbonation conditions and the sight of ice cubes on the participants’ responses, $\chi^2(9) = 252.42$, $p < .0001$. Another three-way interaction effect between the different ice cubes conditions and the sight of carbonation was revealed by the model, $\chi^2(13) = 10.2$, $p = 0.0014$. The color of the stimuli did not significantly influence the categorization of freshness ($F = 1.26$). These results are presented in Fig. 4.

376 *Insert Fig. 4 here*

377

378 The interaction between the different carbonation conditions and the sight of ice cubes
379 appeared to have a significant influence on participants' responses: a Tukey post-hoc analysis
380 revealed that in the 'No sight of ice cubes' condition, both the sound ($b = 0.66$, $z = 9.6$) and
381 sight of carbonation ($b = 0.54$, $z = 7.6$) had a positive effect for categorizing the stimuli as
382 fresh, with an additive effect when the two were presented together, increasing the percentage
383 of responses when the participants categorized the stimuli as fresh (*vice versa* for not fresh),
384 $p < .001$. However, the percentage of stimuli categorized as fresh did not exceed chance level,
385 whatever the carbonation condition. The sight of ice cubes in the drink induced a strong
386 inclination for participants to categorize the stimuli as fresh ($b = 3.27$, $z = 40.9$, $p < .001$),
387 whatever the interaction with carbonation. No additive effect of the sight and sound of
388 carbonation was observed in this case since the combination of the sight of ice cubes and the
389 sight of carbonation decreased the proportions of stimuli that were categorized as fresh. The
390 condition in which the beverage was slightly more likely to be categorized as fresh was the
391 one with the sound of carbonation and the sight of ice cubes ($m = 89.64\%$).

392

393 Another significant influence on the participants' responses was revealed for the interaction
394 between the different ice cubes conditions and the sound of carbonation: a Tukey post-hoc
395 analysis revealed that in the 'No sight of carbonation' condition, both the sound ($b = 1.43$, $z =$
396 19.8 , $p < .001$) and sight of ice cubes ($b = 3.27$, $z = 40.9$, $p < .001$) had a positive effect for
397 categorizing the stimuli as fresh, with an additive effect when the two were presented
398 together, increasing the percentage of responses when the participants categorized the stimuli
399 as fresh (*vice versa* for not fresh). In the 'Sight of carbonation' condition, the same additive
400 effect of the sight and sound of ice cubes was observed in similar proportions. However, as

opposed to the sight of ice cubes, the sight of carbonation did not strongly favor participants' categorization of the stimuli as fresh. As long as ice cubes were visible in the drink, the participants were more likely to categorize the stimuli as fresh in the 'No sight of carbonation' condition ($p < .001$), as opposed to the conditions including the sight of carbonation.

The final model considered revealed another significant three-way interaction between the different carbonation conditions and the sound of ice cubes, $\chi^2(12) = 38.72$, $p < .0001$. In those conditions that included the sound of ice cubes, a similar inclination for participants to categorize the stimuli as fresh more often, whatever the interaction with carbonation, was observed, except that it appeared as less salient as compared to the one induced by the sight of ice cubes, as shown in Fig. 4 (1).

4. Discussion

4.1. The decrease in participants' RTs depends on both the type and number of perceptual features available

Interaction effects that can result from the joint presentation of various perceptual features belonging to different sensory modalities have often been studied using speeded classification tasks (see Marks 2004; Spence, 2018, for reviews). People generally respond more rapidly to multisensory stimuli than to unisensory stimuli. This effect has been characterized as a "statistical facilitation" assuming that the processing time of multisensory stimuli is lower than that of the component unisensory stimuli (Diederich and Colonius 2004). Moreover, previous studies have highlighted that congruent bimodal stimuli lead to shorter RTs and better accuracy in their responses than incongruent bimodal stimuli (see Spence 2011). Based on this theoretical and empirical framework, the present study was designed to investigate the influence of congruent and incongruent audiovisual stimuli on the categorization of freshness

in beverages. We hypothesized that the perceptual features of interest (i.e., ice cubes, carbonation, and color) would influence the expected freshness of the drinks perceived in mouth.

