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Jérémy Roque

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Ecole doctorale Cerveau-Cognition-Comportement (ED3C, ED n°158)

Institut des Systèmes Intelligents et de Robotique / Interaction

Am I expecting this drink to be fresh?

The influence of audiovisual interactions on perceived freshness in beverages

Jérémy Roque

Doctoral thesis in cognitive science

Supervised by Malika Auvray, PhD

Defended on December 7, 2018

Jury composition:

Dominique Valentin	PhD, AgroSup Dijon, CSGA, Dijon, France	Referee
Massimiliano Zampini	Pr, University of Trento, Italy	Referee
John Prescott	PhD, director of TasteMatters Research & Consulting	Examiner
Isabelle Cayeux	PhD, principal research scientist Firmenich, Switzerland	Examiner
Emmanuel Guigon	PhD, Sorbonne Université, CNRS, ISIR, Paris, France	Examiner
Jérémie Lafraire	PhD, Institut Paul Bocuse Research Center, Ecully, France	Examiner
Malika Auvray	PhD, Sorbonne Université, CNRS, ISIR, Paris, France	Thesis director

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GENERAL INTRODUCTION

« La Nature est un temple où de vivants piliers
Laissent parfois sortir de confuses paroles ;
L'homme y passe à travers des forêts de symboles
Qui l'observent avec des regards familiers.

Comme de longs échos qui de loin se confondent
Dans une ténébreuse et profonde unité,
Vaste comme la nuit et comme la clarté,
Les parfums, les couleurs et les sons se répondent. »

Charles Baudelaire, Correspondances, Les Fleurs du Mal (1857)

"Nature is a temple in which living pillars
Sometimes give voice to confused words;
Man passes there through forests of symbols
Which look at him with understanding eyes.

Like prolonged echoes mingling in the distance
In a deep and tenebrous unity,
Vast as the dark of night and as the light of day,
Perfumes, sounds, and colors corresp*ond."*

English translation by William Aggeler, The Flowers of Evil (Fresno, CA: Academy Library Guild, 1954)

In the middle of the nineteenth century, Charles Baudelaire already evoked the multisensory aspect of the world in which human beings evolve and the way the various sensory information may interact, shaping the interface with our surrounding environment. From a slightly different perspective, the present PhD project aims at increasing knowledge of the Human-Food interaction with a focus on consumers' expectations, crossmodal interactions, and categorization judgments. In particular, the present dissertation focuses on the multisensory perception of freshness in alcoholic beverages, intended as perceiving a beverage as fresh, based on visual and auditory sensory cues.

1. The multisensory perception of freshness in beverages: state of the art from the consumer science literature

Refreshing or freshness are common terms often used to characterize certain types of foods and beverages. These concepts have received recent consideration in the field of consumer science mainly because of their hedonic dimension, which is assumed to influence consumers' preference and behavior. According to Labbe, Almiron-Roig, Hudry, Leathwood, Schifferstein, & Martin (2009a) who wrote the most recent literature review on refreshing perception, its sensory basis, and its top-down modulating factors (e.g., learned associations), refreshing is linked to physiological factors such as thirst-quenching and arousal. Moreover, the authors highlighted that refreshing has been associated with specific sensory characteristics related to psychophysiological states linked with water drinking, modulated by previous experiences. According to Labbe et al. (2009a), the concepts of refreshing and oral freshness seem to be closely linked since they have common sensory drivers such as coldness and mint flavor. In fact, several experimental studies have reported the existence of shared attributes between refreshing and freshness. For instance, Bouteille, Cordelle, Laval, Tournier, Lecanu, This, and Schlich (2013) conducted a study in France to investigate the underlying sensory attributes of freshness sensation in plain yoghurts and yoghurt-like products and they considered the word ''fraîcheur'' (the French translation of ''freshness'') in French dictionaries (Le Grand Larousse Illustré, 2005; Trésor de la langue française informatisé, 2012). The four main meanings found were: (1) newness, possessing original qualities unimpaired, (2) coolness, moderate coldness, (3) ability to restore life and energy, and (4) purity. Thus, the proximity between refreshing and freshness appears regarding the link with arousal and some specific sensory characteristics (e.g., coolness, coldness). Moreover, when considering the word ''rafraîchissant'' (the French translation of ''refreshing'') in French dictionaries, the associated definition is "giving freshness". Regarding manufactured beverages, it has also been shown that freshness perception is closely linked to their refreshing properties (Labbe et al., 2009a). For instance, the refreshing sensation of beers has been associated with a cooling sensation (Guinard, Souchard, Picot, Rogeaux, & Sieffermann, 1998). A similar observation was reported by Zellner & Durlach (2002) who showed that 92% of 86 American students listed ''cold'' and ''cool'' when asked to list 10 characteristics of refreshing food and beverages. 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, Du-Plessis, Dommels, &

Wilkinson, 2013; Labbe et al., 2009a; Zellner & Durlach 2002), water (Labbe, Martin, Le Coutre, & Hudry, 2011), and soft drinks (McEwan & Colwill, 1996; Saint-Eve, Déléris, Feron, Ibarra, Guichard, & Souchon, 2010; Zhang, Lusk, Mirosa, & Oey, 2016).

In the present thesis, we address the concept of freshness in beverages instead of refreshing because the term refreshing is more directed toward the post-consumption phase, together with the impact cold beverages may have on arousal or thirst-quenching sensation (Labbe, Gilbert, Antille, & Martin, 2009b). Moreover, 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 or sourness that will contribute to an actual perception of freshness, but also some visual cues for instance, that may trigger freshness expectations), (ii) the aging of the organic ingredients contained in the drink (e.g., aging of the mint leaves in a mojito), or else (iii) the time delay to which the drink has been prepared before being served. This semantic ambiguity and its potential consequences on perception will be more described in chapter 1 and chapter 4. In the following sections, we will thus refer to “perceived freshness” because it covers both the expected and the actual sensation of a given product.

The multisensory aspect of refreshing and freshness perception has often been reported by previous studies that have investigated freshness, or positively correlated psychophysiological concepts such as thirst-quenching, for different types of products (see Table 1). Previous studies that used beverages, oral care category products, or household products have all tended to define freshness as the result of the multisensory integration of olfactory, gustatory, tactile, trigeminal, visual, and auditory cues (e.g., Fenko, Schifferstein, Huang, & Hekkert, 2009; Labbe et al., 2009b; Saint-Eve et al., 2010; Westerink & Kozlov, 2004).

Table 1. Summary of the different categories of sensory descriptors that have been reported to influence expectations and/or actual perception of freshness in beverages or semi-solid products

Each column contains sensory descriptors (spontaneously generated by consumers or provided by authors) that have been reported to influence positively (left column) or negatively (right column) freshness perception (or positively correlated psychophysiological term: refreshing/thirst-quenching/drinkability). The online consumer survey (2015), the expert interviews (2015), and the consumer test (Roque, Lafraire, Giboreau, Brit, Petit, & Garrel, 2016, poster presented at Eurosense) correspond to non-published data coming from three experiments that have been conducted at the beginning of the PhD project by the R&D team of the Institut Paul Bocuse Research Center (see methodological details in Annexes 1-3).

Increasing the expected or actual perceived freshness	Decreasing the expected or actual perceived freshness
Descriptor (**targeted perception** product studied: Authors, year of publication)	**Descriptor** (**targeted perception** product studied: Authors, year of publication)
Basic tastes: **- Sourness** (**freshness/ refreshing** soft drinks: Fenko et al., 2009; **refreshing** gels and water: Labbe et al., 2009a,b, 2011; **thirst-quenching** soft drinks: McEwan & Colwill, 1996; **freshness** soft drinks : Saint-Eve et al., 2010; **freshness** orange juices: Zhang et al., 2016; **freshness** alcoholic beverages: expert interviews, 2015) **- Slight acidity** (**freshness** plain yoghurts and yoghurt-like products: Bouteille et al., 2013)	**Basic tastes:** **- Sweetness** (**refreshing** beers: Guinard et al., 1998; **refreshing** gels: Labbe et al., 2009a; **thirst-quenching** soft drinks: McEwan & Colwill, 1996; **freshness** soft drinks in absence of CO2: Saint-Eve et al., 2010; **freshness** alcoholic beverages: expert interviews, 2015) **- Bitterness** (**freshness** plain yoghurts and yoghurt-like products: Bouteille et al., 2013; **thirst-quenching** beers: Guinard et al., 1998) **- Saltiness** (**thirst-quenching** liquid: waters, soft drinks, fruit juices, soups, semi-solid: yoghurt, jelly, porridge: McCrickerd et al., 2015) **- Metallic** (**thirst-quenching** beers: Guinard et al., 1998)

<u>**Colors:**</u> ➢ **Expectations:** **- Clear (36%), brown (24%)** (**thirst-quenching** soft drinks: Clydesdale et al., 1992) **- Clear (41%), red (33%), orange (30%)** (**refreshing** food & beverages: Zellner & Durlach, 2002) ➢ **Expectations: Color-flavor combination:** (**refreshing** soft drinks: Zellner & Durlach, 2003) -Lemon: **clear (75%), orange, red, yellow (>50%)** -Mint: **clear (73%), green, orange, red (>50%)** -Vanilla: **clear (71%), red, orange (>50%)** ➢ **Tasting: Color-flavor combination:** (**refreshing** soft drinks: Zellner & Durlach, 2003) -Lemon: **purple, clear (>40%)** -Mint: **clear (>40%)** -Vanilla: **no consensus**	<u>**Colors:**</u> ➢ **Expectations:** - **Black (64%), Brown (40%)** (**refreshing** food & beverages: Zellner & Durlach, 2002) ➢ **Expectations: Color-flavor combination:** (**refreshing** soft drinks: Zellner & Durlach, 2003) -Lemon: **brown** -Mint: **brown** -Vanilla: **green** ➢ **Tasting: Color-flavor combination:** (**refreshing** soft drinks: Zellner & Durlach, 2003) -Lemon: **brown** -Mint: **brown** -Vanilla: **red**
Color of the plastic cup: blue and green (cold colors) (compared to red and yellow - warm colors) (**thirst-quenching** soda: Guéguen, 2003)	**Color of the plastic cup: red (compared to white)** (**freshness** still water: Risso et al., 2015)
<u>**Odors:**</u> **-Mint** (**refreshing** gels: Labbe et al., 2009a) **-Peppermint** (**freshness/refreshing** soft drinks: Fenko et al., 2009) **-Lemon and grapefruit smells** (**fresh/ refreshing** soft drinks: Fenko et al., 2009)	**Astringency** (**thirst-quenching** of beer: Guinard et al., 1998)
<u>**Flavors:**</u> **-Orange** (**refreshing** food & beverages: Zellner & Durlach, 2002) **-Strawberry** (**refreshing** food & beverages: Zellner & Durlach, 2002) **-Mint** (**tingling + freshness**)(**fresh** soft drinks : Saint-Eve et al., 2010)	<u>**Flavors:**</u> **-Chocolate** (**refreshing** food & beverages: Zellner & Durlach, 2002) **-Sweetener-like** (**freshness** orange juices: Zhang et al., 2016) **- Strong flavor intensity** (**refreshing/cooling**, **thirst-quenching** and **drinkable** beers: Guinard et al., 1998)

-Cream flavoring (**freshness** plain yoghurts and yoghurt-like products: Bouteille et al., 2013)	**-Milk** (**freshness** plain yoghurts and yoghurt-like products: Bouteille et al., 2013)
Aromas: **-Lemon, orange, mint (menthol)** (**refreshing** gels: Labbe et al., 2009a; **refreshing** food & beverages: Zellner & Durlach, 2002) **-Citrus, peach** (**refreshing** complex sensory attributes: Martin et al., 2005) **-Fresh herbs**, **citrus, tropical fruits, red and yellow fruits** (**freshness** alcoholic beverages: online consumer survey, 2015)	**Aromas:** **-Chocolate** (**refreshing** gels: Labbe et al., 2009a; **refreshing** food & beverages: Zellner & Durlach, 2002)
Associated ingredients: herbs (fresh mint), lemon (**freshness** alcoholic beverages: expert interviews, 2015)	**Malty, hoppy, burnt, after-taste, acidic** (**thirst-quenching** beers: Guinard et al., 1998)
Carbonation (**thirst-quenching/drinkability** beers: Guinard et al., 1998; **thirst-quenching** carbonated lemon drink: McEwan & Colwill, 1996; **thirst-quenching** soft drinks: Peyrot des Gachons et al., 2016; **freshness** alcoholic beverages: expert interviews, online consumer survey, and consumer test, 2015)	**Carbonation/High level of fizziness** (**thirst-quenching** soft drinks: Booth, 1991) **Foam** (**thirst-quenching** beers: Guinard et al., 1998)
Coldness (**freshness** plain yoghurts and yoghurt-like products: Bouteille et al., 2013; **refreshing** gels and waters: Labbe et al., 2009a,b, 2011; **thirst-quenching** soft drinks: Peyrot des Gachons et al., 2016; **refreshing** food & beverages: Zellner & Durlach, 2002; **freshness** alcoholic beverages: online consumer survey, 2015)	**High degree of alcohol** (**freshness** alcoholic beverages: expert interviews and online consumer survey, 2015)
Fluid texture (**freshness** plain yoghurts and yoghurt-like products: Bouteille et al., 2013) **Light texture** (**freshness** alcoholic cocktails: online consumer survey and consumer test, 2016)	**Thickness** (**freshness** plain yoghurts and yoghurt-like products: Bouteille et al., 2013; **thirst-quenching** beers: Guinard et al., 1998; **refreshing** gels: Labbe et al., 2009a; **satiation, satiety and thirst** liquid: waters, soft drinks, fruit juices, soups, semi-solid: yoghurt, jelly, porridge: McCrickerd et al., 2015; **thirst-quenching** soft drinks: McEwan & Colwill, 1996; **thirst-quenching** alcoholic beverages: Scriven et al., 1989; **freshness** alcoholic beverages: expert interviews, 2015) **Viscosity** (**thirst-quenching** of beer: Guinard et al., 1998; **freshness** alcoholic cocktails: online consumer survey, 2015 and consumer test, 2016)

High fat content products (**freshness** fermented milks: Bouteille et al., 2013)	**High caloric content and filling sensation** (**refreshing/cooling**, **thirst-quenching** and **drinkable** beers: Guinard et al., 1998)

Some research have shown different patterns of sensory dominance regarding the various sensory inputs contributing to freshness. However, if we focus specifically on the multisensory perception of freshness in beverages, it can be noted that there is currently little consensus regarding the respective contributions of the various sensory cues that might be involved. For instance, Fenko et al. (2009) documented that for soft drinks, olfactory cues dominated over visual color cues as far as freshness judgments were concerned, based on a collection of declarative data using 9-point scale assessment. Meanwhile, Labbe et al. (2009b) used edible gels, varying in their olfactory (mint and peach), trigeminal (coldness), taste (acidity), and texture (thickness) properties. The latter study revealed the fact that people differed in the main sensory modality 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. Once again, these results are based on declarative data from a trained sensory panel and a consumer test using scale assessments. In another study, Westerink and Kozlov (2004) investigated what constitutes oral 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 show 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 in long-term memory (e.g., particular compounds such as menthol). Thus, the main sensory contributor associated with freshness also seems to depend on several parameters such as the product itself, the time-course of consumption (in the case of beverages), and the past learned associations of consumers.

In terms of methodology, the majority of consumers' studies on freshness perception to date have focused on consumers' expectations by a collection of declarative data, using for instance self-administered questionnaires or visual analog scales (e.g., Bouteille et al., 2013; Fenko et al., 2009; Risso, Maggioni, Olivero, & Gallace, 2015). The literature described above has shown that an important inter-individual variability appears regarding the perception of freshness in beverages when consumers have to generate sensory descriptors on their expected or actual experience of freshness, or when they have to assess the intensity of particular sensations. Research conducted in sensory analysis on complex perception generally interpret this variability as a consequence of several modulating factors such as familiarity with the tested products, individual preferences, or participants' culture (e.g., Parr, Ballester, Peyron, Grose, & Valentin, 2014). Given the complexity of the cognitive mechanisms involved in multisensory perception in the food domain (see Foroni & Rumiati, 2017; Verhagen & Engelen, 2006 for reviews), the use of more objective measures of behavior (i.e., categorization or recognition tasks) would appear as a relevant additional approach. We believe that the use of implicit methodologies represent a promising complementary approach in order to get a better understanding of the multisensory processes at stake with regard to food and beverage. In terms of applied purposes, this might help companies to better understand consumers' expectations of their products and rationalize the process of a new product formulation for instance.

In order to introduce the research hypotheses of the present thesis (chapter 3), the next section presents a summary of the theoretical debates and advances on the multisensory integration processes underlying flavor perception. In addition, we shed light on the reasons why we focus on visual and auditory sensory cues, instead of gustatory and olfactory cues for instance, in order to increase knowledge on the crossmodal interaction effects that may influence consumers' freshness expectations in beverages.

2. Theoretical debates and advances on the multisensory integration processes underlying flavor perception

As opposed to the very poor literature on the multisensory integration processes underlying freshness perception, flavor is the only one type of multimodal perception in the food and beverage domain that has been widely studied, both in consumer science, psychology, and cognitive neuroscience (Auvray & Spence, 2008; Delwiche, 2004; Prescott, 2015; Shepherd, 2012; Small, 2012; Spence, 2015; Verhagen & Engelen, 2006, for major reviews). Then, it appeared as relevant to consider this extensive literature on flavor in order to see whether similar cognitive mechanisms could be involved in freshness perception and which type of experimental approach would be the most appropriate.

In terms of definition, Small and Prescott (2005) proposed that flavor represents a functional sensory system with inputs from somatosensation, gustation, and olfaction where the key would be the functional meaning of the sensation rather than its precise organ or site of origin. For instance, orthonasal olfaction is important in the detection and identification of food since it may help the individual to avoid ingesting poisonous substances. Then, the cognitive system will build an association between the food, its corresponding odor, and its physiological consequences. This information will be stored in memory and will influence the subsequent experiences. Small and Prescott (2005) relate their concept of flavor to the ecological approach proposed by Gibson (1966) in which perceptual systems are defined by function, rather than tied to the organ of transduction.

Beyond the contribution of chemosensory cues (i.e., taste and smell), some authors have claimed that visual and auditory cues that we perceive when eating or drinking should also be taken into account in flavor perception, which finally constitutes a unified percept of the different qualities of foodstuffs (Auvray & Spence, 2008; "Sensory fusion" in Fig. 1).

Regarding the respective contributions of each sensory input, there is a general consensus on the fact that flavor actually results from the retronasal stimulation of the olfactory receptors in the nose and very (or relatively) little from the stimulation of the gustatory receptors on the tongue (Murphy, Cain, & Bartoshuk, 1977; Shepherd, 2012). The somatosensory system has been presented as the third sensory contributor to flavor (e.g., Stevenson, 2012) but the crossmodal interactions resulting from the concurrent association of odors, tastes, and somatosensation (mainly the experience of texture in mouth) of food and beverage products are still under investigation.

Despite the extensive literature on the multisensory integration processes underlying flavor perception, no consensus has been reached so far. For instance, it is generally assumed that a conflict occurs systematically between the spatial information conveyed by the taste signal and the spatial information conveyed by the smell signal, especially the retronasal one (Small and Prescott, 2005). The perceptual consequence of this conflict resolution by the cognitive system is that sensations originating in the nose are "referred to" or experienced as if they were transduced by the receptors in the mouth (Spence, Smith, & Auvray, 2014). This perception of something as appearing to come from the mouth has been called the "location binding" (Stevenson, Prescott, & Boakes, 1995). Other terms such as the "olfactory illusion" (Prescott,

1999) or the "mouth capture" (Shepherd, 2012) have also been used. In other words, it corresponds to the situation in which sensations occurring, or originating, in the nose are "referred to" or experienced as if they were being transduced by the receptors in the mouth (Spence et al., 2014).

It has been suggested that the mouth capture phenomenon could be due to the fact that tactile stimulation is able to capture taste, presumably by providing superior spatial information and enhancing localization (Lim & Green, 2008; Todrank & Bartoshuk, 1991). Tactile information in mouth may therefore have an important role in binding tastes with odors, or odors with tastes for physical stimuli such as a food. However, Lim and Johnson (2012) found that the presence of somatosensory stimulation itself was not sufficient to cause retronasal odor referral to the mouth and it appears that this is more the presence of a congruent taste that significantly increases retronasal odor referral to the mouth. Thus, it seems that other conditions influence the multisensory integration processes occurring in flavor perception (see chapter 1). Nevertheless, the fact that gustatory stimulation cannot be achieved without touch raises the possibility that tactile stimulation may contribute indirectly to retronasal odor referral to the mouth. To add more complexity, somatosensation is involved in the experience of food texture via receptors located within the various tissues of the mouth (Christensen, 1984), but it also transduces sensations relating to temperature, irritation and pain.

Another aspect of complexity in the investigation and the understanding of flavor perception, when considering the interaction between smell, taste, and somatosensation, is that the contribution of olfaction to flavor is largely unnoticed, even when participants are asked to detect its presence. Stevenson (2012) hypothesized that exogenous attentional processes (which depend on stimulus characteristics such as intensity and/or saliency) may be more important in generating oral localization, and when engaged, these may be difficult to voluntarily override. These various findings suggest that the unitary experience of olfaction in flavor is to some degree an attentional phenomenon. Stevenson distinguished this attentional phenomenon in two ways. First, the failure of most people to know that retronasal olfaction is involved in flavor, and second, the difficulty that they have in detecting the olfactory components of flavor may result from concurrent oral stimulation's capturing attention at the expense of olfaction, as mentioned above. Moreover, in neuroimaging studies, odors presented retronasally (via the mouth) have been shown to activate the mouth area of primary somatosensory cortex (where oral touch information is processed), whereas the same odors presented orthonasally do not (Small, Gerber, Mak, & Hummel, 2005). This distinction, which occurs even when subjects are unaware of route of stimulation, suggests a likely neural correlate of the binding process, and supports the idea that somatosensory input is the underlying mechanism. The binding of odors, tastes, and tactile qualities into flavors has thus been referred to a psychological construct (Prescott, 1999; Small, 2012). That is, it relates to a functional, learned joint property rather than a chemical interaction. Thus, top-down modulating factors such as attention and memory inherently participate to the construction of our flavor representations (see Fig. 1).

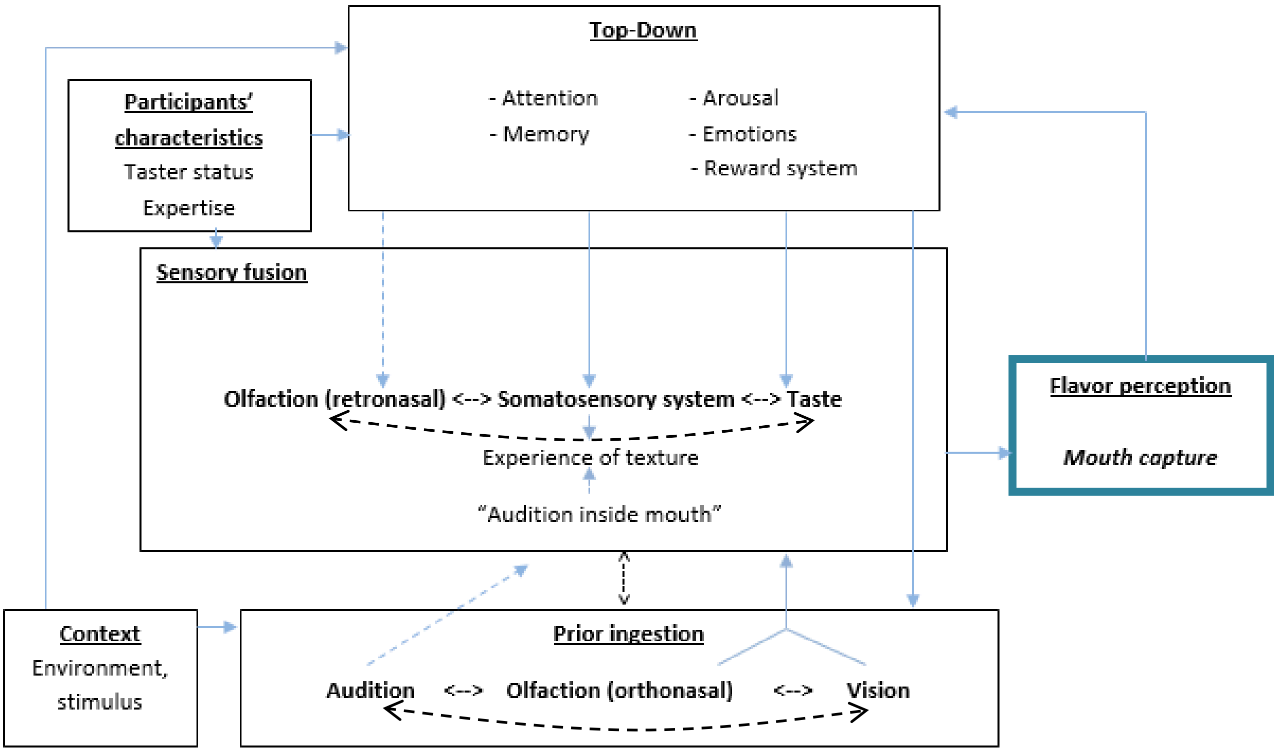

Figure 1: Typology of the bottom-up and top-down factors modulating flavor perception

Main influences
Minor influences
<--> Crossmodal interactions

To sum up, during the consumption of a food or beverage, we all perceive flavor that contributes to our food learning associations and long-term preferences. The investigation of the multisensory integration processes underlying flavor is challenging since the various sensory modalities cannot be properly disentangled in mouth due to the concomitant influence of taste, smell (retronasal), and somatosensation. Nevertheless, it is reasonable to hypothesize that flavor is not the only multimodal representation that matters in the food domain. In fact, in the literature review presented in chapter 1, we will argue that thoroughly considering a particular instance of flavor such as freshness can bring new insights regarding the theoretical debates at hand in flavor perception. For instance, considering flavor or freshness as unified percepts or

not may have various consequences regarding the overall product experience such as different intensity judgments toward the various sensory inputs or different subjective locations of the final percept (e.g., mouth capture in the case of flavor perception).
With regards to the multisensory perception of freshness in beverages and as a first investigation of the crossmodal interaction effects that may influence the corresponding final percept, it might thus be interesting to increase knowledge and better understand the cognitive mechanisms at stake before the actual consumption. In particular, there is still a lack of information on the interaction effects between visual and auditory cues that may indirectly influence the subsequent consumers' experiences by triggering specific sensory expectations (see Piqueras-Fiszman & Spence, 2015; Spence & Wang, 2015 for recent reviews).

This PhD project thus aimed at investigating what the higher degree of specificity of freshness implies regarding the multisensory mechanisms at hand and whether or not the cognitive mechanisms previously identified in flavor perception may be applied mutatis mutandis to freshness. To do so, we first review and discuss the different representational natures that have been suggested to date for flavor and we highlight what are the theoretical and empirical implications for freshness (chapter 1). In terms of methodology, we exploit categorization processes and implicit measures of behavior (chapter 2) to investigate crossmodal interaction effects involving visual and auditory cues that, as we hypothesize, could increase beverages' attractiveness and facilitate consumers' categorization of a given product as fresh (chapter 4). A particular form of crossmodal interactions named crossmodal correspondences was investigated toward specific perceptual features reported to increase the perceived freshness in beverages (chapters 5 and 6).

Within this context, the present PhD project is a joint initiative by the Institut Paul Bocuse Research Center, the Institut des Systèmes Intelligents et de Robotique hosted at Sorbonne University (UMR7222), and Pernod Ricard France, which financially supported the project. At the theoretical level, the aim of this PhD project, started in November 2015, is to explore the sensory and cognitive factors that underlie the multisensory perception of freshness, in the particular case of beverages. A focus was made on the influence of audiovisual crossmodal interactions that may influence the perceived freshness, upstream of the consumption phase. The modulating effects of some top-down factors (e.g., attention) were also considered. At the applied level, the aim of this PhD is to provide some clues regarding the perceptual and top-down factors that can efficiently stimulate the innovation strategy of the Pernod-Ricard group through product formulation and marketing applications.

3. Thesis dissertation's structure

The present thesis dissertation comprises six chapters, articulated in four parts. It begins with a literature review on the cognitive mechanisms underlying the multisensory perception of flavor and freshness (Part A, chapter 1), a second chapter targeting some methodological aspects to justify the chosen approach of the present PhD project (Part A, chapter 2), and a presentation of the research questions and hypotheses, as well as short descriptions of the methodology used for each experiment (Part A, chapter 3).

Part B contains one chapter (chapter 4), presented as a paper written in journal format. This chapter presents the first two experimental studies that have been conducted to investigate the influence of specific audiovisual perceptual features and their interaction effects on freshness ratings and freshness categorization in beverages.

Part C contains one chapter (chapter 5) also presented as a paper written in journal format (submitted). Chapter 5 presents two experimental studies that have been conducted to investigate the potential existence of crossmodal correspondence effects between specific features related to carbonation in beverages (i.e., bubbles size and pouring sounds pitch: Pitch-Size correspondence). The first study aimed at providing evidence of Pitch-Size correspondence effects between the targeted stimuli. The second study aimed at investigating the relative effects of the two associations involved in the Pitch-Size correspondence, and determine whether these effects were robust enough to variations of the stimulus context (i.e., color of the liquid and width of the glass).

Part D contains one chapter (chapter 6) presented as a paper written in journal format (in preparation). Chapter 6 presents the last experimental study that has been conducted to investigate the transitivity aspect that may exist between particular intra- and crossmodal correspondences. In particular, this study aimed at showing the existence of crossmodal associations between bubbles size, pouring sounds pitch, and spatial elevation. An attentional paradigm using direct and indirect tasks enabled us to discuss in which way the different crossmodal correspondences investigated affect the allocation of attention and at which level (perceptual vs. higher order cognitive level) these correspondences might occur.

A general discussion gives an overview and discussion of the thesis as a whole, including a summary of the main findings and the contribution of the empirical chapters (4-6) to current understanding about (i) the multisensory integration processes that underpin freshness perception in beverages, (ii) the top–down factors that influence the explicit attribution of freshness to a beverage by consumers, and (iii) the methodological issues that are inherent to research projects in cognitive science targeting a complex perception such as freshness in the food and beverage domain. Finally, different research perspectives that appear as relevant to further investigate are presented and a general conclusion closed the thesis dissertation.

PART A. LITERATURE REVIEW AND RESEARCH HYPOTHESES

Chapter 1. Understanding freshness perception from the cognitive mechanisms of flavor: the case of beverages

This chapter presents the literature review that has been conducted on the multisensory perception of flavor and freshness. Its aim is to provide a better understanding of the research approach that has been considered in this PhD project from which we draw the research hypotheses (chapter 3) tested in the experiments reported here.

From a consumer's perspective, it makes perfect sense to consider flavor and freshness as intrinsic attributes of food. However, we endorsed a slightly different perspective in this PhD project by considering that these attributes are relational (and consequently are different from the intrinsic properties in the strict sense such as chemical composition). The same analysis has been recently suggested for flavor perception by several authors who present flavor as a complex representation that is constructed by our cognitive system through the different processing steps and the transformation of the initial pieces of information coming from the stimulus (e.g., Shepherd, 2012).

Thus, we exploited the existing literature on flavor perception to shed light on the mechanisms involved in the perception and categorization of freshness in beverages. More precisely, we describe and compare the structure and content of flavor and freshness representations. To do so, we review the competing theses that have been considered until now and we focus on i) the multisensory integration processes that underpin flavor and freshness perception, and ii) the top-down factors that may influence the explicit attribution of freshness to a product or the categorization of a product as fresh by consumers.

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Understanding Freshness Perception from the Cognitive Mechanisms of Flavor: The Case of Beverages

Jérémy Roque[1,2,3], Malika Auvray[3] and Jérémie Lafraire[2,4]*

[1] Centre de Recherche Pernod Ricard, Créteil, France, [2] Center for Food and Hospitality Research, Institut Paul Bocuse, Écully, France, [3] Institute of Intelligent Systems and Robotics, Université Pierre et Marie Curie, Paris, France, [4] Institut Jean Nicod, Ecole Normale Supérieure, Paris, France

Freshness perception has received recent consideration in the field of consumer science mainly because of its hedonic dimension, which is assumed to influence consumers' preference and behavior. However, most studies have considered freshness as a multisensory attribute of food and beverage products without investigating the cognitive mechanisms at hand. In the present review, we endorse a slightly different perspective on freshness. We focus on (i) the multisensory integration processes that underpin freshness perception, and (ii) the top–down factors that influence the explicit attribution of freshness to a product by consumers. To do so, we exploit the recent literature on the cognitive underpinnings of flavor perception as a heuristic to better characterize the mechanisms of freshness perception in the particular case of beverages. We argue that the lack of consideration of particular instances of flavor, such as freshness, has resulted in a lack of consensus about the content and structure of different types of flavor representations. We then enrich these theoretical analyses, with a review of the cognitive mechanisms of flavor perception: from multisensory integration processes to the influence of top–down factors (e.g., attentional and semantic). We conclude that similarly to flavor, freshness perception is characterized by hybrid content, both perceptual and semantic, but that *freshness* has a higher-degree of specificity than *flavor*. In particular, contrary to flavor, freshness is characterized by specific functions (e.g., alleviation of oropharyngeal symptoms) and likely differs from flavor with respect to the weighting of each sensory contributor, as well as to its subjective location. Finally, we provide a comprehensive model of the cognitive mechanisms that underlie freshness perception. This model paves the way for further empirical research on particular instances of flavor, and will enable advances in the field of food and beverage cognition.

Keywords: freshness, flavor, multisensory perception, crossmodal correspondences, beverages

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BI Norwegian Business School,
Norway*

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Carlos Alberto Arce-Lopera,
ICESI University, Colombia*

****Correspondence:***
*Jérémy Roque
jeremy.roque@pernod-ricard.com*

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INTRODUCTION

The perceived freshness of food and beverages has been generally considered as the result of several sensory contributions: olfactory, gustatory, tactile, trigeminal, visual, and auditory (Westerink and Kozlov, 2003; Labbe et al., 2009a,b; Saint-Eve et al., 2010). Databases—Google Scholar and Science Direct—were searched over all years of records using pre-specified terms (freshness, refreshing, perception, consumers) in the consumer science literature. Our searches identified more than one hundred studies dealing with freshness, with a large fraction of the studies focusing on freshness of fruits and vegetables (see Péneau, 2005 for a review) and other food products like bread and biscuits (e.g., Heenan et al., 2008). However, most have considered freshness as a multisensory attribute of food and beverage products without investigating the multisensory integration processes and cognitive mechanisms[1] at hand. Furthermore, the consumer science literature clearly embeds two distinct types of freshness whose cognitive underpinnings are probably very different. To better characterize the subject of the present review, it is thus necessary to first address the sematic ambiguity of the term "freshness".

The semantic ambiguity of "freshness" is straightforward. When experiencing products containing both liquid and solid components as well as several tastants and odorants (e.g., cocktails), consumers can characterize them as fresh based on either the overall multisensory experience (involving for instance coldness, sourness, or a menthol odor), or on the aging of the organic ingredients it contains (e.g., the age of the mint leaves in a mojito). For instance, Péneau (2005, p. 6) defined freshness of fruits and vegetables as the "level of closeness to the original product, in terms of distance, time and treatment". Thus, it seems that at least two meanings may be conveyed by the word "freshness". In this review, we will focus on the first meaning. We will also focus on the multisensory integration processes at the perceptual level and on the top–down factors that may influence those processes. We will consider the case of beverages, by reviewing the perceptual and cognitive mechanisms that cause a particular beverage to be perceived as fresh.

According to Labbe et al. (2009a), the concepts of refreshing and freshness (in the first sense mentioned above) seem closely linked because they have common sensory drivers such as coldness and mint flavor. The notion of refreshment in beverages was also shown to strongly correlate with a thirst-quenching sensation (Labbe et al., 2009b). In the present review, we address the concept of *freshness* instead of *refreshing* because the term refreshing is more directed toward the post-consumption phase, together with the impact fresh beverages have on arousal or thirst-quenching sensation (Labbe et al., 2009a). In the following sections, we will thus refer to "perceived freshness" because it covers both the expected and the actual sensation of a given product.

Freshness, in that restricted sense, has been analyzed at various levels of description. From the *physiological* level of analysis, freshness perception seems linked to the alleviation of unpleasant physical symptoms, such as elevated body temperatures or mouth dryness, during the consumption of a cool or fresh beverage (see Labbe et al., 2009a for a review). With respect to the *sensory* level, several sensory descriptors have been shown to positively or negatively influence freshness perception. Some of them have also been associated with the term "refreshing", as well as with psychophysiological factors involved in freshness perception: "thirst-quenching" and "mouth-wetting" (Labbe et al., 2009a,b, 2011). According to consumers, coldness and sourness are the common sensory properties that enhance freshness perception in food and beverages (Zellner and Durlach, 2002), waters (Labbe et al., 2011), and soft drinks (McEwan and Colwill, 1996; Fenko et al., 2009; Saint-Eve et al., 2010; Zhang et al., 2016). On the other hand, sweetness (McEwan and Colwill, 1996; Guinard et al., 1998; Labbe et al., 2009b) and thickness (Scriven et al., 1989; McEwan and Colwill, 1996; Guinard et al., 1998; Labbe et al., 2009b; McCrickerd et al., 2015) were associated with decreased freshness perception. Regarding colors, a clear color was found to enhance thirst-quenching and refreshing perceptions of soft drinks (Clydesdale et al., 1992; Zellner and Durlach, 2003). Red and orange colors were also associated with an increase in thirst-quenching perception of fruit-based drinks (Zellner and Durlach, 2002). According to different studies, smells like mint, orange (Zellner and Durlach, 2002; Labbe et al., 2009b), peppermint, lemon (Fenko et al., 2009), citrus, and peach (Martin et al., 2005) were judged to be the most refreshing aromas for food and beverages, whereas chocolate was most commonly listed as the least refreshing (Zellner and Durlach, 2002; Labbe et al., 2009b). Other kinds of perceptual features such as carbonation in beverages have also been shown to positively influence freshness perception (McEwan and Colwill, 1996).

However, to go beyond simply listing the perceptual features that contribute to freshness perception, it is necessary to identify the mechanisms that integrate them into a unified freshness perception. The binding of multisensory inputs into one unified percept has been investigated and extensively discussed in the case of flavor (see Auvray and Spence, 2008 for a review). So why does the literature lack of information on the mechanisms of freshness perception?

One possible, simple explanation of this gap is that it would be redundant with the literature on flavor. We will show that this answer should be qualified: even if some redundancies will be unavoidable, freshness differs from flavor in some important respects. Indeed, flavor is more generic than freshness, which in turn seems more generic than particular flavors (e.g., mint flavor). All freshness instances are systematically confounded with particular flavors (e.g., mint or citrus flavors) but all flavors are not necessarily confounded with perceived freshness. This type of relationship corresponds to what is called a "taxonomic hierarchy" between categories or concepts (Murphy, 2002, p. 325). Specifying at which level of the hierarchy freshness is located (superordinate, basic-level, or subordinate) would lead us beyond the scope of the present review. Rather, we aim to determine what the higher degree of specificity of freshness implies, regarding the multisensory mechanisms at hand. Furthermore, we will argue that thoroughly considering a particular instance of flavor such as freshness may shed light on some theoretical debates on flavor perception.

First of all, competing theses regarding the representational nature of flavor and freshness will be reviewed. It will be discussed whether flavor and freshness have to be considered as cases of synesthetic experiences, object representations, or rather as perceptual categories (see Section "The Representational

[1]In the present review, we use "cognitive mechanisms" or "cognitive factors" to refer to the set of mechanisms involved in the extraction and integration of information that constrains, influences, and interacts with the everyday experience of food and drink (Verhagen and Engelen, 2006).

Nature of Flavor and Freshness"). This conceptual clarification will allow us to move to the central question of the present review which is the characterization of the perceptual and cognitive mechanisms that underlie the experience of freshness. The existing literature on the cognitive underpinnings of flavor perception will be used as a heuristic to determine whether or not the same cognitive underpinnings apply *mutatis mutandis* to the perception of freshness. We will focus on the cases of crossmodal interactions and correspondences, which contribute to the experiences of flavor and likely to freshness (see Section "Crossmodal Interactions and Correspondences"). Then, the memory and attentional aspects impacting the perceptual and cognitive processes mentioned above will be described (see Sections "Memory, Expectations, and Knowledge" and "Attention"). Finally, the particular conditions that influence the degree of integration of a multisensory perception, such as congruency and the unity assumption (see Section "Particular Conditions that Influence the Degree of Integration"), will be reviewed. This will allow us to build a preliminary model of freshness perception and provide specific empirical research hypotheses about the putative crossmodal interactions and correspondences that influence the experience of freshness.

THE REPRESENTATIONAL NATURE OF FLAVOR AND FRESHNESS

In this section, we will consider both the computational processes underpinning flavor and freshness perception and the types of representations for which flavor and freshness are eligible. The processes will be addressed first by introducing a distinction between multisensory integration and sensory fusion. Then, the representational nature of flavor will be questioned by considering various types of representations: synesthetic experiences, object representations, and perceptual categories. Each time, the representational nature (structure and content) of freshness will be compared to that of flavor.

Sensory Fusion

During the consumption of a food or beverage, multiple sensory inputs are, under certain circumstances (see Section "Particular Conditions that Influence the Degree of Integration"), integrated by the central nervous system to potentially give rise to a unified flavor perception (e.g., Auvray and Spence, 2008). One of the main functions of the cognitive system is to resolve certain conflicts that occur during the integration process. Sometimes, the conflict resolution between two or more perceptual features can be such that each sensory contributor, or at least one of them, will lose its individual sensory characteristics. This phenomenon has been named sensory fusion (Verhagen and Engelen, 2006). Sensory fusion corresponds to a higher degree of sensory integration and to a particular level of unification between sensory features that can either belong to the same sensory channel (intramodal case) or to two distinct sensory modalities (crossmodal case). An intramodal instance of fusion occurs for instance when two colors (e.g., red and yellow) combine and consequently lose their initial individual sensory qualities to form a new sensation (i.e., red and yellow are merged into orange). The fusion process is specific to particular dimensions of the sensory signal, as it does not seem to occur between basic tastes for instance (e.g., McBurney and Gent, 1979). Indeed, sweetness and bitterness cannot be merged into a third basic taste. A crossmodal instance of fusion occurs when two or more sensory features belonging to distinct sensory modalities are combined and result in a distinct percept. In this case, at least one of the initial sensory inputs loses its respective modal identity (i.e., the perceptual format that specifies the type of sensory modality at the origin of the representation) and the fusion of the two forms one perceptual unit (see Verhagen and Engelen, 2006; Auvray and Spence, 2008 for reviews). For instance, it is generally assumed that a conflict occurs systematically between the spatial information conveyed by the taste signal and the spatial information conveyed by the smell signal, especially the retronasal one (Small and Prescott, 2005). The perceptual consequence of the conflict resolution by the cognitive system is that sensations originating in the nose are "referred to" or experienced as if they were transduced by the receptors in the mouth (Spence et al., 2014). Different terms have been used to describe this subjective phenomenon resulting from a sensory fusion between taste and smell such as the "location binding" (Stevenson et al., 1995), the "olfactory illusion" (Prescott, 1999), or the "mouth capture" (Shepherd, 2012). It is worth noticing that the strong claim that flavor perception is systematically underpinned by sensory fusion conflicts with the idea that humans still have the capacity to analyze a flavor into its parts (e.g., Stevenson, 2014).

In the case of freshness, it is likely that the modal identity of each sensory contributor is not always systematically accessible to the subject. Two non-exclusive hypotheses can be formulated to explain this phenomenon: i) the modal identity of the sensory contributor is not accessible because of a fusion occurring at some point during the multisensory integration and therefore the modal identity of certain contributors is lost, and/or ii) the modal identity of some contributors to freshness is intrinsically ambiguous. In fact, it has been shown that coldness can enhance the perception of freshness (Labbe et al., 2009a) and coldness is mediated by specific receptors found in trigeminal cold-sensing neurons. However, these receptors are widely distributed (on the tongue, in the nasal cavity, and in the peripheral nervous system) and can be activated either by cold temperatures or by different organic compounds with cooling properties such as menthone and menthol (for a review of mechanisms of temperature perception, see Patapoutian et al., 2003). Moreover, it has been shown that some people can experience the "thermal-taste illusion" in which a particular temperature experienced on the tongue will induce other taste sensations (Bajec and Pickering, 2008). Thus, in a nutshell, the mere fact of not being conscious of all the distinct sensory contributors to freshness may be due to a fusion occurring between two or more sensory features during the multisensory integration step, or to ambiguous activations of certain receptors, or, as is likely to both.

Synesthetic Experience

The reasons why some people are often unable to tease apart the relative contributions of smell and taste to flavor perception (Spence and Piqueras-Fiszman, 2014) have been discussed in the previous section. In this section, one step further will be taken to consider why certain odors can elicit changes in the perception of a particular tastant (e.g., Stevenson et al., 1999). For instance, the sensory fusion of taste and smell described earlier can induce a crossmodal enhancement under certain circumstances (congruency dependent, see Section "Congruency" as well as task dependent and attention dependent, see Section "Attention"). The sweetness enhancement that can result from the sensory fusion between a sweet taste and a strawberry odor has been widely studied in flavor perception. When these two perceptual features are experienced together, the strawberry flavor stored in memory will induce a sweetness enhancement: people will tend to perceive the sweetness as more intense for a product with the strawberry odor as compared to a control odorless stimulus with the same concentration of sweet taste[2]. The fact that this pairing can lead to perceptual changes of the taste (i.e., higher sweetness ratings) have led some researchers to argue that flavor perception could result from a synesthetic experience (Stevenson and Boakes, 2004; Verhagen and Engelen, 2006).

Synesthesia has been defined as a neurological condition in which the stimulation of one sensory or cognitive pathway leads to an automatic, involuntary experience in a second sensory or cognitive pathway (Cytowic, 2002). It can be characterized by four criteria that are jointly sufficient for individuating genuine forms of synesthesia: (a) the existence of a conscious pairing between an inducer (e.g., a number) and a concurrent (e.g., a color) perceived at the same time; (b) the relative idiosyncrasy of the pairing; (c) the automaticity of the process which causes an inevitable and involuntary experience of the concurrent when the inducer is present; and d) the consistency of the occurrence over time. Auvray and Farina (in press, see also Deroy and Spence, 2013) have suggested several arguments that question the appropriateness of considering flavor perception as the result of a synesthetic experience. The first criterion of a conscious pairing is not satisfied in the case of flavor perception. In fact, considering the sensory fusion occurring in flavor perception, it is the overall perceptual unit which is perceived by the participants and not the two individual sensory properties at the same time (see **Figure 1**). Regarding the second criterion, it has been shown that the multisensory processes underpinning flavor perception are experienced by everyone, at least intra-culturally (see section "Culture and Expertise"), thus it does not involve idiosyncrasy. Regarding the third criterion of automaticity of the process, controversial results have been found for flavor perception since the sensory fusion is dependent on the task and the attention of the participants (see Section "Attention"). Only the fourth criterion of consistency over time is verified regarding flavor perception. On the basis of the above-mentioned arguments, even if some arguments can be discussed, we argue that they are enough to consider the burden of proof to be on the proponents of the idea that flavor represents a genuine case of synesthetic experience. As freshness reasonably corresponds to a particular instance of flavor, it is then likely that the sensory contributors to freshness can also be bound in one perceptual unit. Moreover, people may often be unable to tease apart the relative contributions of each sensory contributor. Thus, similarly to flavor, we can reasonably argue that freshness does not result from a synesthetic experience.

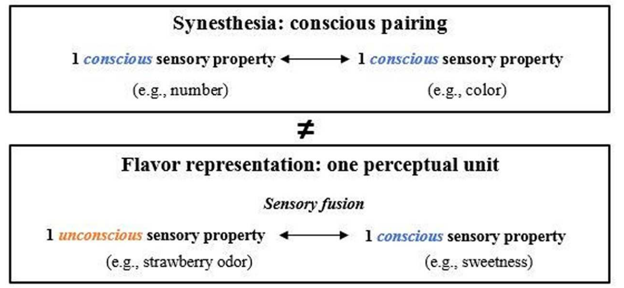

FIGURE 1 | Differences between the cognitive processes underlying synesthesia and flavor representation. In both cases, there is spatio-temporal co-occurrence between two sensory properties belonging to two distinct modalities but they are not actually perceived at the same time in the case of flavor. In fact, only the result of the sensory fusion is perceived.

Object Representation and Categories

It has been put forward that "Object perception could represent a basic processing strategy applied to any sensory system that has to extract meaning from a complex stimulus array" (Stevenson, 2014, p. 1360). Hence, in order to further understand the mechanisms responsible for flavor perception, several authors have considered the object concept (e.g., Auvray and Spence, 2008; Small, 2012). Even though the object concept has been applied to vision, audition, and olfaction (see Stevenson, 2014), it has not been considered for other chemosensory modalities such as taste and chemesthesis (i.e., sensations due to chemical compounds). By listing the criteria that seem to characterize "object-hood" and making a distinction between the various sensory modalities that constitute flavor, Stevenson (2014) discussed whether flavors are integrated by default as objects (i.e. holistically), as a series of perceptual features, or both at different times. He described eight criteria for object-hood, taking into account the structural aspects of the stimulus and memory dependence that reflect respectively the bottom–up and the top–down processes contributing to the constitution of an object representation. One of the criteria that the notion of object-hood depends on is figure-ground segregation. The figure refers to the object itself and the background corresponds to the other perceptual features experienced at the same time and detected by

[2]In addition to the crossmodal enhancement that can result from the sensory fusion between a conscious taste and an unconscious smell, another kind of crossmodal enhancement can also be obtained for instance when one odor and one taste at subthreshold are presented together; Dalton et al. (2000) have shown that the threshold for detecting the odor was then lowered and the participants were sometimes able to detect the odor even if the individual perceptual features were weak.

the same receptor system. To illustrate that notion, let's consider an example: when someone chews gum just before lunch time, the ingredients of the dish in the mouth will be experienced against a flavor background that consists of the remaining perceptual compounds of the gum. However, these persisting gum compounds will also impact the perception of the dish itself. According to Stevenson (2014), there is no evidence that a flavor object can be perfectly differentiated from its background, considering flavor as an object in the mouth. The figure-ground segregation criterion would not be satisfied.

Another reason that leads Stevenson to reject the idea that flavor is eligible for the status of object representation is that flavor-object-representations would have no additional function beyond that of olfactory or visual objects. Three potential functions are considered: detection, identification, and violation of expectancies. According to Stevenson (2009), foods are identified visually and via the orthonasal olfactory system before being placed in the mouth. Thus, forming flavor-object-representations in order to identify and detect foods would carry a useless cost for the cognitive system since these functions are achieved before the oral step. However, Stevenson acknowledges that the violation of expectancies hypothesis is more promising since flavor-object-representations could be compared to representations in memory. This comparison could then help the cognitive system to tease apart the expected properties from the unexpected properties of a given food or beverage. This comparison would then serve as a protective system since the perception of unexpected properties could help the individual to avoid ingesting poisonous substances. However, once again according to Stevenson this hypothesis is redundant since it is plausible that the violation of expectancies does not necessarily imply a comparison process between what is stored in memory and what is actually experienced.

Stevenson's redundancy argument is clearly debatable since it is likely that the system based on taste is the precursor of a more fine grained protective system involving multiple sources of information conveyed by flavor objects. This is at least as plausible as Stevenson's idea, from an evolutionary point of view. Furthermore, Stevenson's argument seems quite inconsistent with the idea that flavor actually represents a functional sensory system with inputs from somatosensation, gustation, and olfaction where the meaning of the sensation would be more involved in the final representation than its precise organ or site of origin (Small and Prescott, 2005). This concept of flavor that focuses on the meaning of the sensation recalls Gibson's (1966) ecological approach in which perceptual systems are defined by their *function*, rather than tied to the organ of transduction. Moreover, even if we concede that flavor objects have no obvious additional functions beyond those of gustatory, visual, or olfactory objects, this can be due to the generic character of the term flavor. Let us consider a more specific instance of flavor such as freshness. According to Labbe et al. (2009a), one possible function of freshness in the mouth is the alleviation of oropharyngeal symptoms (e.g., mouth dryness). Thus, by considering a particular instance of flavor such as freshness, it is possible to highlight specific functions of the flavor object experienced. Moreover, the different perceptual attributes and functions of a particular group of objects are generally contained in categories which have been defined by Rosch (1978) as groups of objects sharing common attributes that are most representative of items inside and less representative of items outside the corresponding category. Rosch (1978) has highlighted that one of the main functions of categories is to structure information and support recognition, discriminability, and inductive reasoning. Therefore, claiming that flavor does not have any specific function seems to imply that it is not eligible for the status of being a category. This is indeed what Stevenson's analysis tends to suggest. According to Stevenson (2014), categorization is a *semantic process* which occurs mainly after the perceptual process (i.e., the construction of the object). However, we will see in the next paragraph how categorization has also been defined on the basis of perceptual processes.

A perceptual theory of knowledge was proposed by Barsalou (1999, p. 578) that highlights the convergence of cognition and perception. He described the nature of perceptual symbol systems as follows: "Subsets of perceptual states in sensory-motor systems are extracted and stored in long-term memory to function as symbols. As a result, the internal structure of these symbols is modal, and they are analogically related to the perceptual states that produced them.". In other words, perceptual symbol systems represent schematic components of the multisensory experience and are intimately intertwined with higher order cognitive levels linked to semantics and memory, which help to structure information into categories. Thus, contrary to Stevenson's idea that categorization is a semantic process that occurs after the perceptual process, according to Barsalou (1999) there is no real distinction between the structure of categories and the perceived features that belong to these categories.

To summarize, considering a specific instance of flavor such as freshness enables us to discuss the multisensory processes that can lead to its specific representational nature and more clearly characterize the perceptual and cognitive mechanisms at stake. For instance, the above-mentioned debate on categorization highlights the fact that a freshness representation could be considered as a category structured into a perceptual symbol system that consistently maintains the junction between the perceptual level and other higher levels of processing (e.g., semantic content). Thus, in order to further characterize the ordinary perceptual experience of freshness, it appears necessary to consider the interactions between the various perceptual features that contribute to freshness and other higher levels of processing. To do so, in the next section, the notion of crossmodal correspondences will be described and distinguished from the notion of crosslevel correspondences.

CROSSMODAL INTERACTIONS AND CORRESPONDENCES

The Crossmodal Perception of Flavor

Several crossmodal interactions have been reported in the case of flavor and the relative contributions of each sensory modality have already been partially documented (see Verhagen and

Engelen, 2006; Shepherd, 2012, for reviews). A large body of research has also explored the evidence regarding the existence, and the consequences for human information processing, of a particular form of crossmodal interactions named *crossmodal correspondences*. Crossmodal correspondences have been defined as "the many nonarbitrary associations that appear to exist between different basic physical stimulus attributes, or features, in different sensory modalities" (see Spence, 2011, p. 972). The literature on flavor perception has highlighted the existence of crossmodal correspondences between many pairs of perceptual features belonging to different modalities constitutive of flavor such as tastes and sounds (Knöferle and Spence, 2012), auditory pitch and smell (Belkin et al., 1997), colors and odors/tastes (Spence et al., 2010, 2015), smells and shapes (Seo et al., 2010), and even shapes and tastes (Velasco et al., 2015).

The aim of this section is to go beyond the mere description of these correspondences in order to bring conceptual clarification. Indeed, crossmodal correspondence mechanisms refer to several phenomena occurring at distinct levels of information processing. Four principal types of crossmodal correspondences have been distinguished (see Spence, 2011 for a review): *Structural correspondences* are possibly innate, but may also depend on the maturation of neural structures for stimulus coding (e.g., between the loudness of a sound and the brightness of a light). *Statistical correspondences* are learned and result from the extraction of certain environmental regularities by the cognitive system. For instance, the correlation between the size, or mass, of an object and its resonant frequency (i.e., the larger the object, the lower the frequency). *Semantically mediated correspondences* may occur when common linguistic terms are used to describe two different stimuli. For instance, when a semantically ambiguous term refers to distinct sets of stimuli depending on the context, such as high and low, which can describe both pitch and elevation. *Emotionally mediated correspondences* consist of associations between basic perceptual features that seem to be mediated by certain dimensions of emotion such as the valence, or the level of arousal induced by the perceptual features.

On the basis of the above-mentioned typology of crossmodal correspondences, two fundamental types of correspondences appear: those occurring only at a perceptual level (e.g., between the size of an object and its resonant frequency), and those involving other levels of processing such as the semantically mediated correspondences and the emotionally mediated correspondences. In the next sections, the expression "crossmodal correspondences" will be used only to refer to the former. In other words, we will stick to the literal meaning of cross*modal* which implies that at least two sensory *modal*ities are involved and that the correspondence occurs at a perceptual level. By contrast, we will use "crosslevel correspondences" to refer to the associations involving another level of processing (e.g., linguistic or emotional).

Beyond the theoretical level, the existence of crossmodal correspondences can be inferred from their effects. For instance, Knöferle and Spence (2012) have reported that stimuli sharing a crossmodal correspondence can induce shorter RTs (reaction times) in a particular task. However, according to the authors, there is little evidence that such stimuli also have perceptual consequences. In line with this hypothesis, Gallace and Spence (2006) have shown that the presentation of either a crossmodally congruent or incongruent sound did not actually change the perceived size of a circle that was presented with it, despite the fact that participants' RTs changed significantly. Two noticeable exceptions are worth mentioning though. Liang et al. (2013) have shown that rounded shapes enhanced sweetness sensitivity (at least at near-threshold levels), whereas angular shapes did not. Another study has highlighted that low-pitched notes played by brass instruments can enhance the perceived intensity of the bitter taste of caffeine, and high-pitched notes played by the piano can enhance the perceived intensity of sucrose (Crisinel et al., 2012). Thus, some crossmodal correspondences seem to lead to a crossmodal enhancement effect, a phenomenon that is well-known in flavor perception (see Section "Synesthetic Experience"). We will argue in the next section that knowing how to trigger the mechanisms of crossmodal correspondences involved in freshness (if any) could facilitate consumers' categorization of a given product as fresh or even lead to freshness enhancement. However, if we want to enhance the freshness perceptual experience by triggering specific crossmodal correspondences, it appears necessary to first determine the type of correspondence likely at hand in freshness perception.