Overall, the participants' RTs were significantly shorter for congruent bimodal stimuli than for incongruent pairs of auditory and visual stimuli. This result is in line with those obtained in previous studies which have investigated the impact of audiovisual interactions or other types of bimodal or trimodal interactions on participants' RTs (e.g., Evans and Treisman 2010; Gallace and Spence 2006; Hecht and Reiner 2009; Misselhorn *et al.* 2016). However, our results highlight that this effect depends on both the type and number of perceptual features involved in the audiovisual interaction, as well as on the type of response required from the participants. First, congruent audiovisual interactions linked to temperature (i.e., ice cubes presented visually and auditorily) induced shorter RTs when the participants categorized the stimuli as fresh and this effect was additive. The decrease in the participants' RTs in the presence of congruent bimodal sensory stimuli may be partly explained by the freshness categorization task which may lead to the activation of the content of the freshness category. Hence, the participants may have focused on the different perceptual features they generally associate with freshness. The fact that coldness is likely one of the main sensory contributors to freshness in beverages (as highlighted by our previous online experiment, see footnote 1) can thus partly explain the decrease in the participants' RTs. Further research is needed to disentangle the specificity of this effect toward freshness since congruent stimuli generally facilitate participants' performance independently of the task. The added value of the results obtained here is that, in a freshness categorization task, the sight of ice cubes was found to have a bigger influence than the sound of ice cubes and the sound of carbonation in the decrease of participants' RTs.

450 On the other hand, the congruency effect inducing shorter RTs for the congruent audiovisual
451 interactions linked to temperature is no longer obtained when there was visible carbonation in
452 the drink, the latter always inducing significantly longer RTs. Thus, in our study, the additive
453 effect of the sound and sight of ice cubes is lost when the stimulus itself becomes more
454 complex. This result suggests that it could be worth going further on research targeting
455 multisensory interactions since the more complex the stimulus becomes (i.e., by adding other
456 sensory cues), the more likely the crossmodal interaction effects can be enhanced or else
457 inhibited. In fact, few studies have considered crossmodal interactions with more than two
458 different perceptual features belonging to the same or different modalities, except those used
459 as distractors in the task. For instance, in Misselorn *et al.*'s (2016) study, a bimodal focus was
460 defined and the third modality was considered as a distractor modulating the congruency of
461 the trimodal interaction between auditory, visual, and tactile modalities. The study revealed
462 that the participants' RTs were shorter for congruent trimodal stimuli than for incongruent
463 ones. The fact that different results were obtained in our study can be attributed to the
464 complexity of the stimuli. In fact, the stimuli used sometimes displayed two different
465 perceptual features of interest belonging to the same modality at the same time (e.g., the sight
466 of ice cubes and the sight of carbonation instead of two perceptual features belonging to
467 different modalities). Moreover, the potential influence of confounding variables such as the
468 variation in visual turbidity of the different visual stimuli was not taken into account. It has to
469 be noted that the participants in Misselorn *et al.*'s study had to respond verbally to the stimuli
470 whereas in our study they answered by pressing one of two response keys. We hypothesize
471 that the modulation of the participants' attention could explain the loss of the additive effect
472 in our study. In fact, the participants' attention could have been directed more to the salient
473 foam on the surface of the liquid than to bubbles present within the liquid itself. In line with
474 this hypothesis, Guinard *et al.* (1998) found that foam decreased the thirst-quenching

character of beers, a psychophysiological factor which has been shown to be positively correlated with the perception of freshness (see Labbe *et al.* 2009a). Although the sight of carbonation induced slower RTs whatever the interaction with ice cubes, the sound of carbonation induced shorter RTs in some conditions, in particular when interacting with the sight or the sound of ice cubes. Thus, it would be worth further investigating the influence of the sound of carbonation in freshness categorization tasks, in particular, when interacting with other perceptual features that positively influence people's perception of freshness in beverages.

4.2. The categorization of freshness is mainly influenced by the sight of ice cubes in a drink

Congruent bimodal interactions resulted in the participants categorizing the stimuli as fresh, mainly when ice cubes could be seen in the drink whereas minor contributions of the sound of ice cubes and both the sight and sound of carbonation were observed. In fact, as long as ice cubes could be seen in the drink, the participants were more likely to categorize the stimuli as fresh regardless of the carbonation condition. Thus, it would appear that the French participants who took part in the present study gave more weight to perceptual features linked to coldness (i.e., ice cubes) when they were asked to categorize various drinks as fresh or not fresh.