The Crossmodal Perception of Freshness in Beverages

The literature on the sensory contributors to freshness perception can feed hypotheses about the crossmodal correspondences that could exist and potentially lead to a freshness enhancement effect (see Labbe et al., 2009a for a review). Several studies have highlighted that carbonation was part of consumers' expectations for fresh beverages (e.g., McEwan and Colwill, 1996; Guinard et al., 1998). Moreover, the perception of the carbonation of a beverage may also be influenced by auditory cues provided by the bubbles (Yau and McDaniel, 1992; Guinard and Mazzucchelli, 1996). Zampini and Spence (2005) conducted several experiments to investigate the role of auditory cues in the perception of carbonation in beverages. In a first experiment, the carbonated water samples were judged to be more carbonated when the overall sound level was increased and/or when the high frequency components (2–20 kHz) of the water sound were amplified. They were also evaluated as being more carbonated when they were held close to the ear rather than further away. Another experiment in which the participants had to assess the level of carbonation and the oral irritation of water samples, in the mouth, revealed that neither the perceived carbonation nor the perceived oral irritation were influenced by variations in the level of auditory feedback. Overall, Zampini, and Spence's results highlight the significant role that auditory cues play in modulating perception of the carbonation of beverages. However, for the perception of carbonation in the mouth, oral-somatosensory and nociceptive cues dominate over auditory cues (see Dessirier et al., 2000; Carstens et al., 2002, for more details on the mode of action of carbonation). Then, a crossmodal correspondence occurring between visual carbonation and the intensity of the trigeminal stimulation due to carbonation can also be expected. Other results have been obtained by recent studies regarding the influence of auditory cues corresponding to the pouring of a beverage on the perception of its temperature (Velasco et al., 2013) or corresponding to the opening of the packaging on the perception of freshness in terms of a new and not-tampered-with product (see Spence and Wang, 2015 for a review). The results obtained by Velasco et al. (2013) have highlighted a crosslevel correspondence between word attributes and sounds that were congruent ("Hot Drink" and the sound of the hot pouring water, and "Cold Drink" and the sound of the cold pouring water).

Regarding flavor, it seems to be difficult to identify semantic ambiguity due to its generic character. Correspondences with a non-perceptual cognitive level (e.g., semantic content) that we characterized as crosslevel correspondences have not been investigated yet in freshness perception. However, in line with the semantically mediated correspondence in which low and high describe stimuli varying in pitch and visual elevation, the semantic ambiguity relative to freshness is more easily identifiable (i.e., multisensory stimulations *versus* aging of fruits and vegetables, see Introduction). It is thus reasonable to suspect potential interactions between the perceptual features themselves that influence freshness perception (e.g., crossmodal correspondences), as well as between the perceptual features and the various meanings assigned to freshness (e.g., crosslevel correspondences).

The perceptual and semantic information is stored in memory and is thus strongly dependent on the participants' background knowledge. If there is a need to better identify the respective contributions and functions of each sensory modality in the case of freshness perception, it is also important to take into account the influence of the cognitive factors such as attention and memory in studies' elaboration and analysis of their limitations.

MEMORY, EXPECTATIONS, AND KNOWLEDGE

Learned Associations and Expectations

Human beings, at least in western countries, are prone to be in contact with a rich food and drink environment in which several associations between various perceptual features (e.g., colors, texture) can be repeatedly encountered. In the case of a negative post-ingestive effect, people will store this information in memory with respect to the poisonous food they ingested and they will subsequently adapt their dietary behavior. Such past experience will drive long-term flavor preference formation and intake (Myers and Sclafani, 2006).

In the case of freshness perception, Labbe et al. (2009a) have argued that the positive experience of alleviation of unpleasant symptoms (thirst, mouth dryness, mental fatigue, feeling too hot) following consumption of a given beverage leads to a learned association of these positive experiences (e.g., between the coldness of a drink and the relief from the sensation of feeling too hot) with freshness perception. This is in line with what Zellner and Durlach (2002) found among a group of American students. When asked to list foods, beverages, and sensory characteristics they considered to be refreshing, the American students mentioned water most of the time (90% of respondents) as well as cold temperature (see also Eccles et al., 2013). Prior learning may explain other associations with freshness, such as the positive association with clear appearance (Zellner and Durlach, 2003) and the negative associations with sweetness, thickness (McEwan and Colwill, 1996; Guinard et al., 1998; Labbe et al., 2009b), intense flavor, and after-taste (Guinard et al., 1998). Labbe et al. (2009a) concluded that further work is needed before assuming that flavor-refreshing learning is as robust as other types of associative learning such as odorant-sweet taste learning.

Moreover, it should be noted that prior learning can modulate the kinetic aspects of food or drink consumption, contributing to an increase or decrease in the perceived intensity of a particular sensory compound (Blissett et al., 2007). The actual moment of swallowing seems particularly important since it has been shown that this is when major aroma pulses are induced (Buettner et al., 2002; Hodgson et al., 2003), thereby making a major contribution to the final percept of the beverage. However, McCrickerd et al. (2014) have highlighted the notion of product dependence by suggesting that the strength of associations formed between a drink's sensory characteristics and its post-ingestive effect would be weak compared to that for solid foods. McCrickerd et al. (2014) think that it could potentially be the case because beverages are consumed rapidly, and this reduced oral exposure time may limit the strength of its oro-sensory signal and subsequent learning. Moreover, a high degree of variability in swallowing patterns has been found between individuals, with some individuals performing simple swallowing actions whereas others incorporate learned tasting behaviors into their everyday consumption routines to adapt their consumption habits to their physiological requirements (Blissett et al., 2007; Buettner and Beauchamp, 2010). It is possible to go further, hypothesizing that some people adapt their consumption habits not only at a physiological level, but also to obtain the most pleasant experience, when consuming a drink that they expect to be fresh. Concerning freshness, Westerink and Kozlov (2003) have highlighted that people tend to value temporary sensory input during the actual freshness experience (e.g., temperature), whereas they tend to keep in long-term memory other sensory features related to the freshness percept (e.g., particular compounds such as menthol).

Beyond the perceptual level, we can also wonder how the semantic properties related to freshness perception influence subsequent experiences of freshness. According to Mathis (2002), semantic properties elicit consumers' knowledge and beliefs (e.g., mental representations built from previous experiences). These mental representations help for stimuli identification, building knowledge of their properties, and the adaptation of consumers' behavior according to their expectations relative to the product experienced. Regarding the concept of expectations it is worth refining the notion to distinguish two levels of expectations: (i) expectations as perceptual priors, what Seriès and Seitz (2013) named the "structural" expectations resulting from the integration of the various perceptual features of a given stimulus, and (ii) expectations as beliefs (implicit or explicit at a doxastic level, see Dretske, 1988, p. 117 for this distinction) that can be manipulated through instructions, sensory cues, or contextual variables (see Seriès and Seitz, 2013). It should be noted that the generation of different taste/flavor expectations can be a function of the participants' background and/or culture (Zellner and Durlach, 2003), expertise/experience with particular food or beverage domains (Parr et al., 2003; Smith, 2007), and age (Philipsen et al., 1995).

Culture and Expertise

The influence of participants' background and culture has been investigated by Nguyen et al. (2002), who conducted a study highlighting that the odors of vanilla, caramel, strawberry, and mint induced sweetness enhancement in western countries where people often experience those odors with sucrose. By contrast, non-western participants did not describe some of these odors as sweet, probably due to a less frequent pairing of these odors with sweetness in their food culture. In another cross-cultural study (Wan et al., 2014), the same seven drinks were presented in three different types of glass to participants from mainland China, the United States, the United Kingdom, South Korea, and India. The results revealed that the same beverage color sometimes set up distinctly different flavor expectations depending on both the type of receptacle and the cultural background of the participants. These sources of variability relative to background knowledge and culture probably have major influences on the lack of consensus concerning the constitutive properties of freshness in food and beverages (Cardello and Schutz, 2003; Heenan et al., 2008; Zhang et al., 2016).

Regarding the influence of expertise, conflicting results have been reported. A handful of studies have highlighted that the level of expertise can help an individual categorize certain flavor components more easily and may improve perceptual capacities (e.g., the capacity to identify the perceptual similarities between two different products; Ballester et al., 2008). This has been nicely illustrated in the case of wine expertise: based on common mental representations, experts are able to efficiently categorize different odors of two types of wine. It has been argued that this allows them to both organize and use their perceptual knowledge more efficiently (see Hughson and Boakes, 2001 for a review). However, some studies have highlighted that expertise did not necessarily result in enhanced perceptual capacities. For instance, Pangborn et al. (1963) investigated the effect of color on sweetness perception. The addition of color to a solution to give the appearance of a rose wine caused wine experts but not novices to judge the solution as sweeter than colorless controls. We may reasonably hypothesize that level of expertise may impact freshness perception as well, since it has been shown that the color, as well as the sweetness of beverages influence the perceived freshness (e.g., Guinard et al., 1998; Zellner and Durlach, 2003). Moreover, different sensory expectations might be triggered by different perceptual features depending on the consumer's background knowledge (Zellner and Durlach, 2003).

Another experiment conducted by Morrot et al. (2001) revealed that expertise did not necessarily improve the perceptual capacities of experts. They investigated whether wine experts could consistently associate olfactory descriptors with different types of wines. In the first session, the participants were asked to draw up a list of olfactory descriptors for a white wine and a red wine (based on a list of descriptors that was supplied to them or their own descriptors). Then, the participants had to indicate which of the two wines most intensely presented the character of each descriptor. In the second session, one week later, the same white wine previously presented in session 1 was artificially colored red with an odorless dye and the participants were asked to do the same task of comparison between the red wine and the white wine (colored red). Morrot et al. (2001) results revealed that the white wine artificially colored red in session 2 was described as a red wine in terms of olfactory descriptors by the panel of 54 experts. They suggested the existence of a "perceptual illusion" due to the color change that would influence the pairing between the different wines and their appropriate sensory descriptors.

Regarding freshness, clear color has been reported by consumers to be the most expected color for fresh food or beverages (e.g., Zellner and Durlach, 2002). Thus, it might be that white wines would be considered fresher than red wines. However, it remains an empirical question whether a change in the color of the wines would be sufficient to impact participants' perception of their relative freshness.

An alternative explanation of Morrot et al. (2001) results has been proposed by Shepherd (2012, p. 139). According to Shepherd, the participants' attention in Morrot et al.'s (2001) study was biased toward using the same descriptors for what they believed to be the same purpose. However, an important source of inter-individual variability can also partially result from the way the participants attend to a specific task (Stevenson, 2012, see Section "Attention"). The influence of attentional factors on both flavor and freshness is considered in more detail in the next section.

ATTENTION

Two different modes of attention have been described by Posner (1980): exogenous and endogenous modes of attention. The exogenous mode of attention is underpinned by the salience of certain environmental features, whereas the endogenous mode corresponds to relatively voluntary mechanisms sensitive to learned events. Alleged influences of exogenous, and to a lesser extent endogenous, attentional processes have been suggested for the mouth capture phenomenon occurring in flavor perception. Further investigation is needed to conclude whether the mouth capture phenomenon can be generalized to all instances of flavor such as freshness.

Exogenous Attentional Processes

Stevenson et al. (2011) manipulated exogenous attention by varying the stimulus characteristics so that either oral or nasal cues became more salient. Their results showed that the participants were prone to shift the localization of the percept toward the physical locus of the more salient cue. Furthermore, Stevenson (2012) has highlighted that the contribution of olfaction to flavor goes largely unnoticed, compared to that of taste and somatosensation, even when participants are asked to detect its presence. Hence, he suggested that exogenous attentional processes may be more important in inducing oral localization than endogenous attentional processes. Therefore, because exogenous attention in turn depends on the stimulus characteristics, we may reasonably expect differences between freshness and other instances of flavor, regarding their subjective location. In the case of beverages, the trigeminal component is likely one of the main contributors to freshness, due to the processing of coldness by the trigeminal cold-sensing neurons for instance (Labbe et al., 2009a). This is not necessarily the case, or at least not to a similar extent, for all types of flavors (e.g., strawberry). We can thus wonder whether the trigeminal component may bias the subjective location of freshness.

Moreover, it has been shown that exogenous attentional processes can also have perceptual consequences regarding the way participants pay attention to the task (e.g., according to the instructions they receive). For instance, while a sweetness enhancement phenomenon can occur after a single co-exposure between a sweet taste and a novel odor, Prescott et al. (2004) have observed that the adoption of a synthetic perceptual strategy during the co-exposure would also be necessary to produce sweetness enhancement. They observed that participants generally used a synthetic perceptual strategy when they were asked to rate the overall flavor intensity of the stimulus. By contrast, when the participants were asked to rate the intensity of several perceptual features of the stimulus separately, they tended to rely more on an analytical perceptual strategy. Sweetness enhancement would thus be dependent on the number and type of rating scales provided to participants. This phenomenon has been called the "halo-dumping" effect; in the case of few rating scales provided, participants tend to dump their ratings for a perceptual feature for which no response scale has been provided (e.g., the intensity of a fruity odor) onto another perceptual feature for which a response scale has been provided (e.g., the sweetness of the fruity odor). However, some studies have provided data that discredit the hypothesis of a systematic halo-dumping effect. For instance, Nguyen et al. (2002) have shown that the odor-taste enhancement effect could occur even when multiple scales are presented.

Endogenous Attentional Processes

Endogenous attention enables us to extract relevant information relatively early from a rich and complex stimulus environment. That is, stimuli are better processed, in terms of response time and accuracy, when they are anticipated. For instance, the results obtained by Ashkenazi and Marks (2004) have highlighted that endogenous attention can improve the detectability of the gustatory flavorant "sucrose" but not the olfactory flavorant "vanillin". The authors suggested that olfactory stimuli would be already fully processed before attention is directed toward them, reducing the functional consequence of endogenous attention. When consuming a beverage that consumers expect to be fresh, endogenous attention may be shifted toward a specific locus in the mouth or nose where consumers expect a freshness experience.

To summarize, it clearly appears that the subjective location of a final percept and the respective contributions of each of its sensory contributors is dependent on several parameters that belong to both the perceptual level (e.g., modulating the intensity of some perceptual features) and higher order cognitive levels such as memory and both exogenous and endogenous attentional processes. Starting by investigating the particular influence of crossmodal interactions and correspondences that can occur in freshness perception will allow us to generate new empirical evidence in terms of the multisensory processes at stake. Nevertheless, it is important to bear in mind that these complex multisensory processes are also dependent on conditions that influence the degree of integration. Two major documented conditions are reviewed in the next section.

PARTICULAR CONDITIONS THAT INFLUENCE THE DEGREE OF INTEGRATION

Congruency

The term congruency was previously evoked in Section "Synesthetic Experience" to highlight some cognitive processes that occur in flavor representations, giving rise in some cases to crossmodal enhancement phenomena. The existing literature on congruency suggests that several types of congruency can occur at different levels but also that the characterization of congruency is generally vague and even sometimes circular. For instance, Schifferstein and Verlegh (1996) defined congruency as the extent to which two stimuli are appropriate for combination in a food product. According to Shepherd (2012), congruency can be defined as the extent to which two stimuli complement each other. Lim and Johnson (2012) suggested a statistical account of congruency according to which congruency would correspond to the extent to which two stimuli commonly appear together and thus are highly associated in a food. Small and Prescott (2005) suggested a distinction using the term "perceptual congruency" that can be observed, according to the authors, when sniffed odors elicit descriptions of qualities that are more usually associated with basic taste qualities and so may arise as a result of repeated pairing (the terms "contiguity" and "synchrony" are also used by Small and Prescott, 2005). This definition of perceptual congruency is close to that of perceptual similarity used by some researchers when referring to perceptual qualities that are alternatively attributed to different compounds. Lim and Green (2007) conducted several studies based on spatial discrimination between capsaicin and QSO4, which can both induce bitterness and burning sensations on the tongue. They concluded that perceptual similarity is a notion that also refers to functions shared by the different compounds in terms of the perceptual consequences they induce.

Another distinction has been suggested by Spence (2011, p. 972), who argued that crossmodal correspondences may be used by humans "along with spatiotemporal and semantic congruency to help solve the crossmodal binding problem" (i.e., determining which of the many simultaneous afferent stimuli in different modalities should be bound together). The use of "along with" suggests that congruency is something different from, though related to, crossmodal correspondences. According to Spence (2011), perceptual congruency can refer to spatial and/or temporal co-occurrence during multisensory integration, in contrast with another type of congruency, "semantic congruency" that refers to the situations in which pairs of stimuli presented vary in terms of their identity and/or meaning. This definition of semantic congruency has also been used together with alternative terms such as appropriateness and/or compatibility effects between the stimuli (e.g., Piqueras-Fiszman and Spence, 2011) as well as the notion of consistency (see Spence, 2011).

These various ways to define congruency have created some confusion between the very notion of congruency and the proper mechanism of crossmodal correspondences. In particular, it has led some researchers to interpret their results in terms of a certain degree of congruency between pairs of stimuli without considering the cognitive mechanisms at hand. For instance, White and Prescott (2001) concluded that simultaneous orthonasal presentation of "congruent" odors (strawberry) was found to shorten RTs for sweetness taste recognition, relative to "incongruent" odors (grapefruit). However, sweet taste and strawberry odor are often co-experienced from childhood and this association is actually learned through repeated exposure. We suggest that the effect on RTs observed by White and Prescott (2001) seems to result from a typical case of crossmodal correspondence, built from past experience of the regular association of sweet taste and strawberry odor, rather than only congruency between these two perceptual features.

In order to clarify the difference between the phenomenon of crossmodal correspondences and the condition of congruency, two types of congruency that appear to occur at two different levels will be distinguished: (i) the perceptual congruency that refers to the spatial and/or temporal co-occurrence of two or more stimuli during multisensory integration, and (ii) the semantic congruency occurring at a higher cognitive level that helps to determine whether or not two or more stimuli are compatible or consistent in terms of identity and/or meaning.

For instance, in the case of freshness perception in beverages, consistency effects could be assessed by measuring the consequences of presenting the sound of a liquid containing bubbles poured in a glass with either a low or high pitch, and a picture of a glass containing either small or big bubbles. If, as we hypothesize, high-pitched sound is consistent with small bubbles and low-pitched sound is consistent with big bubbles, measurable effects can be obtained such as shorter RTs in consistent blocks, highlighting a positive consistency effect. This type of result can provide evidence of a crossmodal correspondence phenomenon occurring between particular perceptual features that influence freshness perception.

Unity Assumption

Besides congruency, "the unity assumption" is another condition that the degree of multisensory integration depends on. As for congruency, the very notion of the unity assumption remains vague and ambiguous. Various ways of understanding the unity assumption have been proposed. According to research on this concept (Welch and Warren, 1980; Welch, 1999), the unity assumption corresponds to the observer's assumption that two or more sensory inputs refer to a single distal event. According to Welch and Warren (1980), the strength of the unity assumption is a function of the number of physical properties (e.g., time, space, temporal patterning, number, shape, size) that are redundantly represented in the stimulus situation, as well as the relative weighting assigned by the observer to these properties. Based on Welch and Warren's (1980) definition of the unity assumption, Vatakis and Spence (2007) have proposed that whenever two or more sensory inputs are highly consistent in one or more dimension(s) (linked to the physical properties of the stimulus as well as influenced by top–down factors such as the semantic content), observers will be more likely to process them as referring to the same underlying multisensory event rather than as referring to separate unimodal events.

There are at least two ways to characterize the unity assumption: on the one hand, the bottom–up approach includes the physical properties linked to the stimulus, such as spatial and/or temporal co-occurrence which actually overlaps with a certain way of understanding congruency (Spence, 2011). On the other hand, some authors have highlighted that it remains unclear whether the unity assumption refers more to a top–down (i.e., more cognitively mediated) or rather to a bottom–up (i.e., more stimulus-driven) process (see Welch and Warren, 1980; Welch, 1999; Spence, 2007, on this point). The top–down approach to the unity assumption also overlaps with a certain way of understanding congruency since the higher cognitive level of congruency (i.e., semantic congruency) would also serve to solve the crossmodal binding problem (Spence, 2011). It should be noted that it also remains unclear whether the process of unification occurs consciously or unconsciously (Bertelson and de Gelder, 2004; Spence, 2007). Then, two main types of unity assumption will be distinguished: (i) the unity assumption as a bottom–up influence in terms of perceptual priors and (ii) the unity assumption as a top–down influence in terms of beliefs. Both types of unity assumption will influence the integration process and will in some cases lead the observer to consider different afferent sensory inputs to refer to the same multisensory event or object.

As was mentioned earlier, flavor is generally presented as a unified percept resulting from the integration of all senses. This implies that each flavor representation will depend on the unity assumption of the observer concerning the multimodal object experienced. Even though the particular influence of such an assumption has not been empirically explored yet for the perceptions of flavor and freshness, it is reasonable to think that it can modulate the degree of integration in the case of such multisensory perceptions. Considering flavor or freshness as unified percepts or not has various consequences regarding the overall product experienced such as different intensity judgments or different subjective locations of the final percept.

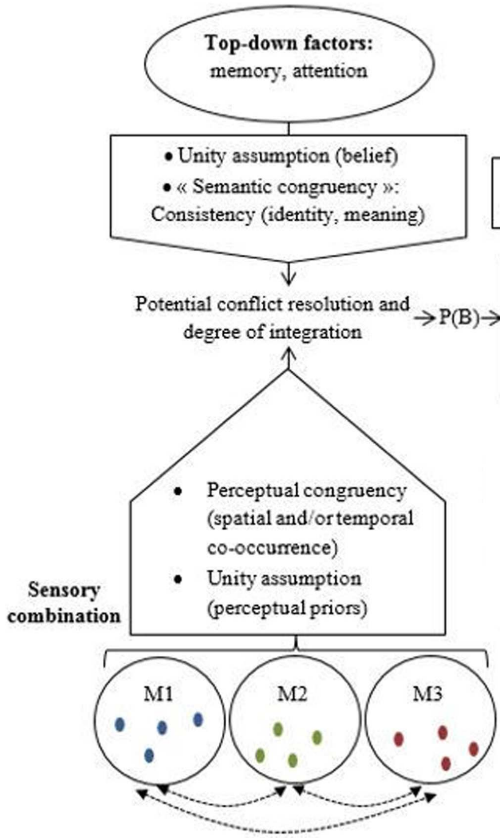

FIGURE 2 | Schematic sequences of the multisensory integration processes leading to freshness perception. M1; M2; M3: Sensory modalities; Perceptual features; Crossmodal interactions; P(B): Binding probability.

CONCLUSION

The present review aimed at exploiting the existing literature on flavor to characterize the perceptual and cognitive mechanisms that underlie the multisensory perception of freshness, in the case of beverages. We have hypothesized that some questions about flavor remained open until now because flavor is a generic term, and in some circumstances its genericity blurs the representational nature of particular instances of flavor such as freshness, as well as the corresponding cognitive mechanisms at hand. In fact, flavor has been characterized in various ways during the past twenty years: it has been suggested that flavor representations could correspond to synesthetic experiences or result from different processes leading to object representations or categories. Given the complexity of the various perceptual and cognitive mechanisms that underpin flavor perception, the main purpose of researchers has been to obtain empirical evidence regarding the respective contributions of each sensory modality. There is a general consensus on the fact that (i) retronasal smell is the main sensory contributor to the experience of flavor even if its implication is generally not consciously perceived, and (ii) the localization of flavor perception has an illusory component due to the mouth capture phenomenon.

Freshness perception has also been described as the result of a multisensory integration and it reasonably corresponds to a particular instance of flavor, underpinned by similar cognitive mechanisms. Similarly to flavor, it appears that freshness perception is characterized by a hybrid content, both perceptual and semantic. In fact, a semantic ambiguity is present regarding freshness since it can alternatively refer to particular sensory stimulations (e.g., coldness, sourness, menthol odor) as well as different characteristics linked to the age or crispness of fruits or vegetables. Due to these different meanings to which freshness can directly refer, it supports a higher degree of specificity compared to flavor. However, the question of the function of flavor objects in the mouth has appeared as a tipping point which has highlighted that considering a particular instance of flavor facilitates the identification of particular functions (e.g., the alleviation of mouth dryness in the case of freshness). Moreover, it is important to bear in mind that freshness potentially differs from flavor with respect to (i) the sensory modality that constitutes its main contributor, (ii) its subjective location (e.g., mouth capture in the case of flavor), and (iii) the typology of its modulating factors.

In order to characterize the perceptual and cognitive mechanisms that underlie the experience of freshness, we focused on the case of crossmodal interactions and correspondences (see Section "Crossmodal Interactions and Correspondences") which can induce measurable effects such as shorter RTs (e.g., faster product categorization) and crossmodal enhancement phenomena resulting from the interaction between two or more sensory inputs under certain circumstances. A distinction has been introduced between the crossmodal correspondences that can occur between two sensory modalities at a perceptual level and the correspondences that involve higher order cognitive levels, in the case of interactions between perceptual and semantic features that we characterized as crosslevel correspondences. This is of particular interest from an applied perspective since freshness features are part of the consumers' sensory expectations and likely determine food and beverage acceptance and appreciation. Indeed, knowing how to trigger the mechanisms of crossmodal or crosslevel correspondences regarding freshness could facilitate consumers' categorization of a given product as being fresh or even lead to freshness enhancement. However, crossmodal correspondence mechanisms still remain to be explored in freshness perception. To enhance the freshness perceptual experience, it is important (i) to identify the specific perceptual features contributing to freshness perception and to specify their respective weights, according to the stimulus context considered (e.g., beverages), and (ii) to obtain empirical evidence of the different types of correspondences that occur regarding freshness perception.

This approach must also consider the impact of top–down influences such as memory, expectations, and background knowledge on freshness, similarly to what has been thoroughly investigated in flavor perception (see Sections "Memory, Expectations, and Knowledge" and "Attention"). For instance, regarding freshness in the case of beverages, the positive learned associations following a particular drink consumption will be stored in memory and will influence the subsequent experiences. The multisensory processes potentially leading to crossmodal enhancement or crossmodal correspondences are function of particular conditions such as the different forms of congruency. Two different types of congruency have been distinguished in this review: on the one hand, the perceptual congruency that refers to the spatial and/or temporal co-occurrence between two or more stimuli during multisensory integration and on the other hand the semantic congruency occurring at a higher cognitive level that helps to determine whether or not two or more stimuli are consistent in terms of identity and/or meaning. The concept of the unity assumption, which has been defined as the condition under which different afferent sensory inputs are processed as referring to the same multisensory event or object, has been analyzed. The fact that there are two ways of interpreting the unity assumption in the literature has been underlined: on the one hand the unity assumption as a bottom–up influence in terms of perceptual priors and on the other hand, the unity assumption as a top–down influence in terms of beliefs.

Although the majority of these particular multisensory processes have been reported in flavor perception, they still remain to be investigated regarding particular instances of flavor such as freshness. From our analyses and the conceptual distinctions that have been introduced, we propose a model of freshness perception that will pave the way for further empirical research in the food and beverage domain, and more precisely on flavor and freshness perception (**Figure 2**).

AUTHOR CONTRIBUTIONS

JR, JL, and MA contributed to the theoretical elaboration, organization of the structure of the arguments, reviewing of the full article. JR and JL wrote most parts of the article.

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Chapter 2. Multisensory perception and crossmodal interactions: what can we learn from implicit measures?

This chapter presents the theoretical and empirical frameworks that have been considered in this PhD project to investigate the crossmodal interaction effects that may occur before the actual tasting of a beverage, based on visual and auditory cues. The literature reported below provides evidence of how the conjoint integration of visual and auditory information may generate crossmodal interaction effects allowing researchers to collect implicit measures of behavior. These measures contribute to the understanding of the multisensory integration processes that shape our expectations which in turn influence our further experiences of a product.

Numerous researchers working on multisensory processes have reported that these processes result from a dynamic reweighting of physical stimulus characteristics and learned associations. In a recent review, Murray, Lewkowicz, Amedi, and Wallace (2016) put forward that this reweighting occurs across multiple timescales, ranging from short-term (i.e., during the learning and encoding of multisensory relations) to long-term (i.e., developmental and lifespan). Interestingly, it has been shown that multisensory interactions may facilitate behavior by inducing faster and more accurate detection, localization, and discrimination (e.g., Stein, 2012 for a review).

Consequently, the complexity of the multisensory perception of flavor (see General Introduction, section 2) has pushed some researchers to consider experimental designs that allow obtaining more objectives measures toward the crossmodal interactions effects at hand. One possible way to reinforce the reliability of the results targeting multisensory cognitive mechanisms is the use of implicit measures. As opposed to self-report measures, in which participants are asked to self-report their feelings and sensations in a conscious deliberate way, implicit measures that are obtained indirectly are considered to be more sensitive to automatic stimulus evaluations (De Houwer, Teige-Mocigemba, Spruyt, & Moors, 2009 for a review). The use of implicit measures have started to be more popular, even in the food and beverage domain (e.g., Knoeferle & Spence, 2012). Through the analysis of participant's reaction times (RTs), error rates and other psychophysics indices (Signal Detection Theory: Green and Swets, 1966), crossmodal interactions effects are studied in relation to different bottom-up (e.g., spatio-temporal co-occurrence) and top-down (e.g., endogenous attention) modulating factors.

Up to now, researchers have mainly focused on categorization processes that can be highly relevant in terms of information processing and its relation to food and beverages. "Categorization is a central function in human cognition. It plays a crucial role in a variety of settings. It is highly relevant in learning and in everyday reasoning, decision-making, and action" (Foroni & Rumiati, 2017, p.272). The brain visually processes and categorizes stimuli differently according to their relevance and the semantic category to which they belong. Thus, food represents a highly salient biological category given its relevance for survival and its inherently rewarding and hedonic nature (LaBar, Gitelman, Parrish, Kim, Nobre, & Mesulam, 2001).

Vision and audition are well appropriate at various levels for the investigation of categorization processes. First, they are both part of the first set of information an individual will face in everyday situations (together with orthonasal olfaction). Recent research has revealed that sensory systems have the capacity to influence one another even at very early processing stages (e.g., Murray, Thelen, Thut, Romei, Martuzzi, & Matusz, 2016). Thus, as reported by Foroni and Rumiati (2017), vision is appropriate to investigate food categorization and decision-making, to some extent, as it is relevant in real-life situations where food perception and categorization is early constructed on visual cues (e.g., food detection, purchase, choice, etc.). Therefore, numerous studies in psychophysics have therefore considered the multisensory integration of visual and auditory cues (see Spence, 2007 for a review). However, a very few have been conducted in the food and beverage domain. One of the objectives of this PhD project was thus to extend the existing knowledge on audiovisual multisensory integration by applying existing paradigms to more complex and ecological stimuli and enable advances in the field of food and beverage cognition.

Two major kinds of paradigms have been used in past research investigating speeded categorization performances. In the field of cognitive science, various speeded classification paradigms have been used to investigate the processing of stimuli comprising the concurrent presentation of an auditory and a visual signal. In these paradigms, the task generally requires the rapid detection or identification of a stimulus in one modality (or on one dimension of a unimodal stimulus), while an irrelevant stimulus in another modality (or another dimension of a unimodal stimulus) is ignored. Any overall increase in latencies induced by variation on the irrelevant dimension is known as Garner interference (Garner, 1974, 1976), but if there is a correspondence between the polarities on the two dimensions, specific pairings may also show interference when the mapping is incongruent and facilitation when it is congruent (see Patching & Quinlan, 2002 for the distinction between Garner and congruency effects).

Beyond the classic speeded categorization paradigms, other implicit designs have emerged at the beginning of the 20th century in the field of social psychology when researchers wanted to investigate implicit attitudes of people toward target concepts and attributes (see Fazio & Olson, 2003 for the distinction between implicit attitude and indirect measurement). Among them, the Implicit Association Test (IAT, Greenwald, McGhee & Schwartz, 1998) is the one that aroused the most interest and the most works. This test is based on the rationale that participants' RTs will be shorter and their responses will be more accurate in congruent blocks (i.e., when one dimension of the target and the congruent attributes are matched onto the same response key) as compared to incongruent blocks. For example, in the IAT conducted by Greenwald et al. (1998) on racial attitudes, participants were first asked to categorize names (e.g., "Latonya" or "Betsy") as typical of blacks versus whites. Here, race is the target concept and the keys are labeled "black" and "white." Participants then categorized a variety of clearly valenced words (e.g., "poison" or "gift") as pleasant or unpleasant, which constitutes the attribute dimension. In the critical phase of the experiment these two categorization tasks were combined. Participants performed this combined task twice—once with one response key corresponding to black/pleasant and the other corresponding to white/unpleasant, and once with one key meaning black/unpleasant and the other white/pleasant—in counterbalanced order. The question concerns which response mapping participants find easier to use. In Greenwald et al.'s (1998) experiment, participants' RTs were shorter when black names were paired with unpleasant than with pleasant words. On average, then, the participants found it much easier to associate the target concept black with the attribute unpleasant than with the attribute pleasant. The IAT thus enables to reveal the existence of implicit attitudes by measuring their underlying automatic evaluation.

However, since its publication, the IAT has stimulated an enormous amount of research revealing its strengths but also its shortcomings. For instance, the fact that IAT results can be interpreted only relatively and do not enable to disentangle the relative effects of the two targeted associations (see General discussion, section 2). Nevertheless, numerous research have shown that the IAT is able to assess various psychological characteristics because its construction makes it a very flexible tool. In fact, stimuli used for its construction can be linguistic, pictorial, sounds or combinations of these different modalities.

Based on this flexibility and the added value that brings the IAT in terms of implicit measures of behavior, modified version of the original IAT have been developed and applied in the food and beverage domain. In particular, the IAT appeared as a relevant and robust tool to reveal the existence of particular crossmodal interactions, namely crossmodal correspondences that may exist between different perceptual features that belong to different sensory modalities (see Spence, 2011 for a review). For instance, Demattè, Sanabria, and Spence (2007) investigated whether the crossmodal associations between odors and the tactile perception of fabric softness, revealed by recent research using subjective report measures (Demattè, Sanabria, Sugarman, & Spence, 2006), would be robust enough to show crossmodal correspondence effects in a modified crossmodal version of the IAT. In order to measure indirect crossmodal associations between olfactory and tactile stimuli, Demattè and colleagues (2007) have adapted the original version of the IAT for several aspects: first, the use of olfactory stimuli was not compatible with the rapid presentation of successive stimuli or for the use of long blocks of trials, as habituation may introduce unwanted variations in olfactory thresholds. Second, instead of using a reminder of the particular stimulus–response combination during the blocks of trials, the authors used a predictive semantic cue provided on each trial, with the purpose of reducing any possible costs due to the switch of attention between the two sensory modalities (i.e., olfactory and tactile). The idea was to reduce the task-switching costs, which constitutes one of the suggested interpretations of the IAT effect (see General discussion, section 2). Moreover, the number of stimuli used in the task was much more inferior (i.e., two odors and two tactile cues) than the number of stimuli that is used in the original IAT for both the target categories and attributes. Important to note, the existence of particular crossmodal correspondences between two perceptual features (e.g., odors and tactile cues) has been suggested as resulting from the extraction of the environmental regularities between the targeted features, for which congruent and incongruent associations may be expected. Thus, this underlying mechanism rules out the possibility that participants' performances in a modified version of the IAT would have resulted only on task-induced memory processes that could ease a particular stimulus–response assignments for one association (i.e., congruent) as opposed to the other (i.e., incongruent). Thus, different crossmodal IAT paradigms have been subsequently used in order to reveal crossmodal correspondence effects between different stimuli, for instance between basic tastes and pitch (Crisinel & Spence, 2009), colors and flavors (Piqueras-Fiszman & Spence, 2011), or basic visual and auditory features (Parise & Spence, 2012).

Handful of studies have shown that multisensory processes not only depend on low-level factors (i.e., stimulus-related: time, space, number, size…) but also work dynamically and conjointly with higher-level processes including semantic congruency, attentional allocation, and task demands (see Ten Oever, Romei, Van Atteveldt, Soto-Faraco, Murray, & Matusz, 2016 for a recent review). As reported by Doehrmann & Naumer (2008), semantics involve a whole network of information related to objects and their diverse properties and is therefore heavily connected to semantic memory. In the case of a complex perception, such as freshness in the food and beverage domain that may convey different meanings, it may be challenging to investigate the influence of semantics during multisensory processing. In particular, the appropriate overlap between the stimuli and the targeted semantic category to which they belong is crucial to evaluate when expecting semantic congruency effects to occur. In terms of methodology, investigating with Signal Detection Theory (Green and Swets, 1966) paradigm a category that has no obvious truth conditions such as freshness represents an important methodological challenge since it is more difficult to exploit hit and false alarm rates in participants' responses to compute the standard psychophysical indices (e.g., d', see Experiment 2, chapter 5).

Ten Oever and colleagues (2016) have provided a summary of how multisensory processes might be defined by their relative dependence to three types of top-down control they labelled as Context, Object, and Goals (see Fig. 2). The fact that multisensory processes, and by extension the particular case of crossmodal correspondences may depend on both bottom-up and top-down modulating factors, have recently pushed some researchers to question the automaticity of the underlying mechanisms (see Getz & Kubovy, 2018; Spence & Deroy, 2013 for a review). Attentional paradigms have been developed in order to investigate at which level (perceptual, automatic, or involuntary level vs. higher order cognitive level called top-down, decision, response, or strategic level involving response selection, language processing, or a specific attentional focus) particular types of crossmodal correspondences might occur (e.g., Chiou & Rich, 2012; Evans & Treisman, 2010). One type of crossmodal correspondences that has been distinguished is the semantically-mediated correspondences that may occur when common linguistic terms are used to describe two different stimuli, for instance pitch and spatial elevation both described as low or high. In this case, the level at which the crossmodal correspondence might arise may be discussed given that the underlying mechanisms likely depend on both bottom-up and top-down processing (Getz & Kubovy, 2018).

Figure 2: Typology of the top-down factors to which multisensory processes depend on (retrieved from Ten Oever et al., 2016)

In rounded boxes, a summary of influences that a multisensory process should be sensitive to in order to be classified as dependent on context, object and the observer's goals, respectively. MS: Multisensory.

One of the characteristics that define crossmodal correspondences is their bidirectionality (Deroy & Spence, 2013). If we consider the crossmodal correspondence between pitch and size, the presentation of a particular size of an object will prime a lower frequency sound just as robustly as the presentation of a lower-pitched sound will prime a larger object. However, several researchers have also demonstrated that higher-pitched sounds tend to be associated with higher elevations in space (e.g., Evans & Treisman, 2010). Thus, it seems reasonable to hypothesize that size and spatial elevation may share an intramodal (involving only vision) or a crossmodal (haptic and visual) correspondence (see Walker & Walker, 2012). The relations that may exist between crossmodal correspondences have been recently theorized by some researchers (Walker & Walker, 2012; Walker, 2016) based on previous work studying the interactions between surface brightness, odor, and auditory pitch (Von Hornbostel, 1931), through the notion of transitivity of implication that exists in logic. Transitivity is a rule governing the relationships linking different properties and might be simply described as "If A implies B, and B implies C, then A implies C".

The same logic might be applied to the relations between pitch, size, and spatial elevation: if small size is associated with high pitch, and high pitch is associated with high spatial elevation, then small size will be certainly associated with high elevation. However, given the fact that some crossmodal correspondences depend on both perceptual and higher order cognitive levels (e.g., linguistic or emotional), Deroy & Spence (2013) pointed out that transitivity should not be expected in every case. The transitivity hypothesis between several correspondences will constitute one of our research questions (see chapter 3 and Part D).

To sum up, in order to investigate crossmodal interaction and correspondence effects between visual and auditory cues that could influence the perceived freshness in beverages, the present PhD project considered the seminal literature on categorization processes, semantic priming, and implicit measures. Recent advances in cognitive science, both fundamental and applied research in the food and beverage domain were also considered.

Chapter 3. Research questions, hypotheses, and methodology

The perception of freshness in beverages is complex and heterogeneous among people (General Introduction, section 1). Thus, the investigation of the audiovisual crossmodal interaction effects that occur before the actual consumption, but may indirectly influence the subsequent consumer's experiences by triggering specific sensory expectations, represent a first step in the understanding of the cognitive mechanisms that underlie this perception. To address this goal, and based on the literature review presented in the two previous chapters, five main objectives were delimitated for the present thesis, presented successively in the following chapter. For each objective, the specific research hypotheses are detailed as well as the methodology employed to test them.

1. Audiovisual crossmodal interaction effects on perceived freshness in beverages (Part B)

1.1. Objectives

The results of previous research have revealed how various types of perceptual features from different sensory modalities may influence the perception of freshness in different product categories. However, there is currently little consensus regarding the respective contributions of the various sensory cues that might be involved. Moreover, among the variety of perceptual features, it is for now unknown whether some of them might induce crossmodal correspondence effects. In oral care products, freshness has been defined as a dynamic time-varying concept, at least during product usage (Westerink & Kozlov, 2004). In the case of beverages and following from the literature review presented in chapter 1, it is likely that the way consumers might perceive a beverage as fresh will vary from the pre- to the post-consumption phase. To avoid this variability, our study was designed to focus on freshness expectations in beverages prior to consumption, taking into account the contribution of audiovisual perceptual features. Based on the literature, we focused on perceptual features cuing temperature, carbonation, and color of the liquid.

The first objective of the present thesis was to explore the influence of congruent and incongruent audiovisual interactions, with perceptual features cuing temperature, carbonation, and color of the liquid on the categorization of freshness in beverages.

1.2. Research hypotheses

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

H2. Two main crossmodal interaction effects were 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 was also expected since different colors can lead to different expectations regarding the corresponding flavor of the liquid, as well as different product categories to which the participants may associate a particular freshness intensity.

1.3. Research methodology

Initially, a preliminary online experiment was conducted through an internet-based testing tool (Qualtrics©) with 84 North American participants 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 as rapidly as possible 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” (Annex 5).

Then, a speeded categorization task was conducted with 84 French participants in a controlled laboratory setting at the Institut Paul Bocuse Research Center. The participants’ task was to categorize as rapidly 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. The software E-prime© was used to record the participants’ RTs.

In both the preliminary online experiment and the laboratory experiment, we also collected socio-demographic data, as well as declarative data (quantitative and qualitative) on consumption habits of the participants, their preferences, and their expectations toward the consumption of fresh alcoholic beverages (Chapter 4, Supplementary results; Annexes 4, 6, 7).

2. Audiovisual crossmodal correspondences and their relative effects (Part C)

2.1. Objectives

The literature on crossmodal correspondences has often reported an association between auditory pitch and the size of circles presented visually (e.g., Parise & Spence, 2012). However, whether this association still exists with more ecological and complex audiovisual stimuli remains to be investigated. On the other hand, some audiovisual perceptual features linked to carbonation in beverages have been shown to influence the perception of freshness. Thus, two features of transparent carbonated beverages have been selected as the ecological counterparts of the above-mentioned pitch and circles. These two features were bubbles size (small vs. big) and the pouring sounds pitch of a carbonated beverage (high-pitched vs. low-pitched). The first experiment conducted aimed at investigating the existence of a Pitch-Size correspondence between the targeted stimuli. A second experiment using a different paradigm was conducted in order to disentangle the relative effects of the two pitch-size associations (small bubbles-high pitch vs. big bubbles-low pitch). In order to increase the difficulty of the task and obtain a reliable design, visual variables (color of the liquid and width of the glass) were added and enabled us to test the robustness of the Pitch-Size correspondence previously shown. We argue that testing for the existence of crossmodal correspondences in beverages can have applied outcomes since the triggering of such crossmodal correspondences, upstream of the consumption phase, could positively influence freshness perception and increase beverages' attractiveness and purchase intention.

The second objective of the present thesis was to test the existence of audiovisual crossmodal correspondence effects between specific cues related to carbonation in beverages, namely between bubbles size and pouring sounds pitch (Experiment 1, chapter 5).

The third objective of the present thesis was to disentangle the relative effects of the two Pitch-Size associations, and see whether the crossmodal correspondence effects were robust enough to variations of the stimulus context (i.e., color of the liquid and width of the glass, Experiment 2, chapter 5).

Finally, in both experiments, explicit data were also collected regarding the bubbles size and the pouring sounds pitch the participants generally associate to the consumption of fresh sparkling beverages. The idea was to determine whether one of the pitch-size associations investigated was “stronger” (i.e., more linked to the freshness category in the participants’ mind) than the other, when the link between the targeted features of carbonated beverages and freshness in beverages was explicitly mentioned to the participants. It also represented an opportunity to compare these explicit data with the implicit ones collected (RTs and error rates), and discuss whether these different types of measures provide consistent results.

2.2. Research hypotheses

H1. The existence of a crossmodal correspondence between two particular perceptual features will induce shorter reaction times and higher accuracy in congruent blocks.

H2. The IAT compatibility effects resulted from the crossmodal correspondence are expected to be strengthened in the presence of a congruent semantic prime; in particular for small bubbles and high-pitched pouring sound that likely more refer to freshness.

H3. The IAT compatibility effects resulted from the crossmodal correspondence may vary according to the stimulus context (i.e., color of the liquid and width of the glass) due to the existing widespread network of correspondences.

2.3. Research methodology

Crossmodal correspondences are often inferred from participants’ RTs using speeded classification tasks, including variants of the Implicit Association Test (IAT) to determine the strength of the association between two perceptual features (e.g., Deroy, Fasiello, Hayward, & Auvray, 2016; Demattè, et al., 2007). This test is based on the rationale that when two stimuli share a strong association, participants’ RTs are shorter and their responses are more accurate (Greenwald, McGhee, & Schwartz, 1998). According to Greenwald, Nosek, and Banaji (2003), the IAT provides a standard method for measuring the strengths of associations between a wide range of items. Thus, a modified version of the Implicit Association Test (IAT) was used in Experiment 1 to investigate the existence of Pitch-Size correspondence effects between bubbles size and pouring sounds pitch of a carbonated beverage. The participants had to respond to four unimodal stimuli which were paired either congruently (small bubbles and high-pitched pouring sound; big bubbles and low-pitched pouring sound) or incongruently (the reverse associations). Moreover, since there is a lack of empirical evidence on the impact of semantic priming on the IAT compatibility effects, we wanted to investigate whether these effects could be strengthened in the presence of a congruent semantic prime. In other words, we tested whether a pre-activation of the targeted concept (i.e., freshness versus neutral prime), to which the stimuli to categorize are semantically related, could increase the IAT compatibility effects. It allowed us to implicitly test the link between the targeted stimuli and the concept of freshness and see how the semantic processing of the prime might influence participants' behavior toward the stimuli of interest. A second experiment was designed to assess the relative effects of the associations (small bubbles-high pitch vs. big bubbles-low pitch) previously uncovered. To this end, a Go/No-Go Association Task was used (Nosek & Banaji, 2001). In this task, the sensitivity in the participants' responses (d', Signal Detection Theory) to congruent and incongruent associations of stimuli was compared between blocks of trials where the target bubbles size was paired with either high-pitched or low-pitched pouring sounds. The visual stimuli varied for the bubbles size (small vs big), the color of the liquid (colorless, yellow, and brown), as well as the width of the glass (four different sizes). The auditory stimuli varied for the pitch of the sound (four different pitches including the two pitches used in the IAT experiment).

3. The transitivity of correspondences and attentional allocation effects (Part D)

3.1. Objectives

As above-mentioned in chapter 2, the relations that may exist between crossmodal correspondences have been recently theorized by some researchers (Walker & Walker, 2012; Walker, 2016) who refer to the notion of transitivity; a rule governing the relationships linking different properties that might be simply described as "If A implies B, and B implies C, then A implies C".

The Pitch-Size and Pitch-Elevation crossmodal correspondences have been widely reported in the literature (e.g., Evans & Treisman, 2010). Few studies have investigated the intramodal Size-Elevation correspondence which is considered as more than likely since the mechanisms underlying this correspondence are certainly extracted from the statistical regularities of our environment; according to the context, people generally infer that a large (and potentially heavy) object will not be able to be located at high spatial location (see Spence, 2011). Nevertheless, Evans and Treisman (2010) failed to show the existence of this intramodal correspondence.

Moreover, the stimuli that are generally used to reveal such types of intra- or crossmodal correspondences are very simple cues corresponding, for instance, to pure tones for the sounds and grey circles or Gabor patches for the visual stimuli. The Pitch-Size correspondence has already been reported for more complex and ecological stimuli (Roque, Lafraire, Spence, & Auvray, 2018b). However, it remains an open empirical question whether the same stimuli would reveal: i) correspondence effects for the Pitch-Elevation and Size-Elevation correspondences, and ii) transitivity between these three different correspondences.

Additionally, the experiments reported in chapter 6 also aimed at testing the robustness of the Pitch-Size correspondence previously identified by Roque and colleagues (2018b) by using a different paradigm than the IAT. Using two distinct tasks' instructions, the allocation of the participants' attention was manipulated toward either the same features on which the correspondences were tested or to different features from those with the hypothesized intra- or crossmodal correspondences. This manipulation enabled us to discuss at which level (perceptual vs. higher order cognitive level) the targeted correspondences might occur.

We argue that a better understanding of the relations that may exist between different intra- and crossmodal correspondences would help food and beverage companies in developing efficient strategies (in terms of formulation, packaging, retail experience, or ads, see Ngo, Piqueras-Fiszman, & Spence, 2012) to better catch consumers' attention and likely increase attractiveness and appreciation of products.

The fourth objective of the present thesis was to test the existence of the intra- and crossmodal correspondences that may exist between bubbles size, pouring sounds pitch, and spatial elevation, and determine whether a transitivity relationship exists.

The fifth, more general objective of the present thesis, was to test the robustness of the tested correspondences across all the experiments: i) using more complex and ecological stimuli than those used in the literature, and ii) replicating their effects with different experimental paradigms (chapters 5 and 6).

3.2. Research hypotheses

H1. The existence of an intra- or crossmodal correspondence between two particular perceptual features will induce shorter reaction times and higher accuracy in congruent trials.

H2. Transitivity hypothesis: If Size and Pitch share a crossmodal correspondence, if Pitch and Elevation share a crossmodal correspondence, then Size and Elevation likely share an intramodal correspondence (see figure 3 below).

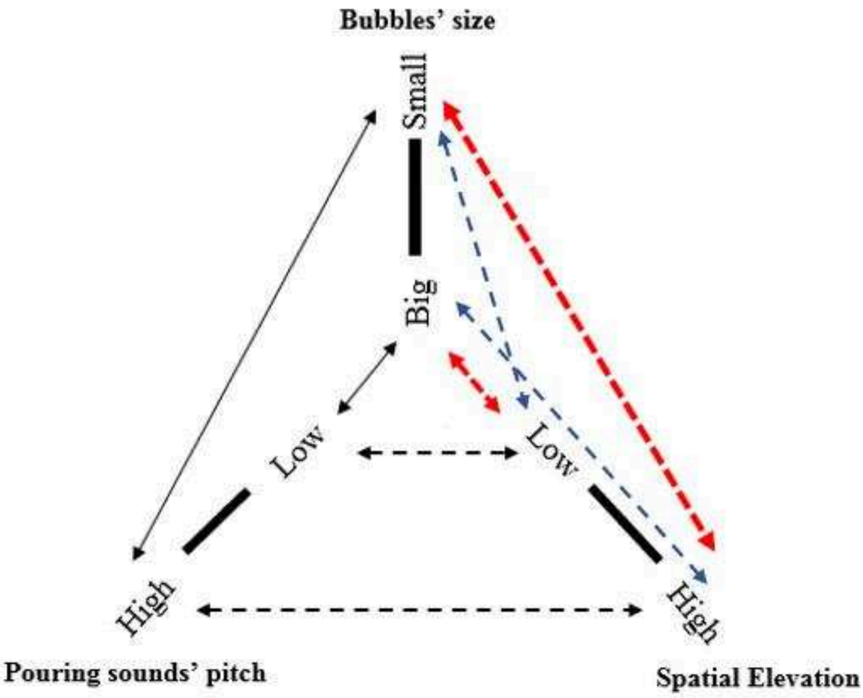

Figure 3: Illustration of the transitivity hypothesis between bubbles Size, pouring sounds Pitch, and spatial Elevation (retrieved from Walker, 2016)

Red arrows depict a confirmation of the transitivity hypothesis. Blue arrows depict a disconfirmation of the transitivity hypothesis.

H3. If the transitivity hypothesis is confirmed, it is expected that a bidimensional congruent visual stimulus (e.g., small bubbles and high elevation in space) jointly presented with a congruent auditory stimulus (i.e., high pitch) will induce a facilitation effect in the participants' performances.

3.3. Research methodology

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, for a review). In speeded classification paradigms, as opposed to the IAT in which participants respond to only one stimulus in one modality at a time, the task requires the rapid identification of a stimulus in one modality (or one dimension of a unimodal stimulus), while an irrelevant stimulus in another modality (or another dimension of a unimodal stimulus) is ignored. Speeded classification was used to compare performance between unimodal visual and auditory presentations and bimodal simultaneous presentations in which the pairings were either congruent or incongruent. An attentional paradigm was used to test whether these interactions arose automatically and possibly suggest an interaction at the perceptual level rather than being mediated by a higher order cognitive level involving, for instance, language processing (high vs. low for both pitch and spatial elevation). In the “Direct tasks”, the participants were asked to respond to the same features on which the correspondences were tested (i.e., bubbles size, pouring sounds pitch, and spatial elevation), whereas in the “Indirect tasks” the participants were asked to respond to different features from those with the hypothesized correspondences (i.e., lateralization of the visual and auditory stimuli).

PART B. AUDIOVISUAL CROSSMODAL INTERACTION EFFECTS ON PERCEIVED FRESHNESS IN BEVERAGES

Chapter 4. The influence of perceived temperature, carbonation, and color of the liquid on the perception and categorization of freshness in beverages

This chapter presents the first experimental studies that have been conducted to investigate the influence of specific audiovisual perceptual features on freshness ratings and freshness categorization in beverages.

The literature has shown that 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 (e.g., Zellner & Durlach, 2002), water (Labbe et al., 2011), and soft drinks (e.g., Saint-Eve et al., 2010). It has also been shown that carbonation can influence freshness perception in beverages both when seen (i.e., density of bubbles) and through the trigeminal pathways (e.g., Guinard, et al., 1998; McEwan & Colwill, 1996). Another study conducted by Zampini and Spence (2005) showed that the perception of carbonation in a beverage may be influenced by the auditory cues provided by the bubbles. Finally, it has often been reported that different colors of a beverage can set up different flavor expectations which will likely influence the categorization of freshness.

Thus, audiovisual stimuli cuing the likely temperature (presence vs. absence of ice cubes), the likely level of carbonation (presence vs. absence of bubbles), and the color of the liquid were used. One of the objectives of the present study was to get more insight on the crossmodal interaction effects that can occur before the tasting step, and to acquire data on the respective contributions of the different targeted stimuli that may contribute to the perception of freshness in beverages.

In terms of methodology, a speeded categorization task on freshness was designed to test how audiovisual interaction effects between perceptual features that may trigger freshness expectations in beverages could influence the participants' performances. Indeed, shorter RTs and higher accuracy in the participants' 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 & Colonius, 2004).

From an applied perspective, we hypothesized that a better understanding of the effects resulting from the interactions between visual and auditory cues, in terms of multisensory processing and behavioral responses, could help food and beverage companies to identify strategies that would facilitate the categorization of their products as fresh from consumers' point of view. Consequently, this could increase products' attractiveness and positively influence consumers' purchase behaviors.

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ORIGINAL ARTICLE

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

Jérémy Roque[1,2,3] | Jérémie Lafraire[2] | Charles Spence[4] | Malika Auvray[3]

[1]Breakthrough Innovation Group, Pernod Ricard, Paris, France
[2]Institut Paul Bocuse Research Center, Ecully, France
[3]Sorbonne Université, UPMC, CNRS, Institut des Systèmes Intelligents et de Robotique (ISIR), Paris, France
[4]Crossmodal Research Laboratory, Department of Experimental Psychology, Oxford University, Oxford, United Kingdom

Correspondence
Jérémy Roque, Centre de Recherche Institut Paul Bocuse, 1 Chemin de Calabert, 69130 Ecully, France.
Email: jeremy.roque@pernod-ricard.com

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Abstract
The study reported here investigated the influence of audiovisual stimuli signaling the likely temperature (the presence versus absence of ice cubes), the likely level of carbonation (the presence versus 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 categorized more the stimuli as fresh 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 beverages would be categorized of 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.

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, Du-Plessis, Dommels, & Wilkinson, 2013; Labbe et al., 2009; Roque, Auvray, & Lafraire, 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: (a) 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), (b) the aging of the organic ingredients contained in the drink (e.g., aging of the mint leaves in a mojito), or else (c) 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, Almiron-Roig, et al., 2009; Roque et al., 2018 for reviews), it appears that the multisensory experience of freshness is likely built from two fundamental cognitive mechanisms that include: (a) expectations elicited by visual, auditory, and orthonasal olfactory cues for which a product can be perceived as

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fresh, before tasting, and (b) 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, Schifferstein, Huang, and Hekkert (2009) documented that for soft drinks and dishwashing liquids, olfactory cues dominated over visual color cues as far as freshness judgments were concerned. Labbe, Gilbert, Antille, and Martin (2009), 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, for example, texture or bubbles), "water-ness" (related to the multiple experiences of having water in the mouth, that is, "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, Almiron-Roig, et al., 2009; Zellner & Durlach, 2002), water (Labbe, Martin, Le Coutre, & Hudry, 2011), and soft drinks (McEwan & Colwill, 1996; Saint-Eve et al., 2010; Zhang, Lusk, Mirosa, & Oey, 2016). Guinard, Souchard, Picot, Rogeaux, and Sieffermann (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, Jones, King, & Spence, 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 & 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, 2015; Spence & Wang, 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, Gover, Philipsen, & Fugardi, 1992; Zellner & 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, Gilbert, et al., 2009) 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, Moors, Wagemans, & Spence, 2017). 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. 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 nonarbitrary 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, Roy, Chen, & Zhang, 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., Demattè, Sanabria, & Spence, 2007; Deroy, Fasiello, Hayward, & Auvray, 2016; Parise & Spence, 2012). This test is based on the rationale that when two stimuli share a strong association (i.e., congruent versus 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 & Treisman, 2011; 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 & 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 & 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 & 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 induce crossmodal correspondences effects.

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

Hypothesis 1. Both visual and auditory perceptual features linked to temperature (presence versus absence of ice cubes[1]), and carbonation (presence versus absence of bubbles[2]) would influence the categorization of freshness in beverages.

Hypothesis 2. Two main crossmodal interaction effects are expected: (a) 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 (b) a tendency to categorize these congruent stimuli as fresh.

Hypothesis 3. 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 versus absence of ice cubes), the likely level of carbonation (presence versus 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."