Regarding the influence of carbonation on the way in which the participants categorized the stimuli as fresh, contrasting results were obtained when compared to the results obtained for the participants' RTs for which the sight of carbonation slowed RTs. In fact, the results on the categorization of freshness highlight that the sight of carbonation still positively contributes to the proportion of stimuli that were categorized as fresh. However, this contribution remains minor as compared to the contribution of the sight and sound of ice cubes. It is possible that

the small differences in the exact volume of the foam as well as the location of the ice cubes in the glass in each condition may have influenced the allocation of the participants' attention, which could have been more directed to either the ice cubes, the foam, or both according to the condition. Moreover, since the visual stimuli used in our study were not dynamic, we can wonder whether the participants considered the bimodal stimuli as referring to one particular drink instead of just two distinct sensory inputs. The present study still lays the groundwork for more ecologically approaches that could take into account various sources of ecological validity: for instance, the use of dynamic stimuli instead of static stimuli (see Gvili *et al.* 2015). Manipulating other perceptual cues for which participants could infer temperature (e.g., condensation on the glass) and carbonation (e.g., sound of opening of carbonated beverages) would also allow researchers to extend the results of the present study.

4.3.The influence of the color of the liquid on participants' RTs and the categorization of freshness

Beyond the influence of audiovisual perceptual features linked to temperature and carbonation, the color of the stimuli was also manipulated. The results failed to show any influence of the color of the stimuli either on the participants' RTs, or on the categorization of freshness. This is not in line, to some extent, with the literature regarding freshness since the results obtained in several studies have highlighted, at least for American consumers, that particular colors of the liquid (clear, orange, and red) positively influenced the perceived freshness of beverages (Clydesdale *et al.* 1992; Zellner and Durlach 2002). However, no consensus emerged concerning the interpretation of brown drinks in these studies. It would seem that the effect of color on the perception of freshness depends on several factors such as the type of measure (quantitative *versus* qualitative), the corresponding flavor (expected or actually tasted), and likely on the participants' cultural background or, at least, their learned freshness-colors associations (see Wan *et al.* 2015). One could, for instance, imagine that a

dark brown liquid might remind people of coffee, whereas the same drink with carbonation would immediately connote a cola drink instead. Finally, similarly to Fenko *et al.*'s (2009) results, the present findings suggest that the interactions between the different perceptual features used in our study may have caused sensory dominance inducing a minor contribution of color on the categorization of freshness as compared to other sensory cues (see also Hecht and Reiner 2009 on sensory dominance).

It is important to note that the present study has certain limitations that should be taken into account in future studies. In relation with the color of the liquid and the potential association with a particular temperature of the beverage (e.g., coffee *versus* cola drink), it can be noted that some psychological traits associated to well-being might also influenced the participants' performances in our study. For instance, Zhong and Leonardelli (2008) have investigated the relation between the feeling of social exclusion in humans and the desire for warm food and drink. They highlighted that social exclusion is associated with feeling cool and leads to an increased preference for warm liquids (e.g., coffee) as compared to cold liquids (e.g., "icy coke"). Whether such a psychological trait may influence participants' performances in a speeded categorization task remains to be investigated.

Furthermore, in order to avoid any association with a particular beverage that the participants could consider as fresh *per se* (due to branding, labelling, or previously learned associations), no specific information on the beverages that the participants had to categorize (as fresh or not) was provided to our participants. However, it is likely that this lack of information might have induced different kinds of associations leading to inter-individual variability that could perhaps explain the lack of effect of color in our study. In this regards, including the color variable in the design as a between-participants factor might also reduce the possibility to reveal a color effect on freshness judgments. In fact, the number of participants per color was

550 quite small ($N=12$) and the mechanisms underlying some crossmodal interactions have been
551 shown to be relative and not absolute (see Spence 2011, on the relative aspect of crossmodal
552 correspondences). Consequently, having color as a between-participants factor did not allow
553 visual comparisons of the different colored beverages in our study.

554 Moreover, it should be noted that only one saturation of each of the 7 colors was used and that
555 the selection of different saturations might have produced different results. Hence, it remains
556 an open empirical question for future research to determine whether similar results could be
557 obtained towards freshness in more ecological conditions. For instance, the external validity
558 of the findings reported here could be investigated within the context of an advertisement by
559 accommodating both auditory and visual inputs. It would enable to understand how the
560 audiovisual interaction effects that may trigger consumers' freshness expectations translate
561 into the marketplace and whether or not higher levels of perceived freshness increase
562 purchase intention.