[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.

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

2.2.1 | 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 versus four rectangular ones), carbonation (carbonated transparent lemonade 6.2 g/L CO_2 versus still water), and colors (colorless, blue, green, yellow, orange, brown, and red, created using food-coloring, see Supporting Information). 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, CO_2 content, and color cues in the various different conditions (see Figure 1).

2.2.2 | Auditory stimuli

The sounds of 250 ml of liquid being poured into a glass were recorded for 2 s across the factorial design giving rise to four different sounds: (a) still liquid without ice cubes, (b) carbonated liquid without ice cubes, (c) still liquid with four rectangular ice cubes, (d) carbonated liquid with four 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 CO_2). 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 software.[3]

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., 2017), 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 1,000 ms. Next, the bimodal stimulus was displayed for 2,000 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 Figure 2).

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

[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, Miles, and Field (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.

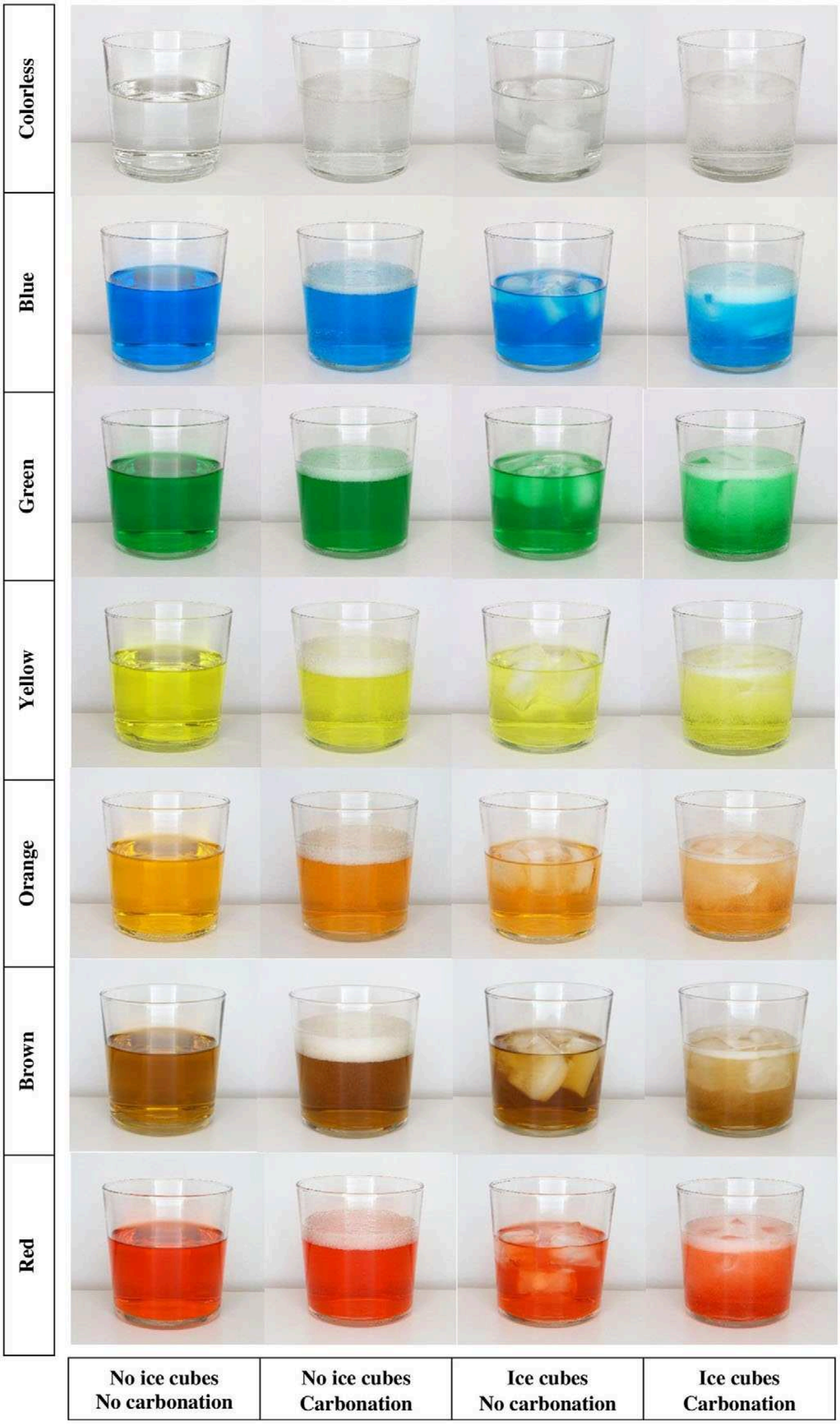

FIGURE 1 Pictures of the different visual stimuli used varying in temperature, carbonation, and color

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 versus incongruent stimuli) on participants' RTs. This model (R^2_C = 0.464, see Nakagawa & Schielzeth, 2013) revealed a significant main effect of congruency, $\chi2$ [1] = 33.7, p < .0001. Overall, the participants' RTs were significantly shorter for congruent stimuli (m = 1,047 ms ±6.68 *SEM*) than for incongruent stimuli (m = 1,081 ms ± 3.96 *SEM*).

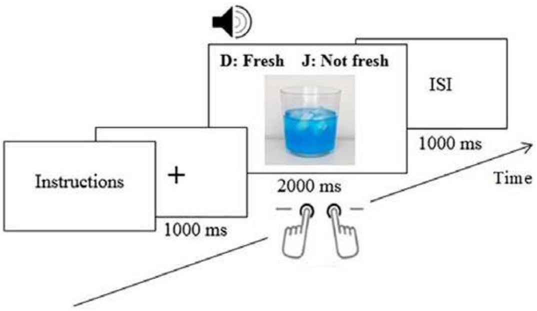

FIGURE 2 Timeline. ISI = intertrial stimulus interval. Note that the assignment of the two response keys was counterbalanced across participants

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 Figure 3.

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 nonsignificant 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.

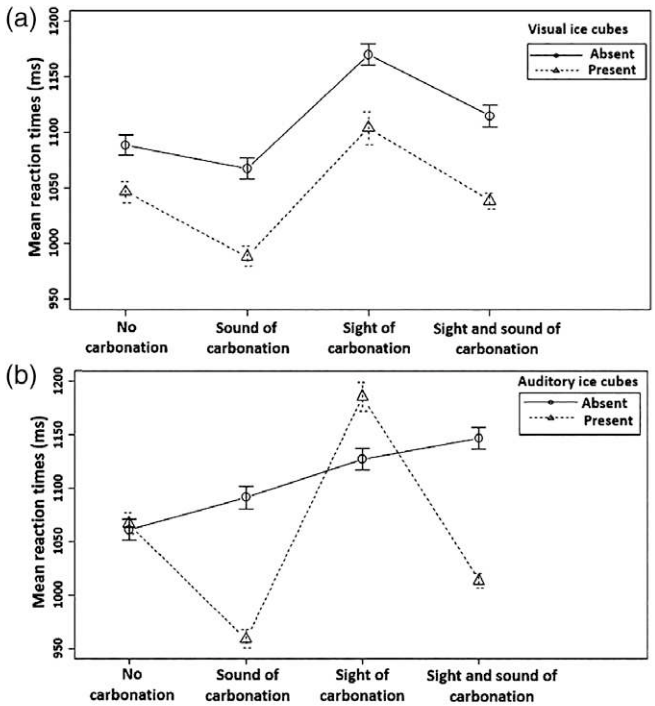

FIGURE 3 Mean RTs (in ms) for the three-way interactions between (a) the sight of ice cubes and the different carbonation conditions; (b) the sound of ice cubes and the different carbonation conditions. The error bars represent the *SEM*. (a) For both solid and hatched black lines, respectively, all 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. (b) 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

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, $\chi2(9) = 252.42$, $p < .0001$. Another three-way interaction effect between the different ice cubes conditions and the sight of carbonation was revealed by the model, $\chi2(13) = 10.2$, $p = .0014$. The color of the stimuli did not significantly influence the categorization of freshness ($F = 1.26$). These results are presented in Figure 4.

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

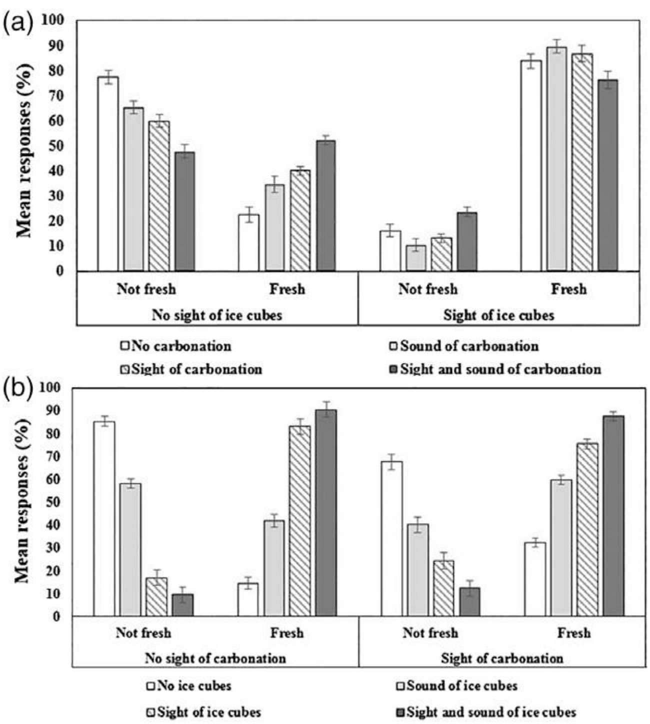

FIGURE 4 Mean responses (%) for the categorization of freshness according to (a) the different carbonation conditions and the sight of ice cubes; (b) the different ice cubes conditions and the sight of carbonation. $N = 84$ for each condition. The error bars represent the *SEM*. (a) All the represented means are significantly different from each other, except the comparisons between the light-gray and the hatched bars in the no sight of ice cubes condition and the white and the dark-gray bars in the sight of ice cubes condition, respectively, for not fresh and fresh categories that failed to reach statistical significance. (b) All the represented means are significantly different from each other, except the comparisons between the dark-gray bars in the "No sight of carbonation" condition and those in the "Sight of carbonation" condition, respectively, for not fresh and fresh categories that failed to reach statistical significance

Another significant influence on the participants' responses was revealed for the interaction between the different ice cubes conditions and the sound of carbonation: a Tukey post hoc analysis revealed that in the "No sight of carbonation" condition, both the sound ($b = 1.43$, $z = 19.8$, $p < .001$) and sight of ice cubes ($b = 3.27$, $z = 40.9$, $p < .001$) had a positive effect for categorizing the stimuli as fresh, with an additive effect when the two were presented together, increasing the percentage of responses when the participants categorized the stimuli as fresh (vice versa for not fresh). In the "Sight of carbonation" condition, the same additive 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, $\chi2(12) = 38.72$, $p < .0001$. 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 Figure 4a.

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 & 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 & Treisman, 2011; Gallace & Spence, 2006; Hecht & Reiner, 2009; Misselhorn, Daume, Engel, & Friese, 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.

On the other hand, the congruency effect inducing shorter RTs for the congruent audiovisual interactions linked to temperature is no longer obtained when there was visible carbonation in the drink, the latter always inducing significantly longer RTs. Thus, in our study, the additive effect of the sound and sight of ice cubes is lost when the stimulus itself becomes more complex. This result suggests that it could be worth going further on research targeting multisensory interactions since the more complex the stimulus becomes (i.e., by adding other sensory cues), the more likely the crossmodal interaction effects can be enhanced or else inhibited. In fact, few studies have considered crossmodal interactions with more than two different perceptual features belonging to the same or different modalities, except those used as distractors in the task. For instance, in Misselhorn et al.'s (2016) study, a bimodal focus was defined and the third modality was considered as a distractor modulating the congruency of the trimodal interaction between auditory, visual, and tactile modalities. The study revealed that the participants' RTs were shorter for congruent trimodal stimuli than for incongruent ones. The fact that different results were obtained in our study can be attributed to the complexity of the stimuli. In fact, the stimuli used sometimes displayed two different perceptual features of interest belonging to the same modality at the same time (e.g., the sight of ice cubes and the sight of carbonation instead of two perceptual features belonging to different modalities). Moreover, the potential influence of confounding variables such as the variation in visual turbidity of the different visual stimuli was not taken into account. It has to be noted that the participants in Misselorn et al.'s study had to respond verbally to the stimuli whereas in our study they answered by pressing one of two response keys. We hypothesize that the modulation of the participants' attention could explain the loss of the additive effect in our study. In fact, the participants' attention could have been directed more to the salient foam on the surface of the liquid than to bubbles present within the liquid itself. In line with 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, Almiron-Roig, et al., 2009).

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 & 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, Woods, Seoul, Butcher, & Spence, 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 & 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 (i.e., social exclusion) 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 quite small (N = 12) and the mechanisms underlying some crossmodal interactions have been shown to be relative and not absolute (see Spence, 2011, on the relative aspect of crossmodal correspondences). Consequently, having color as a between-participants factor did not allow visual comparisons of the different colored beverages in our study.

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

Finally, by avoiding the presence of organic ingredients (e.g., mint leaves) and directing the participants' attention to the expected in-mouth freshness that they might perceive from the different beverages, we aimed at constraining the interpretation of the word freshness reducing the association with the aging of organic ingredients or time delay. However, when the participants answered to a beverage that contained visual ice cubes (or visual carbonation) and subsequently answered to visual stimuli with the same color but for which visual ice cubes (or bubbles) were absent, it is possible that they interpreted this sequence as ice cubes' melting (or bubbles vanishing). In this case, the meaning of freshness could have been associated to the time delay between the preparation and the consumption of the drink. Extending this hypothesis, the relation between an increasing time delay and a decreasing perception of freshness of the beverages could also be associated to an increasing perception of the microbial population. It has been shown that this potential source of poisoning may generate incidental disgust in consumers that will reduce their preference for the products they perceive as contaminated (see Hobbs & Roberts, 1987; Motoki & Sugiura, 2018).

On the basis of our results, it would appear that an interesting perspective for future investigation would be to address the crossmodal interaction effects that can occur in the categorization of freshness between different kinds of audiovisual perceptual features linked to temperature, carbonation, and color. We believe that the effects resulting from the interaction of visual and auditory cues could be triggered to facilitate consumers' categorization of a given product as fresh. This idea is in line with some empirical studies that have highlighted that audiovisual inputs can significantly influence the final percept of the product experienced (Piqueras-Fiszman & Spence, 2015; Spence, 2015). However, the influence of other major sensory contributors (e.g., olfactory cues) cannot be disregarded (Martin et al., 2005, see Auvray & Spence, 2008; Spence, Auvray, & Smith, 2014, for reviews). Thus, one promising perspective would be to enrich the stimulus context by adding sensory contributors beyond the audiovisual in order to generate additional results on the multisensory mechanisms that underlie freshness perception in beverages. Enriching that way the stimulus context by adding, step-by-step, distinct sensory contributors, is required to generalize our results to more ecological contexts. Another interesting follow-up in real consumption context would be to investigate the influence of ambient temperature during the consumers' freshness evaluation of beverages while modifying the products' temperature and color (see Motoki, Saito, Nouchi, Kawashima, & Sugiura, 2018 who have shown that ambient warm temperature decreases the preference for savory foods). Modulating the ambient temperature might also enable researchers to understand the mechanisms that lead some populations living in warm countries to consider hot beverages (e.g., hot mint tea in North Africa) as fresh or 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 twofold 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 the influence of color on freshness perception 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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ORCID

Jérémy Roque http://orcid.org/0000-0002-8293-4995
Charles Spence http://orcid.org/0000-0003-2111-072X

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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Supporting information

Table 1. References and volumes of food-colorings used to generate the different colors and conditions of visual temperature (presence versus absence of ice cubes).
The final volume in each condition was completed to 200 mL with either still water or carbonated lemonade at ambient temperature.

Color	**Food-colorings references**	**Food-colorings volume** (µL)	
		Visual temperature: No ice cubes	**Visual temperature: 4 ice cubes**
Colorless	NA	NA	NA
Blue	E133	140	92.4
Green	E102 + E133	280 + 140	184.8 + 92.4
Yellow	E104	200	132
Orange	E104 + E129	100 + 50	66 + 33
Brown	E150d	50	33
Red	E129	400	264

Supplementary results

1. The influence of stimuli and participants' RTs on freshness categorization in the laboratory experiment

(i) Sight of ice cubes

An ascendant hierarchical classification on participants' RTs revealed two groups:

1. Long RTs: mean=1444.9 ± 3.1 SEM ms, N= 5643
2. Short RTs: mean=786.2 ± 2.3 SEM ms, N= 7333

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 and the participants' RTs as independent variables, the final model considered (Tjur's coefficient of discrimination: D=0.39, see Tjur, 2009) revealed a significant two-way interaction effect between the sight of ice cubes and the participants' RTs group on the participants' responses, $\chi2(8)= 363.5$, $p<0.0001$. These results are presented in Figure 4 below.

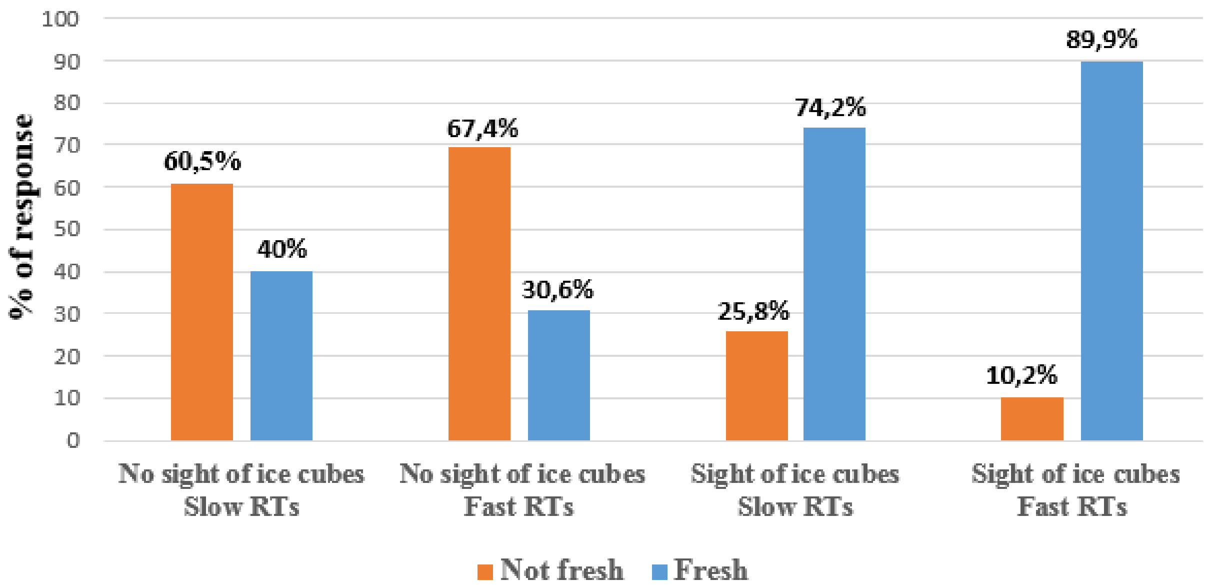


Figure 4: Percentages for Fresh and Not fresh responses according to the interaction between the sight of ice cubes and the speed of the participants' RTs

In the No sight of ice cubes condition, the stimuli were more categorized as being not fresh independently of the speed of RTs. For fast RTs, it can be noted that the percentage of response for not fresh response is almost twice bigger than for fresh response. In the Sight of ice cubes condition, the stimuli were more categorized as being fresh independently of the speed of RTs. For fast RTs, it can be noted that the percentage of response for fresh response is almost nine times bigger than for not fresh response.

These results are thus consistent with the fact that coldness (here cuing by the presence of ice cubes) positively contribute to freshness perception in beverages (e.g., Zellner & Durlach, 2002), both in decreasing participants' RTs and increasing the categorization of the corresponding beverages as fresh.

(ii) Sight of carbonation

Another two-way interaction effect between the sight of carbonation and the participants' RTs group on the participants' responses was revealed by the model, $\chi2(9)= 6.2$, $p=0.013$.

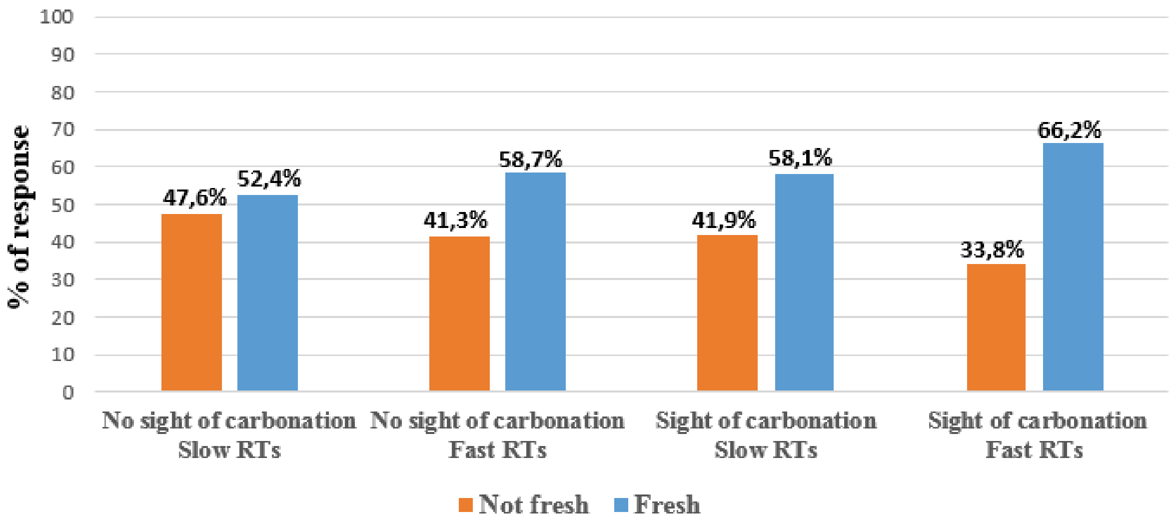


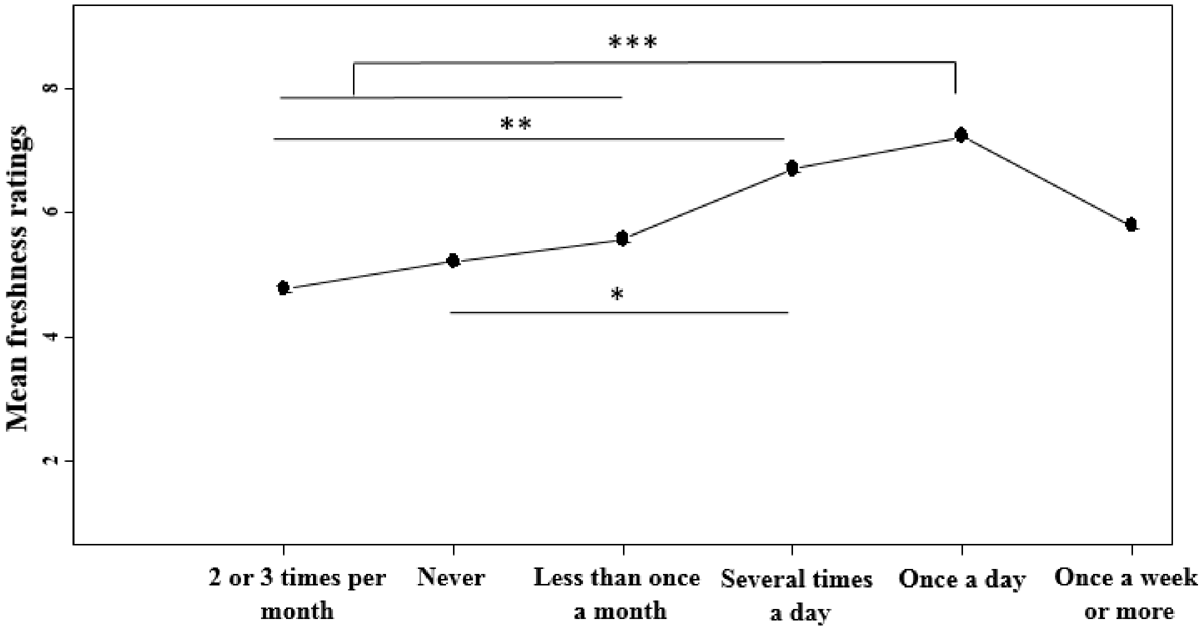
Figure 5: Percentages for Fresh and Not fresh responses according to the interaction between the sight of carbonation and the speed of the participants' RTs

Both stimuli with or without visual carbonation were more categorized as fresh than not fresh. However, in the condition Sight of carbonation for fast RTs, it can still be noted that the percentage of response for fresh response is almost twice bigger than for not fresh response.

This result is consistent with the fact visual carbonation may increase the perceived freshness of beverages (e.g., McEwan & Colwill, 1996).

2. The influence of sweetness liking and consumption habits on freshness ratings in the preliminary online experiment

Linear mixed-effects models were fitted to the data with participants as a random variable and the congruency variable as nested. When considering the variables linked to the frequency of consumption of different types of alcoholic beverages as independent variables and the freshness ratings as the outcome variable, the final model considered ($R^2_C=0.282$) revealed a significant main effects of their frequency of consumption of beers, $\chi2(7) = 20.42$, $p=0.001$ (see Figure 6 below).



<u>Figure 6: Mean of freshness ratings according to the frequency of consumption of beers</u>

N=84 American participants. *p<0.05, **p<0.01, ***p<0.001

A Tukey post-hoc analysis revealed that the participants who declared daily consuming beers (once a day: n=7; several times a day: n=9) assessed as being significantly fresher the stimuli displayed in this study, as compared to the participants who declared rarely or never consuming beers (2 or 3 times per month: n=11; less than once a month: n=15; never: n=27).

Another linear mixed-effects model (R^2_C=0.334) revealed significant two-way interaction effects between visual ice cubes and the participants' liking of sweet beverages ($\chi 2(6) = 13.4$, p=0.0013), as well as between visual carbonation and the participants' liking of sweet beverages ($\chi 2(7) = 70.6$, p<0.0001).

From the data distribution on the participants' liking of sweet beverages (9 points Likert scale) three groups of participants appeared:

- Group1: Participants who hate or moderately appreciate the consumption of sweet beverages: N=21, m=3.57 ± 1.2 SD
- Group2: Participants who appreciate the consumption of sweet beverages: N=40, m=7.1 ± 0.6 SD
- Group3: Participants who love the consumption of sweet beverages: N=23, m=9

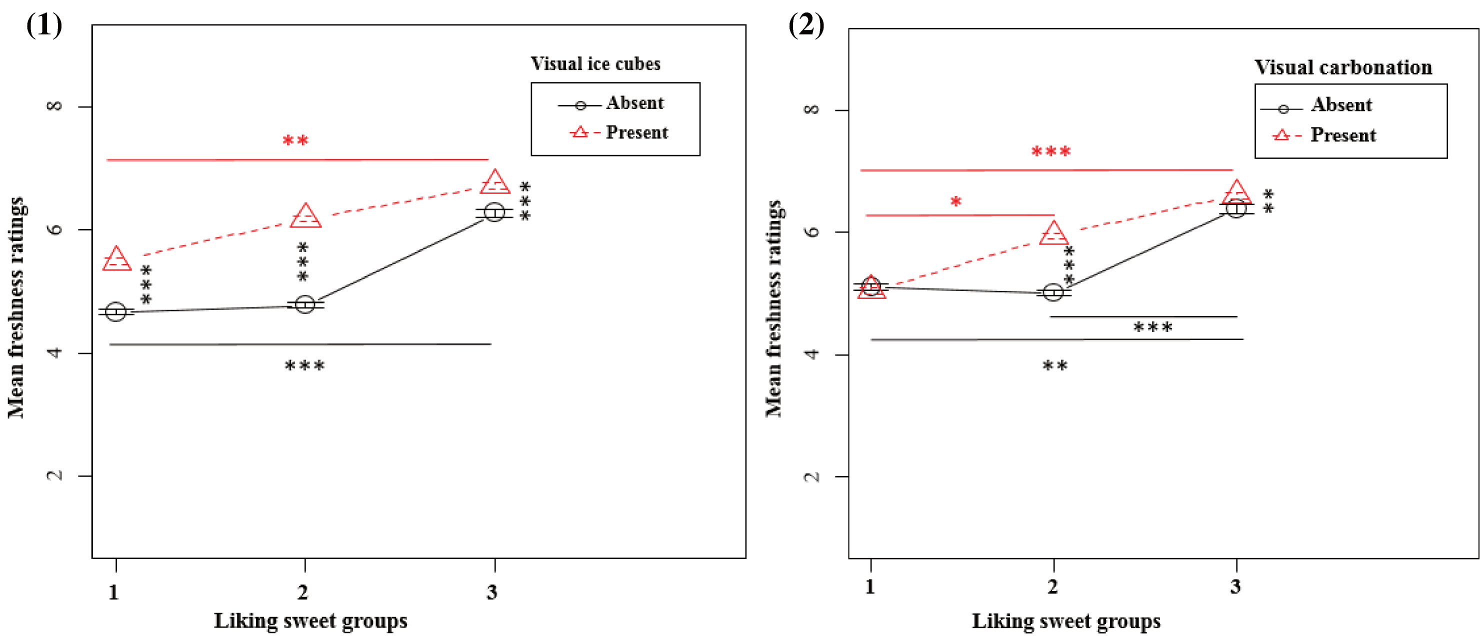


Figure 7: Mean freshness ratings according to the presence or not of (1) visual ice cubes and (2) visual carbonation as function of the participants' liking sweet groups

N=84 American participants. *p<0.05, **p<0.01, ***p<0.001

A Tukey post-hoc analysis revealed that the stimuli were always assessed as being significantly fresher in the presence of visual ice cubes. Moreover, the participants who declared loving the consumption of sweet beverages (Grp3) assessed as being significantly fresher the stimuli containing visual ice cubes as compared to the participants who declared hating or moderately appreciating the consumption of sweet beverages (Grp1).

Regarding the interaction with visual carbonation, a Tukey post-hoc analysis revealed that the stimuli were assessed as being significantly fresher in the presence of visual carbonation by the groups of participants who declared appreciating (Grp2) or loving (Grp3) the consumption of sweet beverages. Moreover, the mean freshness ratings of these two groups were significantly higher as compared to the participants who declared hating or moderately appreciating (Grp1) the consumption of sweet beverages.

Overall, these results reveal how the declared preferences of consumers toward basic tastes in beverages may interact with their freshness ratings on the basis of audiovisual cues. The observed relationship between the participants who declared loving the consumption of sweet beverages and their higher freshness ratings in the presence of visual ice cubes or visual carbonation is quite inconsistent with the literature. In fact, sweetness has been generally reported as a freshness inhibitor (e.g., McEwan & Colwill, 1996 with UK participants assessing soft drinks). However, this discrepancy might be explained by the consumption habits and culture of the participants involved in our study (i.e., American participants for the online experiment).

3. Frequency of consumption: differences between American and French participants

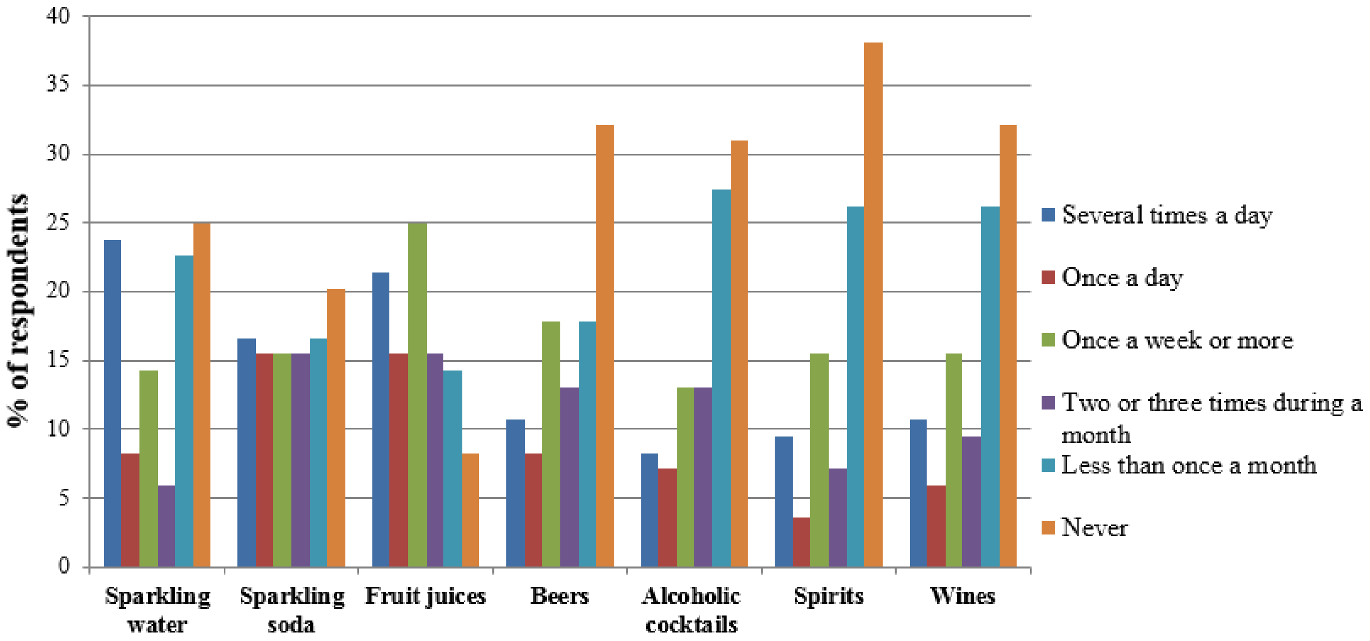


Figure 8: Percentages of American respondents according to their frequency of consumption of different types of beverages (online experiment)

N=84.

For the 84 American participants in the online experiment, sparkling waters, fruit juices, and sodas are the most frequently consumed. Less than 20% of the participants declared consuming alcoholic beverages (beers, cocktails, wines, spirits) once a week or more. More than 25% of the participants declared consuming cocktails, wines, and spirits less than once a month and more than 30% declared never.

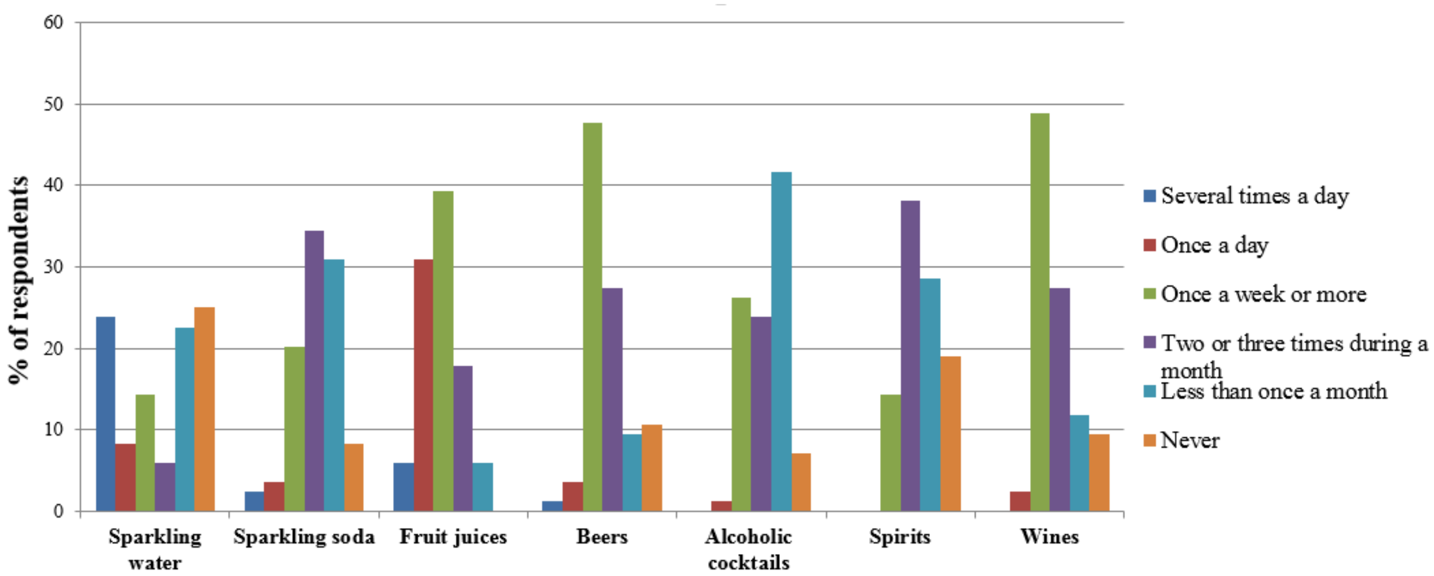


Figure 9: Percentages of French respondents according to their frequency of consumption of different types of beverages (laboratory experiment)
N=84.

For the 84 French participants in the laboratory experiment, sparkling sodas are less consumed as compared to American participants. Bigger proportions are particularly salient for French participants regarding their consumption of fruit juices (39.3%), beers (47.6%), alcoholic cocktails (26.2%), and wines (48.8%) that declared consuming once a week or more.

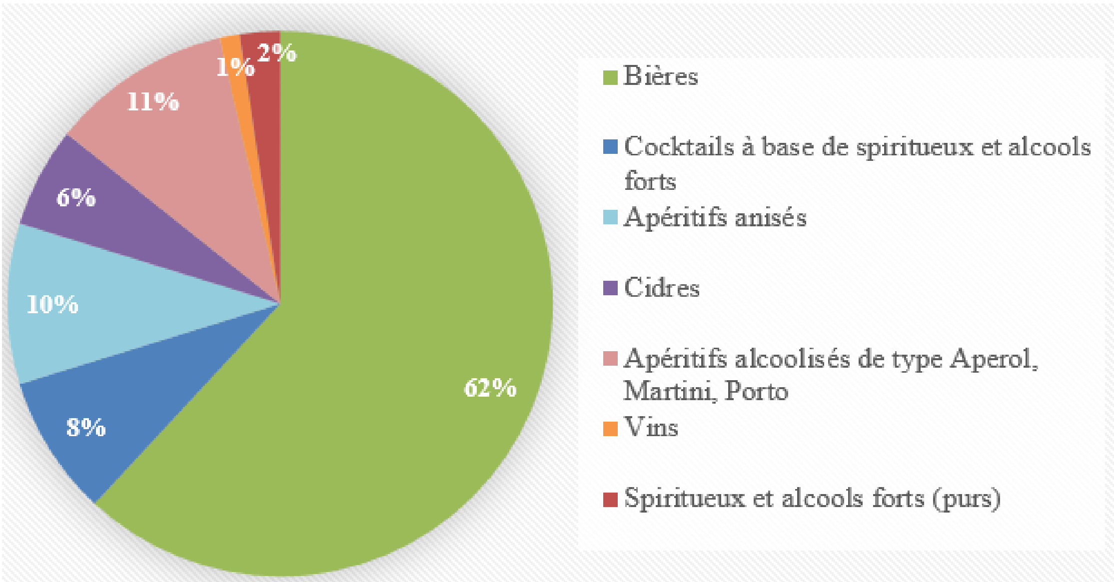
4. Alcoholic beverages considered as fresh: differences between American and French participants

Two lists of distinct groups of alcoholic beverages were established as being representative of the diversity of the American market on one side and the French market on the other side (see Annexes 6 and 7). The participants were asked to select, among this list, the group of alcoholic beverages they associate the most to fresh alcoholic beverages (CATA: Check All That Apply).

<u>Figure 10: Percentages of American respondents as function of the alcoholic beverages groups the most representative of freshness (online experiment)</u>

N=84.

American participants considered beers and cocktails as being the alcoholic beverages groups the most representative of freshness (followed by wines and ready to drink mixed beverages). These proportions were not significantly different.



<u>Figure 11: Percentages of French respondents as function of the alcoholic beverages groups the most representative of freshness (laboratory experiment)</u>

N=84.

French participants considered significantly more beers as being the alcoholic beverages group the most representative of freshness (Chi-squared test and Marascuilo procedure on Xlstat, $\chi 2(6) = 186.67$, $p < 0.0001$).

5. Specific drinks associated to fresh alcoholic beverages and corresponding characteristics: differences between American and French participants

Once the participants indicated the alcoholic beverages group the most representative of freshness according to them, an open-ended question asked them to quote a particular drink they associate the most to freshness, among the previous chosen group. A second open-ended question also asked them to indicate which characteristics make this drink (i.e., the one they quoted) fresh, according to them.

Similarities and differences between American and French participants are presented in the word clouds below. Only words cited at least twice were considered.

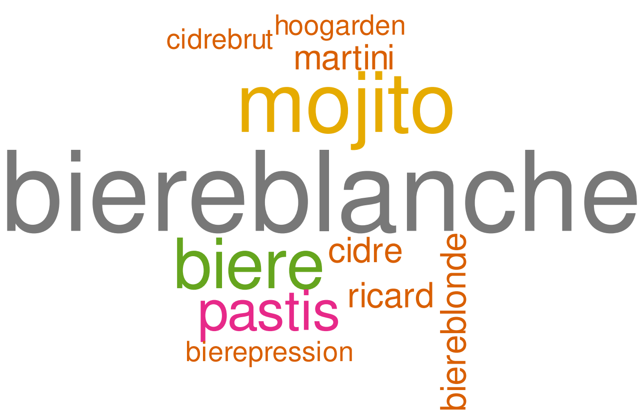
Q6- Within this group of alcoholic beverages, please quote the particular drink you associate the most to a fresh alcoholic beverage:

Q7- According to you, which characteristics make this drink fresh?

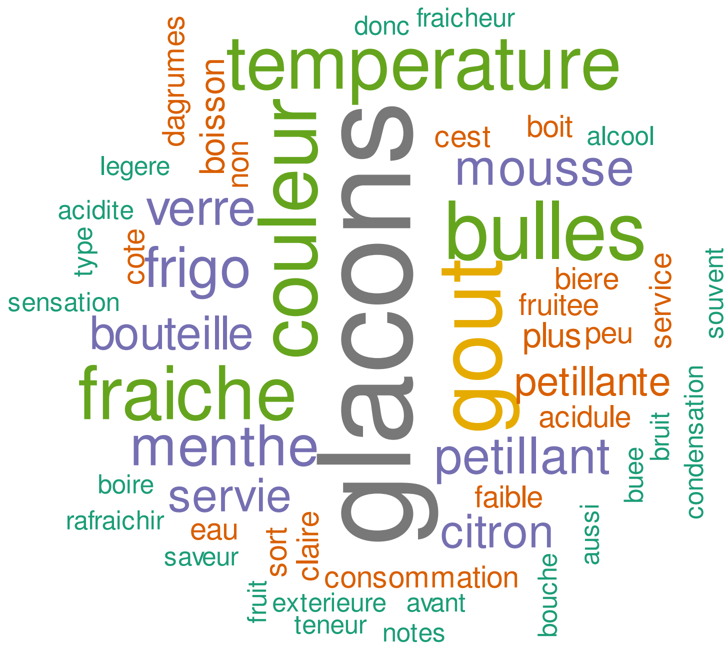
The American participants reported “beer”, “bud”, and “corona” as the particular drinks they associate the most with fresh alcoholic beverages within the beer category. For the cocktail category, corresponding to the second category of alcoholic beverages they considered as the most representative of freshness, they reported “mojito”, “margarita” and “vodka” based cocktails as the particular drinks they associate the most with freshness.

Regarding the characteristics that would make the corresponding drinks fresh, several items stressed by the American participants referred to the notion of coldness (“ice”, “cold”, “temperature”), whereas others referred to the notion of carbonation (“bubbles”, “fizz”, “fizziness”). In terms of associated flavor or fruit content, “lime” was the most cited.

Q6- Dans ce groupe de boissons alcoolisées, pouvez-vous citer une boisson qui vous évoque le plus une boisson alcoolisée fraîche ?



Q7- A votre avis, quelles caractéristiques la rendent fraîche ?



The French participants reported “bière blanche” (white beer), “bière” (beer), “bière blonde” (blond beer), and “hoogarden” (meaning Hoegaarden brand) as the particular drinks they associate the most with fresh alcoholic beverages within the beer category. For the cocktail category, corresponding to the third category of alcoholic beverages they considered as the most representative of freshness, they reported “mojito” as the particular drink they associate the most with freshness.

Regarding the characteristics that would make the corresponding drinks fresh, several items stressed by the French participants referred to the notion of coldness (“glaçons” – ice cubes, “temperature”, “frigo” – fridge), whereas others referred to the notion of carbonation (“bulles”

- bubbles, “pétillant” – sparkling, “mousse” – foam). “Couleur” (color) was one of the most cited word. In terms of associated flavor or fruit content, “menthe” (mint), “citron” (lemon), and “agrumes” (citrus fruits) were the most cited.

6. Expected aromas for fresh alcoholic beverages: differences between American and French participants

A list of 15 different aromas was established (see Annexes 6 and 7) and the participants were asked to select, among this list, the aromas that could be found in fresh alcoholic beverages according to them (CATA: Check All That Apply).

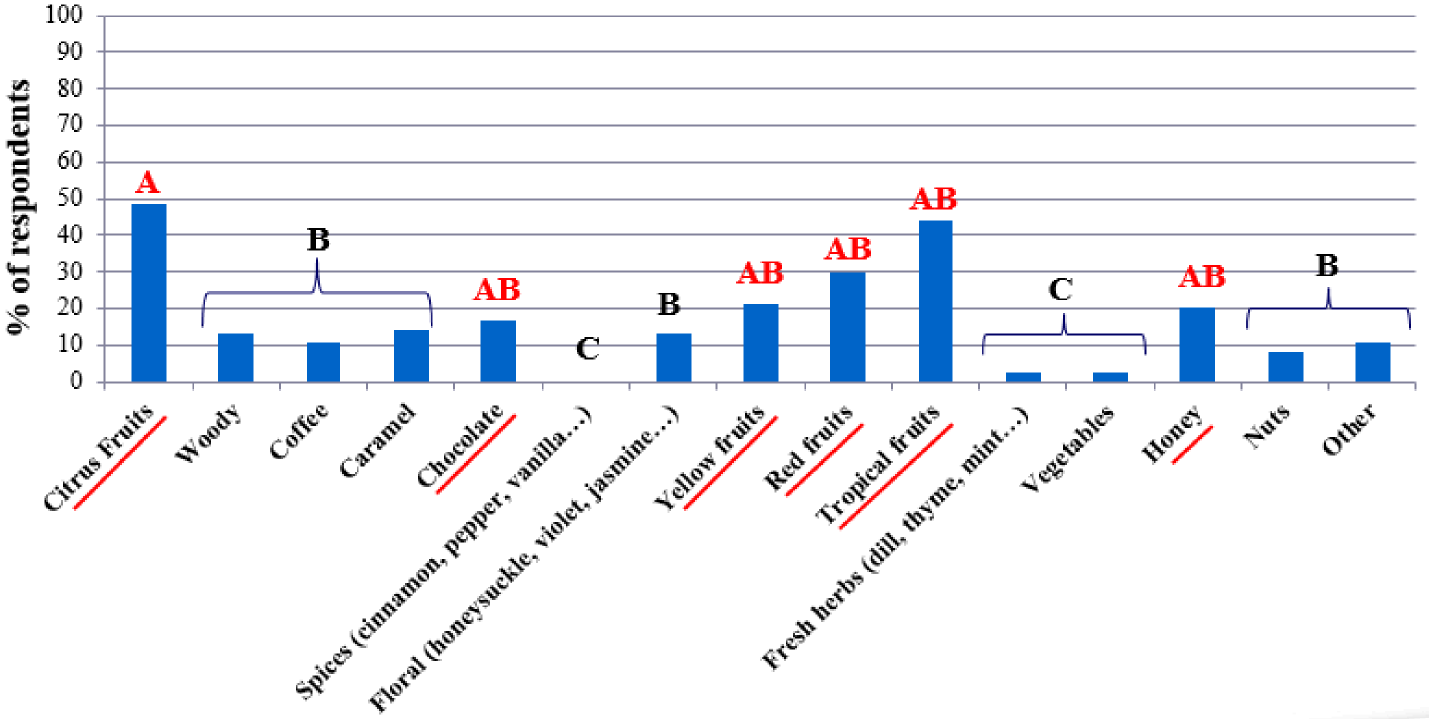


Figure 12: Percentages of American respondents as function of the aromas that could be found in fresh alcoholic beverages (online experiment)

Chi-squared test and Marascuilo procedure on XLStat ($\chi 2(14) = 167.86$, $p < 0.0001$).

For the American participants, citrus fruits (≈50%) were the aromas that could be found the most in fresh alcoholic beverages. The other aromas that were the most selected were tropical fruits (≈45%), red (≈30%) and yellow (≈20%) fruits, as well as honey (≈20%) and chocolate (≈15%).

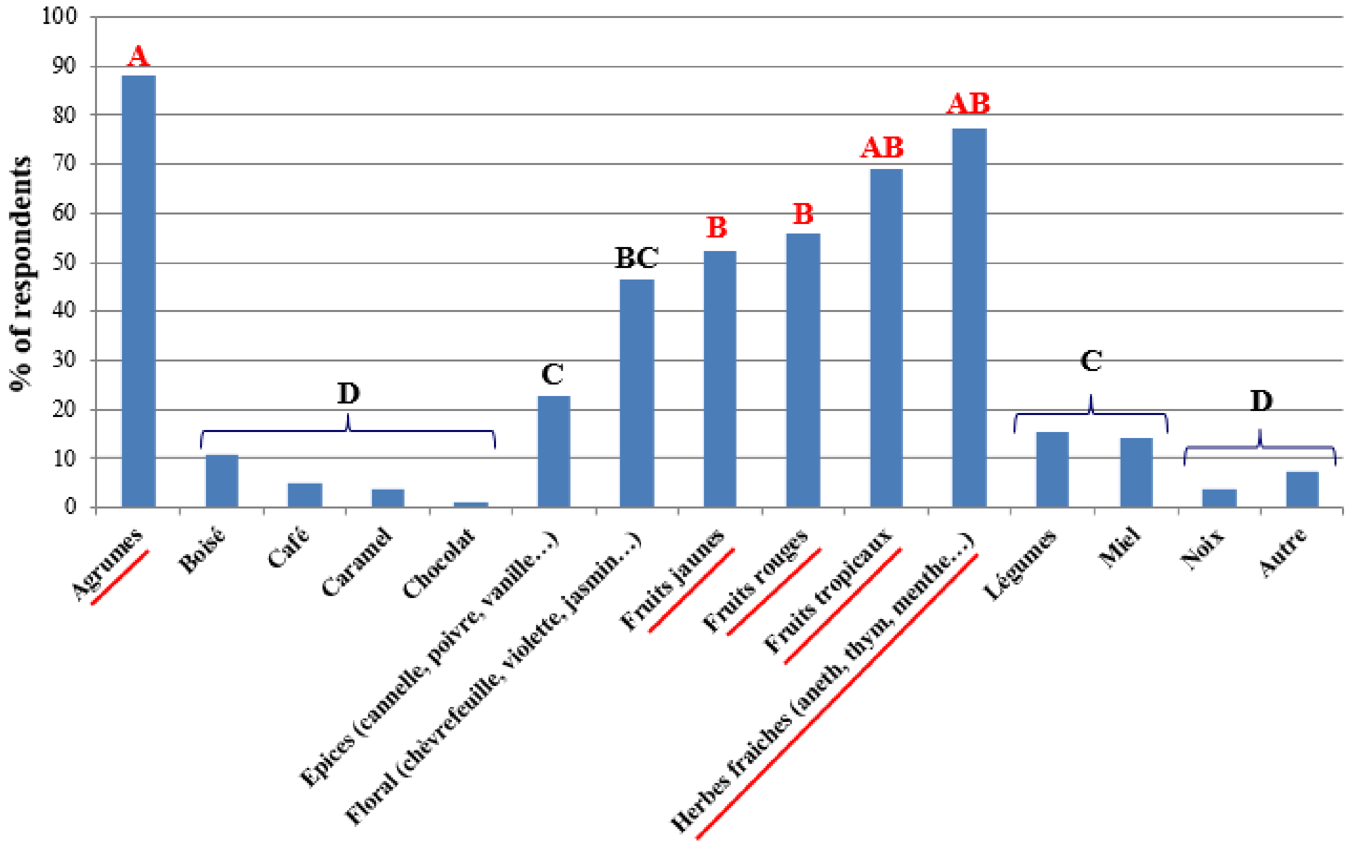


Figure 13: Percentages of French respondents as function of the aromas that could be found in fresh alcoholic beverages (laboratory experiment)

Chi-squared test and Marascuilo procedure on XLStat ($\chi 2(14) = 499.23$, $p < 0.0001$).

For the French participants, “Agrumes” (citrus fruits≈88%), “Herbes fraîches” (fresh herbs≈75%), “Fruits tropicaux” (tropical fruits≈70%), “Fruits rouges” (red fruits≈55%), “Fruits jaunes” (yellow fruits≈52%), as well as “Floral” aromas (≈45%) were the aromas that could be found the most in fresh alcoholic beverages.

Thus, a common set of aromas are reported both by American and French participants as being the aromas that could be found the most in fresh alcoholic beverages: citrus fruits and fruits in general including tropical, red, and yellow fruits. However, clear differences appear for fresh herbs and floral aromas which are also selected respectively by more than 40% and 70% respectively of French participants whereas 10% or less of American participants selected them. On the contrary, around 20% of American participants selected chocolate and honey aromas as good exemplars for fresh alcoholic beverages whereas 10% or less of French participants selected them. Once again, these discrepancy might be explained by cross-cultural drinking habits.

7. Expected general characteristics for fresh alcoholic beverages: differences between American and French participants

A list of 18 different general characteristics was established (see Annexes 6 and 7) and the participants were asked to select, among this list, the characteristics that could be found in fresh alcoholic beverages according to them (CATA: Check All That Apply).

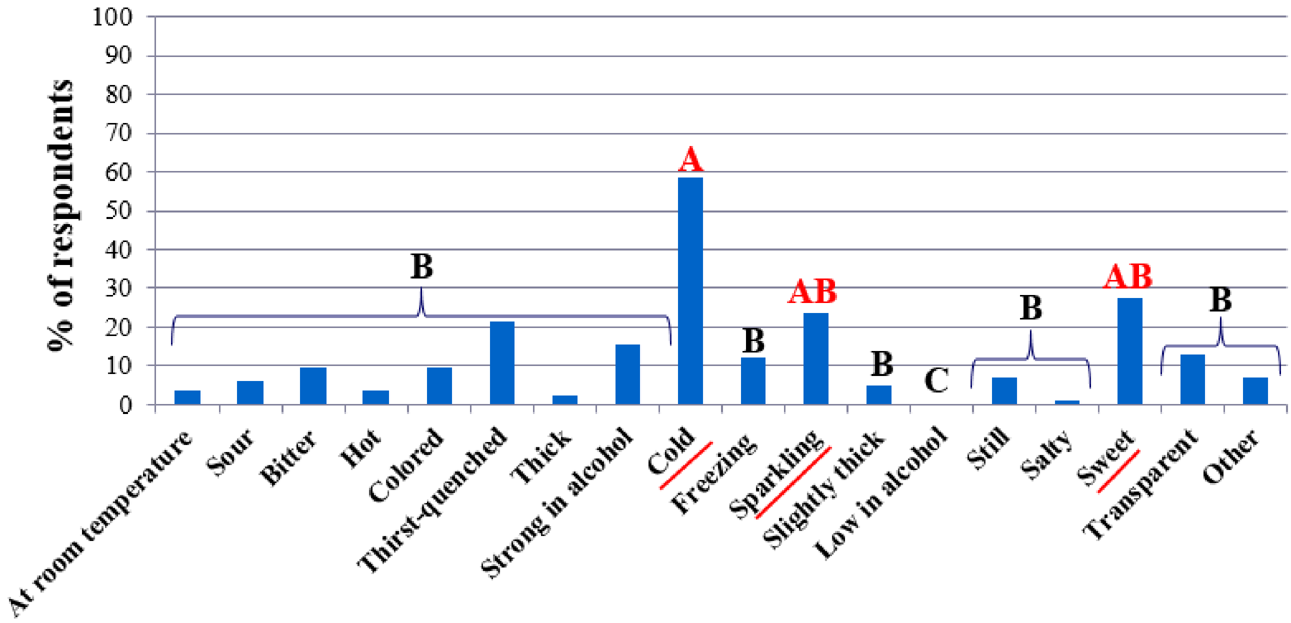
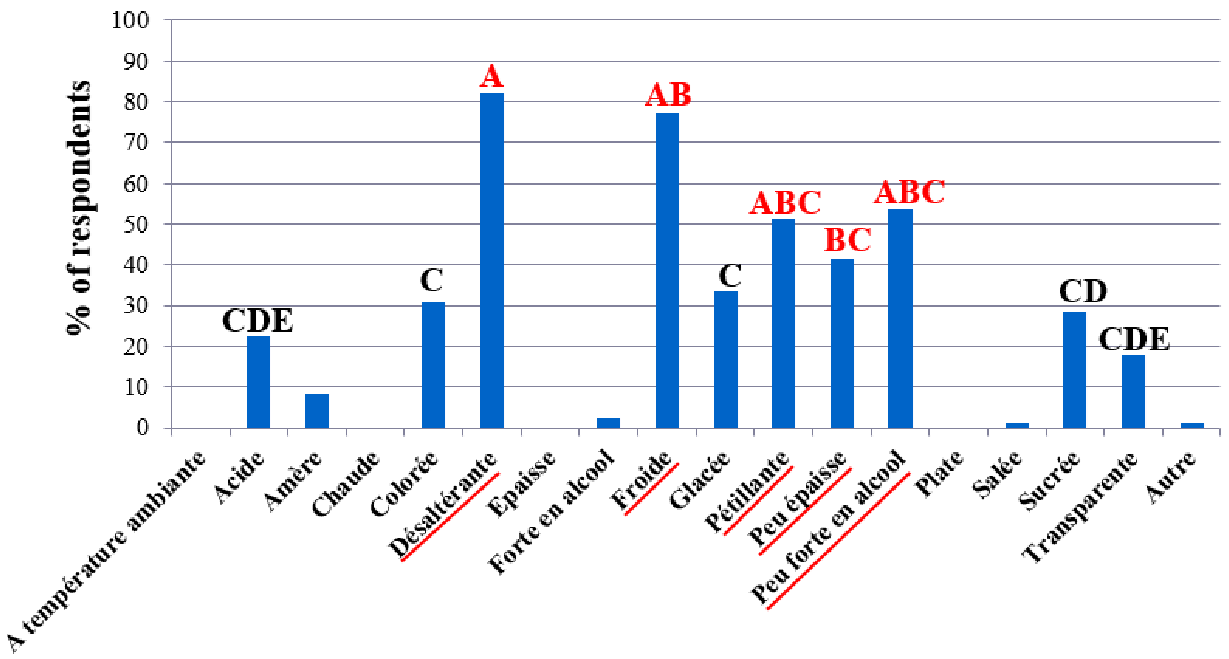


Figure 14: Percentages of American respondents as function of the general characteristics that could be found in fresh alcoholic beverages (online experiment)

Chi-squared test and Marascuilo procedure on XLStat ($\chi2(17) = 249.48$, $p < 0.0001$).