563 Finally, by avoiding the presence of organic ingredients (e.g., mint leaves) and directing the
564 participants' attention to the expected in-mouth freshness that they might perceive from the
565 different beverages, we aimed at constraining the interpretation of the word freshness
566 reducing the association with the ageing of organic ingredients or time delay. However, when
567 the participants answered to a beverage that contained visual ice cubes (or visual carbonation)
568 and subsequently answered to a visual stimuli with the same color but for which visual ice
569 cubes (or bubbles) were absent, it is possible that they interpreted this sequence as ice cubes'
570 melting (or bubbles vanishing). In this case, the meaning of freshness could have been
571 associated to the time delay between the preparation and the consumption of the drink.

572 Extending this hypothesis, the relation between an increasing time delay and a decreasing
573 perception of freshness of the beverages could also be associated to an increasing perception
574 of the microbial population. It has been shown that this source of poisoning may generate

575 incidental disgust in consumers that will reduce their preference for the products they perceive
576 as contaminated (see Hobbs & Roberts, 1987; Motoki and Sugiura, 2018).

577

578 On the basis of our results, it would appear that an interesting perspective for future
579 investigation would be to address the crossmodal interaction effects that can occur in the
580 categorization of freshness between different kinds of audiovisual perceptual features linked
581 to temperature, carbonation, and color. We believe that **such** mechanisms could be triggered
582 to facilitate consumers' categorization of a given product as fresh. This idea is in line with
583 some empirical studies that have highlighted that audiovisual inputs can significantly
584 influence the final percept of the product experienced (Piqueras-Fiszman and Spence 2015;
585 Spence 2015). However, the influence of other major sensory contributors (e.g., olfactory
586 cues) cannot be disregarded (Martin *et al.* 2005, see Auvray and Spence 2008; Spence *et al.*
587 2014, for reviews). Thus, one promising perspective would be to enrich the stimulus context
588 by adding sensory contributors **beyond** the audiovisual in order to generate additional results
589 on the multisensory mechanisms that underlie freshness perception in beverages. Enriching
590 that way the stimulus context by adding, step-by-step, distinct sensory contributors, is
591 required to generalize our results to more ecological contexts. Another interesting follow-up
592 in real consumption context would be to investigate the influence of ambient temperature
593 during the consumers' freshness evaluation of beverages while modifying the products'
594 temperature and color (see Motoki *et al.* 2018 who have shown that ambient warm
595 temperature decreases the preference for savory foods). Modulating the ambient temperature
596 might also enable **researchers** to understand the mechanisms that lead some populations living
597 in warm countries to consider hot beverages (e.g., hot mint tea in North Africa) as fresh or
598 refreshing (see Roque *et al.* 2018 for the distinction between these two concepts). In addition,

it might be interesting in future research to investigate if the color of the liquid plays a bigger role in modulating freshness perception for hot as compared to cold beverages.

5. Conclusions

To summarize, the results of the present study highlight how both visual and auditory perceptual features linked to temperature and carbonation can influence the categorization of freshness in beverages. In particular, a two-fold effect has been revealed regarding the congruency of the interaction between the visual and the auditory features. First, the decrease in RTs for congruent bimodal stimuli depends on both the type and number of perceptual features involved as well as on the type of response. In particular, the sight of ice cubes mostly contributed to the decrease in the participants' RTs when the stimuli were categorized as fresh, followed by the sound of ice cubes, and the sound of carbonation. On the other hand, the sight of carbonation induced longer RTs potentially caused by the modulation of the participants' attention. Second, congruent bimodal stimuli that displayed the perceptual features of interest have induced an inclination for participants to be more likely to categorize the stimuli as fresh. In particular, the sight and sound of ice cubes mostly contributed, followed by the sound and sight of carbonation. Even though no effect of color was observed here, we believe that it certainly depends on several factors such as the type of measure (quantitative *versus* qualitative), the corresponding flavor (expected or actually tasted), the meaning of freshness that is targeted, and likely on the participants' cultural background or, at least, on their learned freshness-colors associations as well. Thus, further investigations regarding multisensory interactions in the case of freshness perception in beverages could extend the results obtained here to shed new light on the congruency effect and the respective contributions of the perceptual features involved. In particular, if specific mechanisms such as crossmodal correspondences can be triggered upstream (i.e., in anticipation) of the

consumption phase, it could positively influence freshness perception and may ultimately increase beverage attractiveness and appreciation.

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¹ Ice cubes were selected as the most relevant perceptual feature of interest for which participants could infer the temperature of the drink, and consequently the expected perceived freshness in mouth, among the range of eligible sensory cues (e.g., condensation on the glass).

² Carbonation in our study refers to both bubbles present within the liquid and the foam on its surface.

³ Initially, an online experiment was conducted through an internet-based testing tool (Qualtrics©) with 84 North American participants (50% female, mean age 33.8) in order to investigate the potential influence of the targeted stimuli (i.e., audiovisual perceptual features cuing temperature, carbonation, and color) on the perception of freshness. In this pilot study, the participants had to rank the perceived freshness of each bimodal stimulus corresponding to a particular beverage, on a 9-point Likert scale ranging from “Not fresh at all” to “Very fresh”, as rapidly as possible. Viewing ice cubes had a significant positive effect on the participants’ freshness ratings whatever the interaction with carbonation, $p < .001$ ($b = 0.64$, $t(1) = 9.1$, effect size: Pearson’s correlation coefficient $r = 0.99$). However, the sound of ice cubes had a significant negative effect on the freshness ratings, $p < .001$ ($b = -0.31$, $t(3) = -4.4$, effect size: $r = 0.93$). Both the sound ($b = 0.46$, $t(4) = 5.3$, effect size: $r = 0.94$) and sight ($b = 0.1$, $t(2) = 0.97$, effect size: $r = 0.57$) of carbonation significantly increased the participants’ freshness ratings, $p < .001$. Moreover, this effect was additive when the two were presented together. The color of the beverage had no effect on the freshness ratings ($F = 0.76$). To be noted that the effect sizes “ r ” reported in this study have been computed as Pearson’s correlation coefficients, as advised by Field and colleagues (2012). “ r ” was computed as $r =$

$\sqrt{(t^2/(t^2+df))}$, where t stands for the individual t values for each level of variables stored in the model and df contain the degrees of freedom. r may thus range from 0 (no effect) to 1 (a perfect effect). The effect is considered as large when r is equal or higher than 0.5. When $r=0.5$, the effect accounts for 25% of the variance.

FIG. 1. PICTURES OF THE DIFFERENT VARIATIONS IN TEMPERATURE AND CARBONATION, FOR THE BROWN FOOD-COLORING.

FIG. 2. TIMELINE. ISI: Intertrial Stimulus Interval. Note that the assignment of the two response keys was counterbalanced across participants.

FIG. 3. MEAN RTs (IN MS) FOR THE THREE-WAY INTERACTIONS BETWEEN (1) THE SIGHT OF ICE CUBES AND THE DIFFERENT CARBONATION CONDITIONS; (2) THE SOUND OF ICE CUBES AND THE DIFFERENT CARBONATION CONDITIONS. The error bars represent the SEM. (1): for both solid and hatched black lines, respectively, all means are significantly different from each other. Except in the No carbonation condition, all means in the presence of ice cubes are always significantly different from the means in the absence of ice cubes. (2): For both solid and hatched lines, all means are significantly different from each other. Except in the No carbonation condition, all means in the presence of ice cubes are always significantly different from the means in the absence of ice cubes.

FIG. 4. MEAN RESPONSES (%) FOR THE CATEGORIZATION OF FRESHNESS ACCORDING TO (1) THE DIFFERENT CARBONATION CONDITIONS AND THE SIGHT OF ICE CUBES; (2) THE DIFFERENT ICE CUBES CONDITIONS AND THE

818 SIGHT OF CARBONATION. N=84 for each condition. The error bars represent the SEM.
819 (1): All the represented means are significantly different from each other, except the
820 comparisons between the light-gray and the hatched bars in the No sight of ice cubes
821 condition and the white and the dark-gray bars in the Sight of ice cubes condition,
822 respectively for not fresh and fresh categories that failed to reach statistical significance. (2):
823 All the represented means are significantly different from each other, except the comparisons
824 between the dark-gray bars in the 'No sight of carbonation' condition and those in the 'Sight
825 of carbonation' condition, respectively for not fresh and fresh categories that failed to reach
826 statistical significance.