According to the American participants, cold (≈60%) was the most selected characteristic that could be found in fresh alcoholic beverages. The other characteristics that were the most selected were sweet (≈26%) and sparkling (≈22%). Surprisingly, the characteristic "thirst-quenched" has been selected by less than 25% of the participants.



<u>Figure 15: Percentages of French respondents as function of the general characteristics that could be found in fresh alcoholic beverages (laboratory experiment)</u>

Chi-squared test and Marascuilo procedure on XLStat ($\chi2(17) = 552.96$, $p < 0.0001$).

According to the French participants, "Désaltérante" (thirst-quenched≈80%) was the most selected characteristic that could be found in fresh alcoholic beverages. The other characteristics that were the most selected were "Froide" (cold≈76%), "Peu forte en alcool" (low in alcohol≈52%), "Pétillante" (sparkling≈50%) and "Peu épaisse" (fluid texture≈40%).

Two general characteristics are selected both by American and French participants as characteristics that could be found in fresh alcoholic beverages: cold and sparkling. The third characteristic the most selected by Americans is "sweet" which is quite inconsistent with the literature but consistent with the results on the liking sweet groups reported above (section 2). These results suggest that for French consumers, at least five general characteristics could be found in fresh alcoholic beverages whereas there is less consensus for the Americans. It could be interesting to investigate the respective weights and interaction effects of these different general characteristics on the perception of freshness in alcoholic beverages. Cross-cultural studies on these questions could help beverages companies to adjust their product formulation and marketing campaigns. The choice of the appropriate words, the size, font, and colors of the letters, the ideal place on the packaging or the billboard in order to trigger the corresponding consumers' expectations are also important aspects to consider (e.g., Ngo et al., 2012).

8. Prototypical color associated with sparkling beverages: differences between American and French participants

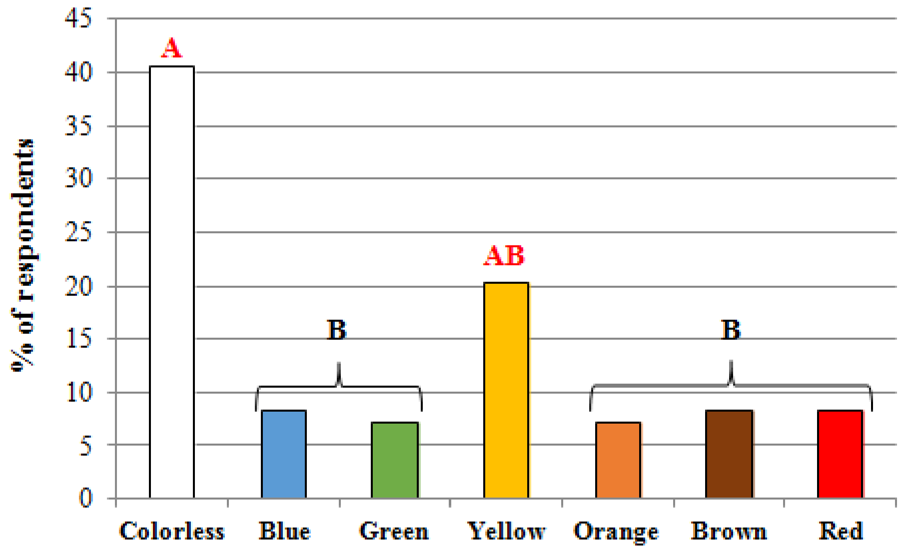


Figure 16: Percentages of American respondents as function of the color they associate the most with sparkling beverages (online experiment)

Chi-squared test and Marascuilo procedure on XLStat ($\chi2(6) = 63.8$, $p < 0.0001$).

The American participants significantly selected in higher proportions colorless (≈40%) and yellow (≈20%) as the colors they associate the most with sparkling beverages.

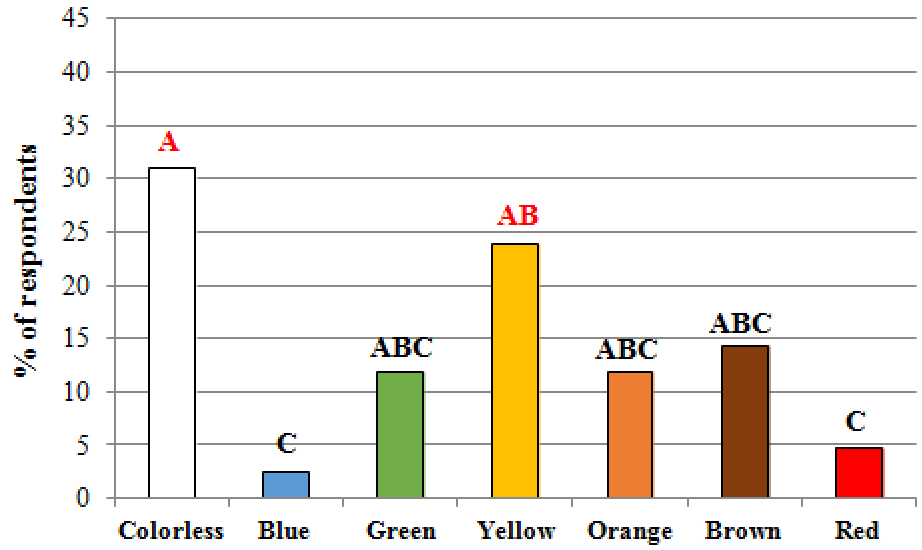


Figure 17: Percentages of French respondents as function of the color they associate the most with sparkling beverages (laboratory experiment)

Chi-squared test and Marascuilo procedure on XLStat ($\chi2(6) = 42$, $p < 0.0001$).

The French participants significantly selected in higher proportions colorless (≈30%) and yellow (≈24%) as the colors they associate the most with sparkling beverages. Red and blue colors (<5%) were significantly less selected.

The literature on the perception of freshness in beverages and the results reported in this chapter both provide evidence of a positive influence of carbonation on perceived freshness in beverages. The supplementary results on color reported here are not directly associated to freshness in beverages but focus on the color the participants (French and American) selected as the most representative of a sparkling beverage. By extension, we may hypothesize that their choices may also correspond to the color they would associate the most to a fresh sparkling beverage, since sparkling beverages are generally consumed cold. These results are thus consistent with the literature that has investigated whether a particular color or group of colors were mainly associated to fresh beverages by consumers, even though there is a lack of consensus. In fact, some studies have reported that clear beverages are favored, in contrast to dark ones, when consumers have to characterize the appropriate color for fresh beverages (Clydesdale, Gover, Philipsen, & Fugardi, 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). The results reported here may then provide additional information by showing that for both French and American participants in these studies, colorless (i.e., transparent) as well as yellow colors are the most representative of sparkling beverages, and consequently they may be the two colors the most associated with freshness, at least in sparkling beverages.

PART C. AUDIOVISUAL CROSSMODAL CORRESPONDENCES AND THEIR RELATIVE EFFECTS

Chapter 5. Implicit associations between bubbles size and pouring sounds pitch in carbonated beverages: a promising way to increase freshness perception and categorization

This chapter presents the second set of experimental studies that have been conducted to investigate the potential existence of crossmodal correspondence effects between specific cues related to carbonation in beverages, namely between bubbles size and pouring sounds pitch. The relative effects of the two associations (small bubbles-high pitch vs. big bubbles-low pitch) involved in the Pitch-Size correspondence were also investigated.

We hypothesized the existence of Pitch-Size correspondence effects in carbonated beverages based on (i) the often reported crossmodal correspondence between auditory pitch and the size of circles presented visually (e.g., Evans & Treisman, 2010), (ii) the crossmodal correspondence between carbonated water and high-pitched meaningless words (Spence & Gallace, 2011), and the one between temperature-related words attributes and pouring sounds pitch (Velasco, Jones, King, & Spence, 2013), and (iii) the empirical evidence that some audiovisual perceptual features linked to carbonation in beverages may influence the perception of freshness (see Roque, Auvray, & Lafraire, 2018a; Roque et al., 2018b, chapters 1 and 4).

In terms of methodology, a crossmodal version of the Implicit Association Test (IAT) was used as it represents a standard method for measuring the strengths of associations between different perceptual features (see Greenwald et al., 1998 for the original version, and e.g., Demattè et al., 2007 for a crossmodal version). This test is based on the rationale that when two stimuli share a strong association, participants' RTs are shorter and their responses are more accurate when they classify the stimuli according to the target categories. A semantic priming was also added in order to investigate whether IAT compatibility effects could be enhanced by a congruent semantic prime. In order to evaluate the relative effects of these associations, a Go/No-go Association Task (GNAT) has been used in a second experiment.

From an applied perspective, we hypothesized that a better understanding of how to tap into the crossmodal correspondences that can occur 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 acceptance and appreciation.

Audiovisual crossmodal correspondence between bubbles size and pouring sounds pitch in carbonated beverages

Jérémy Roque[a,b,c*], Jérémie Lafraire[b], Malika Auvray[c]

[a] Breakthrough Innovation Group, Pernod Ricard, 75009 Paris, France
[b] Institut Paul Bocuse Research Center, 69130 Ecully, France
[c] Sorbonne Université, UPMC, CNRS, Institut des Systèmes Intelligents et de Robotique (ISIR), F-75005 Paris, France

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Abstract

The literature on crossmodal correspondences has reported an implicit association between auditory pitch and the size of visually-presented circles. However, whether this association still holds with more ecological and complex audiovisual stimuli remains to be investigated. Interestingly, research on flavor perception has reported the influence of specific audiovisual cues linked to carbonation in beverages. In the study reported here, two features of transparent carbonated beverages have been selected as the ecological counterparts of the above-mentioned pitch and circles: the bubbles' size (small vs. big) and the pouring sounds' pitch (high-pitched vs. low-pitched). To study a potential crossmodal correspondence between pitch and size in carbonated beverages, a modified version of the Implicit Association Test (IAT) was used (Experiment 1). The participants had to respond to four unimodal stimuli that were paired either congruently (small bubbles and high-pitched sound; big bubbles and low-pitched sound) or incongruently (the reverse associations). Semantic priming with freshness was added in order to investigate whether it can enhance IAT compatibility effects. The results revealed shorter reaction times and more accurate responses in congruent blocks. This confirms the existence of the pitch-size correspondence between the bubble size and the pouring sound pitch. However, the semantic priming related to freshness had no effect on the participants' responses. In order to evaluate the relative effect of the two associations, a Go/No-go Association Task (GNAT) was used in a second experiment (Experiment 2). Shorter reaction times were obtained in congruent blocks, similar to Experiment 1, but there was no significant difference regarding sensitivity in the participants' responses. Thus, these results do not allow disentangling the

relative effect of the two pitch-size associations investigated here. Our study provides the first empirical evidence of a pitch-size crossmodal correspondence using more ecological and complex audiovisual stimuli. Therefore, it opens a research avenue for the food and beverage industry, as triggering crossmodal correspondences, upstream of the consumption phase, can positively influence freshness perception and may ultimately increase beverages' attractiveness.

Keywords: Crossmodal correspondences, Implicit Association Test, Go/No-go Association Task, beverages, carbonation, freshness perception

1. Introduction

Crossmodal interaction effects that can occur during food and beverage consumption has received growing attention in different fields of research due to interest in the multisensory processes and cognitive mechanisms that influence eating and drinking behaviors (see Auvray & Spence, 2008; Prescott, 2015; Shepherd, 2012; Small, 2012; Spence, Auvray, & Smith, 2014; Verhagen & Engelen, 2006, for major reviews). Several crossmodal interactions have already been investigated in the case of flavor (e.g., interactions between taste and smell, taste and touch, and vision and taste) and the relative contributions of each sensory modality to flavor perception have already been partially documented. A large number of studies have reported the influence of visual cues on different product experiences (see Spence, Levitan, Shankar, & Zampini, 2010, for the influence of color on taste and flavor perceptions). Some studies have also recently provided empirical evidence of the influence of auditory cues on flavor perception (e.g., see Spence, 2015, for a review). For instance, Zampini and Spence's (2004) study showed that a product's sound can create expectations about its textural properties. In particular, their study showed that the perception of both the crispness and staleness of potato chips was altered by varying the loudness and/or frequency (i.e., objective pitch) of the auditory feedback elicited during the biting action. These results confirm the influence of auditory cues on flavor perception during the actual consumption of products. However, there is still a lack of information on the audiovisual interaction effects that occur before the actual consumption, but which can still influence the consumers' subsequent experiences by triggering specific sensory expectations (see Piqueras-Fiszman & Spence, 2015, for a review). Interestingly, it has been shown that a mismatch between the expected and actual attributes of a product can result in a disconfirmation of expectation that will negatively affect the consumers' subsequent behaviors.

The results obtained by Cardello and Sawyer (1992) revealed that the acceptability of different products was impaired when the participants' expectations were not confirmed, that is when their actual perception did not match the product description or the labelling information provided to them.

Thus, it appears timely to investigate more in depth the crossmodal interactions that occur before the tasting step in food and beverage perception. In particular, the two experiments reported here focused on a particular form of crossmodal interactions named crossmodal correspondences. Crossmodal correspondences have been defined as the non-arbitrary associations between perceptual features that belong to different sensory modalities (see Spence, 2011, for a review). The association between auditory pitch and visually-presented objects' size is one of the most documented crossmodal correspondences. That is, smaller objects are typically matched with higher-pitched sounds and larger objects with lower-pitched ones (Evans & Treisman, 2010; Gallace & Spence, 2006; Parise & Spence 2012). Such correspondences between crossmodal sensory dimensions can reflect environmental regularities extracted by the cognitive system (i.e., pitch-size correspondence, for example, might reflect the properties of acoustic resonance, whereby the larger the object, the lower the frequency). The stimuli that are generally used to highlight the pitch-size correspondence consist of pure tones and simple grey circles.

In a review on multisensory integration, perception, and ecological validity, De Gelder and Bertelson (2003) reported that even though past research has shown that simple cues were sufficient to elicit robust multisensory integration, it is reasonable to question whether simple cue combinations are sufficient for the understanding of the complex naturalistic situations in which humans evolve. This view has also been defended by Crisinel, Jacquier, Deroy, and Spence (2013) when they investigated the existence of crossmodal correspondences between olfactory stimuli and the sounds of musical instruments. According to Crisinel and colleagues, "in more ecologically valid situations, a network of cross-modal correspondences may come into play at one and the same time (e.g., think only of the shape, color, and texture of product packaging), and the stimuli are often more complex than those typically used in laboratory research" (p. 46). In the case of beverages, the perception of freshness is of particular interest since it is generally perceived as pleasurable by consumers and it may thus influence their purchase and consumption behavior (see Eccles, Du-Plessis, Dommels, & Wilkinson, 2013; Labbe, Almiron-Roig, Hudry, Leathwood, Schifferstein, & Martin, 2009a; Roque, Auvray, & Lafraire, 2018a, for reviews). We believe that knowing how to trigger the mechanisms of crossmodal correspondences involved in freshness can facilitate consumers' categorization of a given product as fresh. Consequently, it could help increase beverages' attractiveness and appreciation, upstream of the consumption phase. It remains to show that some audiovisual perceptual features, associated with the perception of freshness in beverages, do display crossmodal correspondence effects such as the pitch-size correspondence.

The influence of particular audiovisual features involved in the multisensory perception of freshness in beverages has already been investigated (see Roque et al., 2018a for a review). For instance, it has been shown that the perception of freshness of a drink can be influenced by the amount of carbonation that people may infer via the visual density of bubbles (see Guinard, Souchard, Picot, Rogeaux, & Sieffermann, 1998; McEwan & Colwill, 1996; Peyrot des Gachons, Avrillier, Gleason, Algarra, Zhang, Mura et al., 2016). Regarding the influence of auditory cues, one study has recently highlighted that hearing bubbles when a beverage is poured in a glass influences both participants' reaction times (RTs) and their inclination to categorize a beverage as fresh (Roque, Lafraire, Spence, & Auvray, 2018b; see also Zampini & Spence, 2005). Other studies have also shown the existence of crossmodal correspondences, for instance between the sonic properties of the pouring sounds of hot (lower pitch) and cold (higher pitch) water and the attributes of the congruent words "hot drink" and "cold drink" (Velasco, Jones, King, & Spence, 2013; see also Spence & Wang, 2015, and Wang & Spence, 2017). Another crossmodal correspondence related to carbonation in beverages has been reported by Spence and Gallace (2011). Their study showed that carbonated water was more associated with high-pitched meaningless words, such as 'kiki' and 'takete'. By contrast, still mineral water was more strongly associated with softer, lower-pitched pseudo-words, such as 'bouba' and 'maluma'. The authors concluded that sound symbolism, in relation with semantic associations, could help constrain the development of new product names/brands by improving the potential impact of consumers' expectations. Based on the literature described above, it appears that the bubble size and the pouring sound pitch of carbonated beverages represent good ecological counterparts of the simple audiovisual stimuli generally used to investigate pitch-size correspondence effects (i.e., pure tones and simple circles). Since high-pitched pouring sounds are associated with coldness in beverages (Velasco et al., 2013) and coldness is likely one of the main sensory contributors to freshness in beverages (Roque et al., 2018a,b), we hypothesize that small bubbles and high-pitched pouring sounds are more associated with freshness in beverages than big bubbles and low-pitched pouring sounds.

In terms of methodology, the majority of consumer studies on freshness perception to date have focused on consumers' expectations, obtained by collecting declarative data, using self-administered questionnaires or visual analog scales (e.g., Fenko, Schifferstein, Huang, & Hekkert, 2009; Labbe, Gilbert, Antille, & Martin, 2009b). In order to investigate the crossmodal correspondence effects described above, implicit measures are generally used since they enable experimenters to obtain more objective measures of the associations between stimuli without having to overtly inform participants of the targeted associations. As opposed to self-reported measures, in which participants are asked to self-report their feelings and sensations in a conscious deliberate way, implicit measures that are obtained indirectly are considered to be more sensitive to automatic stimulus evaluations (see De Houwer, Teige-Mocigemba, Spruyt, & Moors, 2009 for a review). In the last decade, the use of implicit measures has started to be more popular in the food and beverage domain (e.g., see Knöferle & Spence, 2012, for a review of studies that investigated crossmodal correspondences between sounds and tastes using implicit measures). More precisely, crossmodal correspondences are often inferred from participants' RTs using speeded classification tasks, including variants of the Implicit Association Test (IAT), to determine the strength of the association between two perceptual features (e.g., Demattè, Sanabria, & Spence, 2007; Deroy, Fasiello, Hayward, & Auvray, 2016). This test is based on the rationale that when two stimuli share a strong association, participants' RTs are shorter and their stimuli categorization responses are more accurate (Greenwald, McGhee, & Schwartz, 1998). According to Greenwald, Nosek, and Banaji (2003), the IAT provides a standard method for measuring the strengths of associations between a wide range of items. More recently, Parise and Spence (2012) have argued that IATs should be used more extensively to measure correspondences between crossmodal and unimodal sensory signals and might be a key technique for discovering novel correspondences. Regarding the relation between the target stimuli (i.e., bubble size and pouring sound pitch) and the perception of interest (i.e., freshness), the theoretical framework of semantic priming was considered. Indeed, in semantic priming tasks, it has been shown that prime-derived and target-derived pieces of information interact at the stage of categorizing the target. Consequently, semantic congruency effects (i.e., shorter RTs and better accuracy) can be observed and reflect facilitation in categorizing targets (McNamara, 2005).

The two experiments reported here were designed to investigate the existence of a crossmodal correspondence between pouring sound pitch and bubble size for a carbonated beverage. In Experiment 1, we used a modified version of the IAT (Greenwald et al., 1998) to explore the possible associations between the pouring sound pitch and bubble size. Moreover, we investigated whether a pre-activation of the targeted concept of freshness, with which the stimuli are semantically related (i.e., features of carbonated beverages), could increase IAT compatibility effects. We expected that a congruent semantic prime (i.e., related to freshness as opposed to neutral) would shorten participants' RTs and increase their accuracy for small bubbles and high-pitched pouring sound, in congruent blocks. Experiment 2 was designed to assess the relative effects of the two associations uncovered in Experiment 1. To this end, a Go/No-go Association Task was used (Nosek & Banaji, 2001). In this task, sensitivity (d') to congruent and incongruent stimuli was compared between blocks of trials where the target bubble size was paired with either high-pitched or low-pitched pouring sounds.

2. Experiment 1: IAT

2.1. Methods

Participants

Forty French participants (50% female, mean age 48, ranging from 18 to 74 years old) completed Experiment 1. 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 a particular expertise in beverages in terms of leisure activities, education, or profession. Each individual session lasted approximately 45 min and participants were compensated with a 15€ voucher. All the participants provided written informed consent prior to taking part in the study. The experiment was approved by the local ethical committee.

Stimuli

In order to select the appropriate stimuli, so that they are easily distinguishable from one another, discriminability tasks were conducted with 6 participants (100% female, mean age 32). For the visual stimuli, pictures of 200 mL of colorless carbonated-liquid (Schweppes Indian Tonic, 8.7 g/L CO_2) in a standard glass were created. Pictures were taken in the same laboratory conditions in order to control for the light, room temperature, and ambient liquid temperature. Pictures were taken when the liquid motion was stabilized and the foam was absent at the surface of the liquid (i.e., 2 seconds after pouring the 200 mL volume) since a negative effect of the foam on the participants' RTs was found in previous research (see Roque et al., 2018b). The picture in which the bubbles were the most visually identifiable and outlined was selected. Then, the picture's background was standardized by keeping only one bubble, using Microsoft's application Paint. This bubble was copied and pasted on the locations of the other bubbles that were previously deleted. Finally, this picture was duplicated and the bubbles' sizes were modified to obtain four different sizes. Hence, four pictures were obtained, in which the bubbles size was the only feature that varied. Only the lateral walls of the glass were kept within the picture to avoid any prototypical association of the shape of the glass with a particular drink (see Fig. 1).

For the auditory stimuli, the sound of 250 mL of liquid (carbonated lemonade, 6.2 g/L CO_2) poured into a glass was recorded for 2 sec. Then, the background noise was reduced and four pouring sounds with different pitches, from lower-pitched to higher-pitched sounds (677 Hz, 886 Hz, 960 Hz, and 1086 Hz), were created using Audacity 2.1.3 software.

During the discriminability tasks (either visual or auditory), one picture or one sound was presented for 2 s, directly followed by the presentation of another picture or sound for 2 s. The participants' task was a forced-choice task in which they had to answer whether they perceived the bubble size (or the pitch of the sound) on the second picture (of the second sound) as smaller or bigger (higher or lower) as compared to the first presented picture (sound). Error rates were calculated from the participants' responses (i.e., whether they discriminated well or not the bubbles sizes and the pouring sounds pitch). The visual stimuli that were better differentiated were those with the smallest and the third largest bubble size (4.17% error rate), shown in Figure 1. The auditory stimuli that were better differentiated were the lowest (677 Hz) and the highest-pitched (1086 Hz) sounds (7.4% error rate).

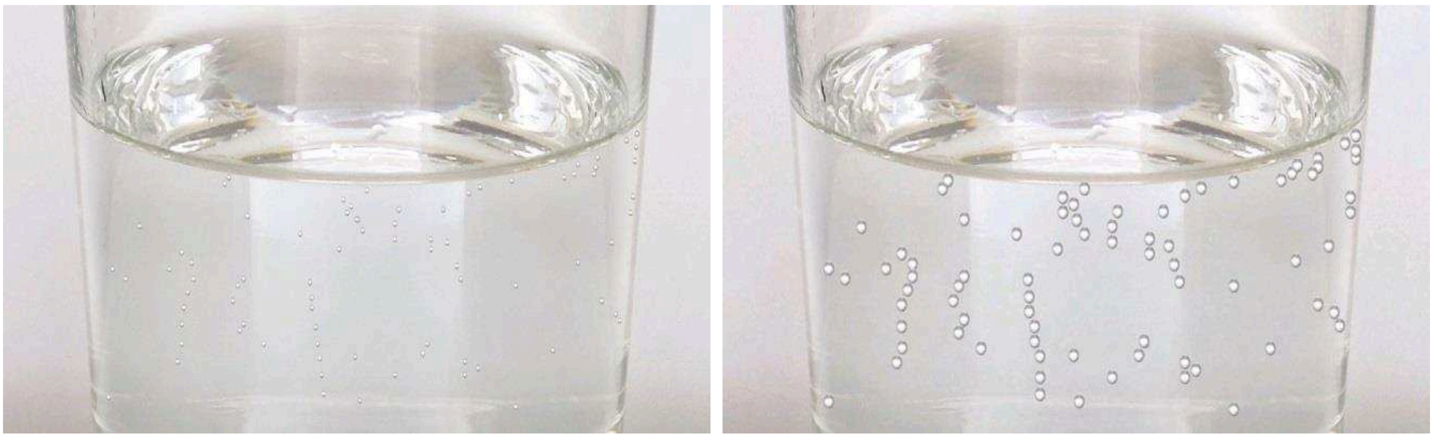

Fig. 1. Pictures of the two visual stimuli with different bubble sizes used in Experiment 1.

Design

A slightly modified version of the IAT described by Greenwald et al. (1998) was programmed with E-prime©, and incorporated the later suggestions for improvement made by Greenwald et al. (2003). The first block of 24 trials consisted of practice at the small-big bubbles classification task. The second block of 24 trials consisted of practice at the pitch classification task. The third and fourth blocks consisted of the first combined task (16 and 48 trials, respectively), including the classification of both the bubbles size and the pouring sounds pitch. Half of the participants started with the same key for high-pitched sounds and small bubbles. For the other half of participants, the high-pitched sounds and big bubbles were initially associated with the same response key. The fifth block of 24 trials consisted of practice, this time of the small-big bubbles classification with reversed response key associations. The sixth block consisted of the second (reversed) combined task. As was suggested by Nosek, Greenwald, and Banaji (2005), the number of trials in this block was increased to 32 trials. The seventh and final block was composed of 48 trials of the reversed combined task (see Table 1 for a summary of the IAT blocks). To be noted that blocks three and six served as practice of blocks four and seven, respectively.

Since a semantic prime was incorporated into the IAT task, the entire design was repeated in order to have one session with a neutral prime (neutral consonant letter string: 'NGHTKLPRD', see Wentura & Degner, 2010) and another session with a prime related to freshness (i.e., 'FRAICHEUR' in French). The two sessions were counterbalanced across participants and were separated by a 10 min break.

Table 1

Summary of the design for the IAT blocks.

Block	Task	Left key response	Right key response	No. Of trials
1	Single task (practice)	Small bubbles	Big bubbles	24
2	Single task (practice)	High-pitched	Low-pitched	24
3	Combined task	Small bubbles+high-pitched	Big bubbles+low-pitched	16
4	Combined task	Small bubbles+high-pitched	Big bubbles+low-pitched	48
5	Reversed single task (practice)	Big bubbles	Small bubbles	24
6	Reversed combined task	Big bubbles+high-pitched	Small bubbles+low-pitched	32
7	Reversed combined task	Big bubbles+high-pitched	Small bubbles+low-pitched	48

The order of blocks was counterbalanced such that half of the participants started with the small bubbles and high-pitched association in blocks 3 and 4 whereas the other half started with the big bubbles and high-pitched association. The response keys used were also counterbalanced, with half of the participants initially responding to low-pitched sounds with the left key. This design was repeated twice in order to have one session with a neutral prime and another session with a prime related to freshness.

Procedure

The experiment was conducted in a quiet test room at the Institut Paul Bocuse Research Center. The participants sat on a chair 70 cm from a LCD computer monitor with a resolution of 1600 x 900 pixels (60 Hz refresh rate) and they wore headphones (Sony MDR-ZX110) for which the volume was adjusted to a clearly audible level. The participants' level of thirst was evaluated twice on a 7-point Likert scale, once at the beginning of each session (neutral prime and freshness prime session). Before starting each session, the participants were also asked to drink a 200 mL glass of still water in order to control for their level of hydration (see Labbe et al., 2009b, on the influence of thirst and hydration state on alertness and cognitive performances).

The participants were instructed to "categorize as rapidly and accurately as possible different sounds and pictures linked to the consumption of beverages" by pressing one of the two response keys (D or J) on the computer keyboard with their left and right index fingers. Instructions about the mapping between the stimuli and the relevant response keys consisted of a schematic representation of the two response keys with the corresponding stimuli displayed next to the keys. There was no time limit to learn the new stimulus–response mapping that remained in written form in the top-right and top-left corners of the screen as a reminder throughout the experiment. In each trial, the participants started by looking at a fixation cross at the center of the screen for 1 s. Then, the semantic prime was displayed for 250 ms (as suggested by Wentura & Degner, 2010), directly followed by the 2 s presentation of the target stimulus, which the participants had been instructed to categorize. Feedback in the form of a red cross was provided after each incorrect target-response and remained on the screen for 500 ms. Each trial was separated by a blank screen corresponding to the intertrial stimulus interval (ISI) of 1 s. RTs and accuracy of the participants' responses were recorded.

At the end of the experiment, the participants were asked explicitly to rate which bubble size and which pouring sound pitch they generally associate with the consumption of fresh sparkling beverages on two 7-point Likert scales ranging from "Very small bubbles" to "Very big bubbles" and from "Very low-pitched sound" to "Very high-pitched sound".

Data analysis

Five participants (2 males, 3 females) appeared as outliers in the data distribution due to more than 10% of their trials being unanswered (mean 21.4% of trials unanswered; mean unanswered trials for the remaining thirty-five participants: 2.5%). They were removed from the subsequent analyses due to their weak performances that might reflect a poor understanding and/or involvement in the task. The improved scoring algorithm suggested by Greenwald et al. (2003) was used. Thus, trials from the third and sixth blocks, previously designed as practice, were included in the data analysis. In order to normalize the RT distributions, the RT data were log-transformed. D-measures were computed as the difference between mean RTs for blocks three and six (Mean block 6 – Mean block 3) and blocks four and seven (Mean block 7 – Mean block 4), with each resulting difference then divided by the standard deviation of the two blocks. Note that the computation of the D-measures was reversed for half of the participants, for whom these blocks were reversed. Moreover, the RTs from the trials in which the participants responded correctly were submitted to a repeated-measure analysis of variance (ANOVA) with the within-participants factors of Congruency (congruent vs. incongruent), Modality (visual vs. auditory), Stimuli (small vs. big bubbles, low-pitched vs. high-pitched sounds), and Prime (neutral vs. freshness). The same analysis was performed considering the participants' mean error rates (%) as the dependent variable. Tukey post-hoc analyses were subsequently performed. Effects were considered significant when $p<.05$. Statistical analyses were performed using R 3.4.1.

2.2. Results and discussion

When considering the participants' RTs as the dependent variable, the repeated-measure ANOVA revealed a significant main effect of Congruency ($F=481$, $p<.0001$), and Stimuli ($F=11.1$, $p<.0001$). The participants responded more rapidly in the congruent blocks ($m=794$ ms $\pm$ 3.9 standard error of the mean SEM) than in the incongruent blocks ($m=897$ ms $\pm$ 4.6 SEM), independently of the modality (see Fig. 2. 1). Unlike previous studies on audiovisual crossmodal correspondences, in our study RTs for the visual stimuli were not shorter than those for the auditory stimuli (e.g., Parise & Spence, 2012). This can be partly explained by the complexity of the stimuli used in our study compared to the quite simple and well-studied stimuli generally used in previous research. The presentation time of the targeted stimuli is also generally much shorter (300 ms) than the 2 s time-out used here, which could have influenced the processing time of the stimuli and thus impacted participants' RTs.

When considering the mean error rates as the dependent variable, the repeated-measure ANOVA revealed only a significant main effect of Congruency ($F=20.7$, $p<.0001$). The participants made fewer errors in congruent blocks than in incongruent blocks, independently of the modality (see Fig. 2. 2).

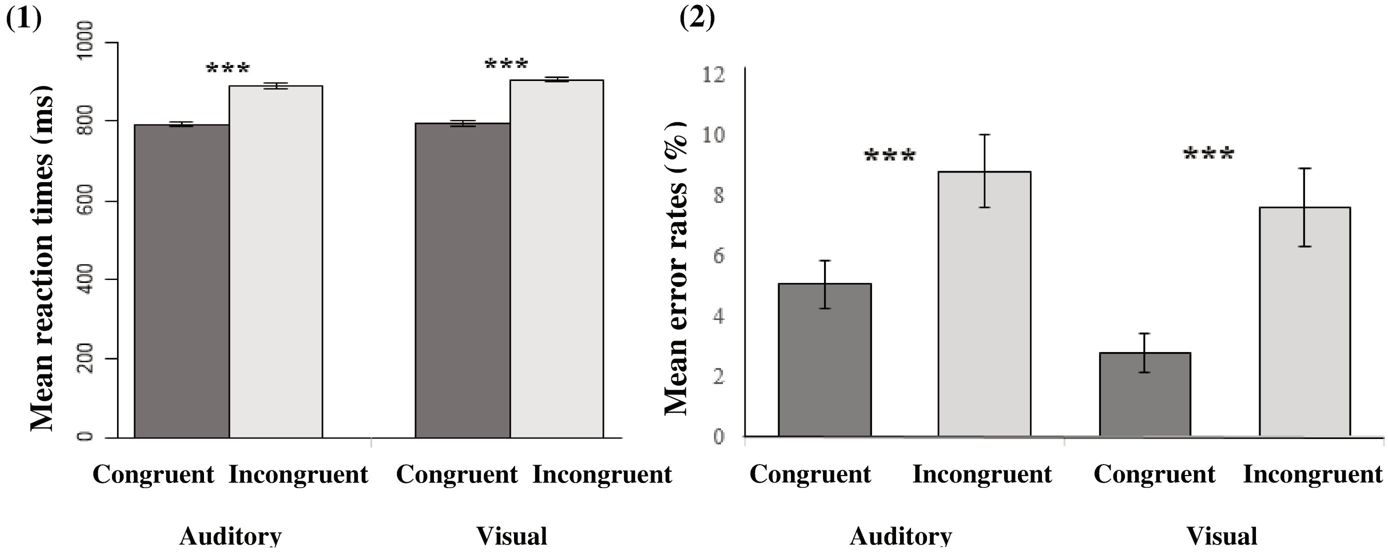

Fig. 2. Mean RTs (1) and mean error rates (2) in response to the visual and auditory stimuli according to the congruency of the interaction. Error bars represent the standard error of the mean across participants and the asterisks indicate significant statistical difference (p<.001).

Regarding the significant effect of the stimuli used, a Tukey post-hoc analysis revealed that the participants responded more rapidly to low-pitched sounds (m=822.4 ms ± 5.7 SEM) than to high-pitched sounds (m=858.1 ms ± 6.6 SEM), p<.001. The interaction with Congruency was not significant (F=1.1, p=0.29). A Spearman correlation between the participants' age and the participants' RTs revealed that the older the participants, the slower they performed the task (rho=0.29, p<.0001). This result is consistent with previous findings in cognitive science (e.g., Ratcliff, Spieler, & McKoon, 2000) which reported that RTs are generally slower for elderly people than for younger people. The age of the participants did not significantly influence their mean error rates (F=3.8, p=0.061).

Finally, there was no effect of the prime on the participants' RTs (F=1.01, p=0.3) or mean error rates (F=0.8, p=0.38). Several hypotheses can explain the null effect of the prime, which have already been discussed in the literature on semantic priming. For instance, Klauer, Eder, Greenwald, and Abrams (2007) have stated that even when a semantic congruency effect is expected (i.e., an overlap between prime-words and target stimuli), there is still uncertainty regarding the extent of the overlap. Indeed, it is not certain that the overlap will be larger for congruent prime-target pairs than for incongruent prime-target pairs. Regarding carbonation in beverages, freshness appeared to be a relevant concept to test for semantic congruency effects since audiovisual cues linked to carbonation can influence freshness perception (see Roque et al., 2018b). However, whether any semantic overlap between the freshness prime and the target stimuli used in our study is large enough to cause a semantic congruency effect remains to be investigated. The fact that the concept of freshness is large and heterogeneous among people (see Fenko et al., 2009; Zhang, Lusk, Mirosa, & Oey, 2016) potentially reduced the ability to show semantic congruency effects when the word 'freshness' was used as a semantic prime. In terms of methodology, the null effect of the prime may also depend on the duration of presentation of either the prime or the stimuli, or both. Some studies have shown that the response window procedure (see Klauer et al., 2007) that uses long-established principles of speed accuracy trade-off could increase the sensitivity of the measures.

Due to the null effect of the prime, the participants' RTs were combined across prime condition for the computation of the D-measures described above. A one-sample t-test was conducted on the D-measures. The mean value was significantly different from zero (mean, M=0.56, SD=0.46; t_{34}= 7.15, p<.0001). This result confirms that the associations between small bubbles and high-pitched sound and between big bubbles and low-pitched sound were stronger than the reverse associations. However, IAT designs do not allow disentangling the relative effects of the two pitch-size correspondences (small bubbles-high pitch vs. big bubbles-low pitch). We can thus conclude that both may exist, but we cannot exclude the possibility that only one of them is responsible for the effect reported here.
Nonetheless, the Spearman correlation between the participants' explicit ratings of which bubble size and pouring sound pitch they associate with fresh sparkling beverages was significant, rho=0.15, p<.0001. In particular, the data distribution shows, at least for the pouring sound pitch, that the participants associate the consumption of fresh sparkling beverages with very high-pitched sounds more than with very low-pitched sounds. The relative effects of the two pitch-size correspondences were then explored in Experiment 2.

3. Experiment 2: GNAT

3.1. Methods

Participants

Thirty French participants (50% female, mean age 36, ranging from 18 to 60 years old) completed Experiment 2. The same criteria as in Experiment 1 for the recruitment of the participants were applied. The study also lasted approximately 45 min and participants were compensated with a 15€ voucher.

Stimuli

In order to obtain a reliable GNAT (Go/No-go Association Task) design for the analysis of the sensitivity in the participants' responses, more stimuli than the two visual and two auditory stimuli in Experiment 1 had to be introduced here. Three sets of 12 visual stimuli (small bubbles, big bubbles, and neutral stimuli - varying in the presence of ice cubes and in turbidity) were created for this experiment. Each set of 12 visual stimuli varied in the color of the liquid (colorless, yellow, and brown), and the width of the glass (4 different widths). In order to restrain the duration of the experiment to 45 min, only two colors of liquid were selected, based on the literature on freshness perception in beverages. In particular, yellow has often been reported as a freshness enhancer in beverages (Clydesdale et al., 1992; Zellner & Duralch, 2002, 2003) whereas brown has been reported most of the time as a freshness inhibitor (Zellner & Duralch, 2002, 2003) even though there is no consensus on this (see Clydesdale et al., 1992). For the colorless liquid stimuli, we used the same two colorless liquid stimuli as in Experiment 1. The yellow and brown visual stimuli were created with 200 mL of still water using food-coloring (see supplementary materials and Fig. 3). Bubbles for the yellow and brown stimuli were copied and pasted from the colorless stimuli and the color contrast was adjusted in Photoshop. Previous discriminability tasks confirmed that variations in the color of the beverage and the width of the glass did not significantly affect the perceived bubble size ($N=8$, 7 females/1 male, mean age 30; color: $F=0.28$, $p=0.76$; width: $F=0.17$, $p=0.92$) or the perceived bubble quantity ($N=8$, 5 females/3 males, mean age 24; color: $F=1.23$, $p=0.3$; width: $F=2.5$, $p=0.07$).

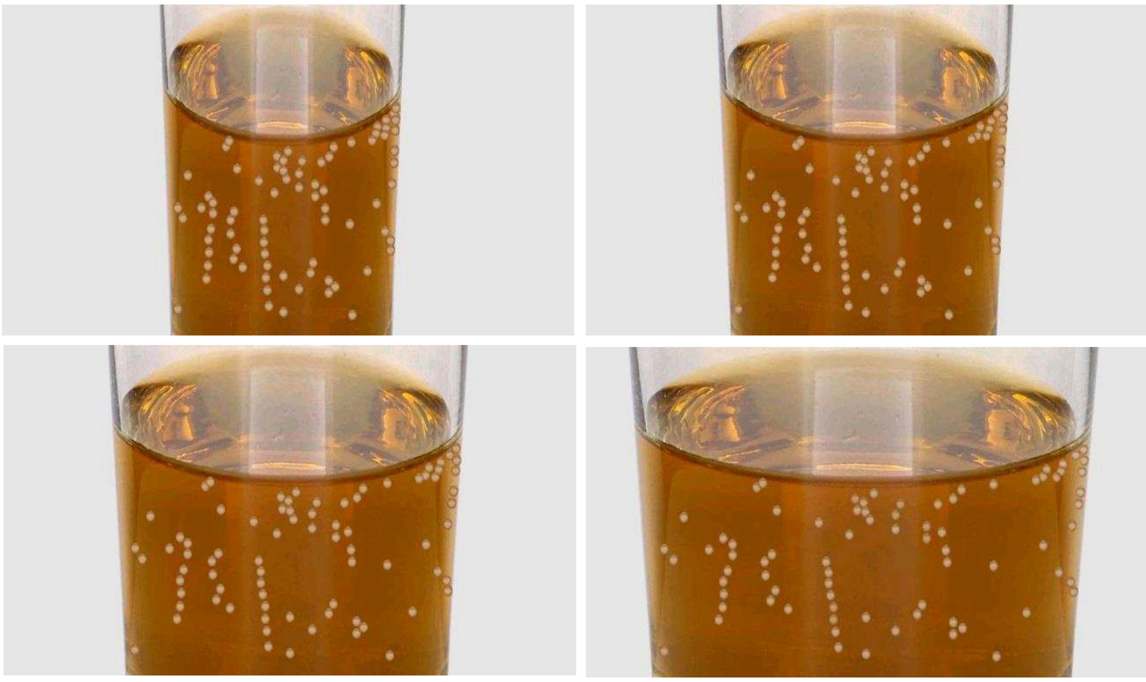

Fig. 3. Pictures of the big bubbles visual stimuli used in Experiment 2, varying the width of the glass, for the brown liquid.

See the supplementary materials for the other sets of visual stimuli that were used.

The auditory stimuli were the same as in Experiment 1, with two additional pitches added, one lower (576 Hz) and one higher (1187 Hz). These two pitches were added to increase task complexity, while still making sure that they would be easily distinguishable from one another. Thus 4 auditory stimuli varying in pitch intensity were used in Experiment 2: low pitch 1: 576 Hz, low pitch 2: 677 HZ, high pitch 1: 1086 Hz, and high pitch 2: 1187 Hz.

Design

A slightly modified version of the GNAT described in Nosek and Banaji (2001) was programmed with E-prime©, incorporating the later suggestions for improvement made by Williams and Kaufmann (2012) for the appropriate number of trials.

The four first blocks of 24 trials each consisted of practice at the small-big bubbles and the low pitch-high pitch go/no-go task. In the visual practice single tasks, 8 random stimuli from each set of 12 visual stimuli were presented. In the auditory practice single tasks, four pouring sound pitches were presented 6 times in a random order. The fourth practice single tasks were randomized.

Four blocks of 24 trials of the “practice combined task” and 72 trials of the “critical combined task” then constituted the go/no-go task, in congruent and incongruent response blocks. In the 24 trials of the practice combined task,, 4 random stimuli from each set of 12 visual stimuli were presented as well as 6 high pitch stimuli (3 trials for each high pitch) and 6 low pitch stimuli (3 trials for each low pitch). During the practice blocks, feedback was given on each of the participants’ responses (a green circle or a red cross presented on the screen for 100 ms), reminding the participants of the expected classification. In the 72 trials of the critical combined tasks, for instance targeting the congruent association between small bubbles and high pitch, each visual stimuli was presented once, in addition to 18 high pitch stimuli (9 trials for each high pitch) and 18 low pitch stimuli (9 trials for each low pitch). This led to 72 trials with 30 Go trials (30 congruent associations between small bubbles and high pitch), 42 No-go trials (30 congruent associations between big bubbles and low pitch and 12 task-irrelevant trials with the neutral visual stimuli). The four different combined tasks were presented in a random order across participants. In total, each participant responded to 480 trials.

Procedure

The experiment was conducted in the same conditions as Experiment 1. On-screen instructions were given before each block of trials. The participants were instructed to press the space bar as rapidly and accurately as possible if the picture or the sound belonged to one of two target categories (e.g., small bubbles or high-pitched). As a reminder to the participants, the target categories were presented at the top of the screen, on the left and right sides, throughout the block. Trials were separated by an inter-stimulus interval (ISI) of 150 ms. Each picture or sound was presented for 2 s or until the space bar was pressed. RTs and accuracy of the participants’ responses were recorded.

Similarly to Experiment 1, the participants were asked explicitly to rate which bubble size and which pouring sound pitch they generally associate with the consumption of fresh sparkling beverages on two 7-point Likert scales ranging from “Very small bubbles” to “Very big bubbles” and from “Very low-pitched sound” to “Very high-pitched sound”. The participants were also asked to rank 6 different pouring sounds with different pitches (576 Hz, 677 Hz, 886 Hz, 960 Hz, 1086 Hz, and 1187 Hz) from ‘not fresh at all’ to ‘very fresh’.

Data analysis

Two participants (1 male, 1 female) appeared as outliers in the data distribution due to more than 25% of their trials being unanswered (mean 27.4% of trials unanswered; mean of trials unanswered for the remaining twenty-eight participants: 1.3%) and they were removed from the subsequent analyses, similarly to Experiment 1. To test for the influence of Congruency (congruent vs. incongruent), Modality (visual vs. auditory), stimuli characteristics (bubble size, color, width of the glass, pitch, pitch intensity), and participants' characteristics (gender, age, explicit freshness ratings of bubble size and pouring sound pitch) on the participants' RTs, linear mixed-effects models were fitted to the data with participants as a random variable.

For the sensitivity (d') in the participants' responses, the approach described by Nosek and Banaji (2001) was followed, using signal detection theory (SDT - Green and Swets, 1966). d' was computed for each combined task according to Grier's formulas (Grier, 1971). $d' = 1/2 + [(y - x)(1 + y - x)/4y(1 - x)]$, where y stands for the probability of a hit and x corresponds to the probability of a false alarm. d' may thus range from 0 to 1, with 0.50 indicating responses at chance level, and 1 indicating maximum discriminability. Paired-sample t-tests were conducted to compare the sensitivity (d') of participants' responses to the target categories between blocks of trials in which the bubble size was combined with high-pitched or low-pitched sounds.

3.2. Results and discussion

When considering the participants' RTs as the dependent variable, the final model ($R^2_C = 0.29$, see Nakagawa and Schielzeth, 2013) revealed a significant main effect of Congruency ($\chi2(1) = 17.6$, $p<.001$), Modality ($\chi2(2) = 9.5$, $p=0.002$), bubble size ($\chi2(3) = 14.6$, $p<.001$), color of the liquid ($\chi2(5) = 24.3$, $p<.001$), and pitch intensity ($\chi2(8) = 29$, $p<.001$). A significant two-way interaction effect between the color of the liquid and the bubble size was also revealed by the model ($\chi2(10) = 10.3$, $p=0.006$). Overall, the participants' RTs were significantly shorter in the congruent blocks (m=704 ms ± 6.3 SEM) than the incongruent blocks (m=736 ms ± 6.6 SEM). This result is in line with the results on RTs obtained in Experiment 1 and it confirms the existence of the pitch-size correspondence effects. The participants' RTs were also shorter for auditory stimuli (m=716 ms ± 6.1 SEM) than for visual stimuli (m=726 ms ± 7 SEM). The interaction between Modality and Congruency was not significant ($p=0.08$), even if a clear tendency is observed between the mean RTs for visual stimuli in congruent blocks (m=700 ms ± 9 SEM) as opposed to incongruent blocks (m=752 ms ± 11 SEM).

A Tukey post-hoc analysis revealed that the participants' RTs were also shorter for low pitch 1 (m=668 ms ± 9 SEM) than for low pitch 2 (m=744 ms ± 11.6 SEM, $p<.001$) and high pitch 1 (m=729 ms ± 13.4 SEM, $p=0.0149$). The participants also responded more rapidly to high pitch

2 (m=724 ms ± 13.7 SEM, p=0.04) than to low pitch 2. The interaction between pitch intensity and Congruency was not significant (p=0.24). Regarding the two-way interaction effect between the color of the liquid and the bubble size, a Tukey post-hoc analysis revealed that the participants' RTs were longer (p<.001) for the small bubbles when the beverage was yellow than for any other combination (small bubbles with colorless or brown beverages, and big bubbles with colorless, yellow, or brown beverages). The interactions of the color of the liquid (p=0.97) and the bubble size (p=0.29) with Congruency were not significant. Thus, the RT analysis does not allow for any conclusion regarding the relative effects of the two associations involved in the pitch-size correspondence reported here.

A second model ($R^2_C = 0.27$) revealed a significant main effect of the age of the participants ($\chi2(1) = 4.8$, p=0.03) on their RTs. Further analysis was based on two participant age groups revealed by the data distribution: one group of 15 participants (mean age=24, ranging from 18 to 30 years old) and one group of 13 participants (mean age=53, ranging from 38 to 60 years old). A repeated-measure ANOVA revealed a significant main effect of the age group (F=8.1, p<.01), bubble size (F=12.1, p<.0001), and pitch intensity (F=9.6, p<.0001) on the participants' RTs. Interactions of the age group with the bubble size (F=4.9, p=0.007) and the pitch intensity (F=2.9, p=0.02) were also significant. A Tukey post-hoc analysis revealed that the RTs of the older group for the small bubbles were significantly longer than both their RTs for the big bubbles (p<.001) and the RTs of the younger group independent of the bubble size (p<.01). Regarding the interaction between the age group and the pitch intensity, a Tukey post-hoc analysis revealed that for the highest pitch, the RTs of the older group were significantly longer than the RTs of the younger group (p=0.01). Similarly to Experiment 1, an age effect appears on the participants' RTs, which is in line with what has been generally reported in the literature. The fact that the participants' RTs in the older group were longer for the small bubbles and the highest pitch is likely to be attributable to a decrease in visual and auditory capacities with age.

Regarding the analysis of the participants' sensitivity in their responses, no significant effects of congruency (see Table 2), color of the liquid, or width of the glass appeared. Once again, nothing can be concluded about the relative effects of the two associations involved in the pitch-size correspondence reported here. Overall, the participants' mean error rates were less than 4%. Thus, the fact that we cannot disentangle the relative effects of the two pitch-size correspondences may be due to i) an equal strength of the two associations under the conditions of this experiment, ii) the fact that the task was too easy to perform for the participants to show any differences in sensitivity (d'), or iii) the combination of both of these parameters.

Table 2

Sensitivity (d’) for each bubble size in the two different pairing conditions, and significance level from paired-sample t-tests in Experiment 2.

Visual stimuli	**Measure**	**Pairing condition**		**p**
		High pitch	**Low pitch**	
Small bubbles	d’	0.994	0.984	0.3
Big bubbles	d’	0.995	0.995	0.8
p		0.8	0.7	0.9

Regarding the analysis of the explicit measures collected, data distribution shows that a bigger proportion of participants associate more the consumption of fresh sparkling beverages with small bubbles and high-pitched sounds than to big bubbles and low-pitched sounds.

The data of 13 participants were analyzed for the ranking task and they did not reveal a significant effect of the rank of the sounds. However, it can be noted that the two lowest pitch sounds were ranked as not fresh by more than 50% of the participants.

Concerning implicit measures, further investigations are needed to disentangle the relative effects of the two associations involved in the pitch-size correspondence shown in Experiments 1 and 2. On the other hand, in explicit measures, when the participants assess the corresponding perceived freshness, their ratings show that they associate small bubbles and high-pitched pouring sounds to freshness in beverages more than big bubbles and low-pitched pouring sounds.

4. General Discussion

The first experiment reported here aimed at investigating the existence of crossmodal correspondence effects between audiovisual perceptual features linked to carbonation in beverages. In particular, congruent associations (i.e., between small bubbles and high-pitched pouring sound and between big bubbles and low-pitched pouring sound) were expected to be stronger than the incongruent associations. The second experiment aimed to investigate the relative effects of the two pitch-size correspondences shown in Experiment 1. The robustness of these correspondences was also tested through variations of the stimulus context (i.e., color of the liquid and width of the glass). Shorter RTs and higher accuracy in congruent blocks were obtained in Experiment 1 and confirmed the existence of the crossmodal correspondence between bubble size and pouring sound pitch. These results provide the first empirical evidence that complex audiovisual stimuli are also subject to pitch-size correspondence effects (e.g., Parise & Spence, 2012). The analysis of the latency in the participants' responses in Experiment 2 confirms the existence of the pitch-size correspondences revealed in Experiment 1. Variations in the color of the liquid and width of the glass did not significantly interact with the congruency of the audiovisual interaction, which suggests that the pitch-size correspondence effects investigated here are robust to variations of the stimulus context. The sensitivity (d') in the participants' responses was not significantly influenced by the congruency of the interaction, the color of the liquid, or the width of the glass. Thus, further research is needed to disentangle, on the basis of implicit measures, the relative effects of the two pitch-size correspondences reported here. For instance, we can hypothesize that significant differences in the participants' sensitivity could be shown by using a different bubble density.

In previous studies that have investigated crossmodal interaction effects, most of the time two or more stimuli were presented at the same time with the participants being instructed to respond to only one or two of them (e.g., Evans & Treisman, 2010; Hecht & Reiner, 2009; Misselhorn, Daume, Engel, & Friese, 2016). In these cases, it is unclear how much of the reported effects are due to the presence of the stimuli participants are instructed to respond to, or to the presence of an irrelevant stimulus. Parise and Spence (2012) concluded that IAT results cannot be interpreted in terms of the processing costs and/or benefits (i.e., crossmodal facilitation) associated with the simultaneous presentation of certain combinations of stimuli, or in terms of a failure of selective attention since only one stimulus is presented at any time in the IAT and both modalities are equally relevant to the task (i.e., there are the same number of trials for each stimulus and for each condition of congruency). However, other researchers reported that IAT compatibility effects could also arise due to factors other than the relevant features themselves, such as the similarity between stimuli in terms of shared perceptual characteristics, salience, or the feeling of familiarity they induce (e.g., De Houwer et al., 2009).

Some inter-individual differences might also influence the participants' performance and the way in which they indirectly associate stimuli. For instance, McEwan and Colwill (1996) reported that the level of carbonation required in a drink for it to be either thirst-quenching or acceptable appears to be an individual requirement. A few people seem to like a highly carbonated drink, but most of them prefer a drink to be slightly sparkling or still. The number of bubbles in our study did not vary, but it is possible that the participants have associated a particular bubble size and quantity with a specific carbonation intensity in a drink. Moreover, it should be noted that all the participants in our experiments were French residents, and that further experiments would be necessary in order to explore more in depth the role of cultural differences on this particular crossmodal correspondence. In fact, De Houwer et al. (2009) reported that the IAT compatibility effects can also be partly explained by the similarity among stimuli with regard to semantic commonalities (e.g., meaning) which is assumed to be sensitive to cultural differences. Further experiments using the IAT could be used to study other aspects of sounds as well as other sensory cues linked to carbonation, or other perceptual features of interest regarding freshness perception in beverages.

The implicit measures collected in our study do not allow for determining whether the two associations (small bubbles-high pitch and big bubbles-low pitch) equally contribute to the global effect. However, in the two experiments, when the participants were explicitly requested to assess which bubble size and pouring sound pitch they generally associate with fresh sparkling beverages, the results indicate that they associate small bubbles and high-pitched pouring sounds to freshness in beverages more than big bubbles and low-pitched pouring sounds. One of the factors that could explain the differences in the results obtained with implicit and explicit measures is the fact that the putative semantic mediation of the crossmodal correspondence with freshness was implicitly investigated only in Experiment 1, using a semantic priming. The resulting null effect of the semantic prime is probably due to either the level of association between the audiovisual stimuli and freshness – which can partly correspond to what Nosek (2005) called "evaluative strength" as one of the moderators of the relationship between implicit and explicit evaluation – or time presentation adjustments or, as is likely, to both.

The relationship between implicit and explicit measures has been debated for decades in the social cognition literature using the original versions of the IAT and GNAT (Blaison, Chassard, Kop, & Gana, 2006; Nosek, 2005). Nosek and Banaji (2001) reported that while early theories and data suggested that these two types of measure were not related (e.g., Greenwald & Banaji, 1995), implicit-explicit correspondences may be observed under some conditions and for some attitude (e.g., Cunningham et al., 2001). It is likely that a positive relationship between implicit and explicit measures would indicate greater construct validity (Greenwald et al., 2003). Although, Blaison and colleagues (2006, p.314) have suggested that the observed discrepancy between implicit and explicit measures could also provide evidence of the lack of contamination of indirect measures by the declarative ones that contain various biases (e.g., limited introspective abilities). Thus, it seems that the relationship between implicit and explicit measures requires further investigation when considering crossmodal correspondences between specific perceptual features that may contribute to a complex perception such as freshness in beverages. Moreover, the associations that may be mediated by another level of processing (e.g., linguistic or emotional, see Roque et al., 2018a) still remain to be explored in the case of freshness perception in beverages.

Another interesting follow-up of the experiments reported here would be to investigate the notion of transitivity between crossmodal correspondences, as it has been recently theorized by Walker (2016). For instance, if small bubbles are associated with high-pitched pouring sound, and high-pitched pouring sound is associated with high spatial elevation, then small bubbles might be associated with high spatial elevation. Understanding the relations that may exist between different crossmodal correspondences would represent a promising way to develop efficient strategies (in terms of formulation, packaging, retail experience, or ads, see Ngo, Piqueras-Fiszman, & Spence, 2012; Spence & Wang, 2015) to better catch consumers' attention and likely increase attractiveness and appreciation of products.

5. Conclusion

The results of the two experiments reported here confirm the existence of a pitch-size crossmodal correspondence between bubble size and pouring sound pitch in carbonated beverages. This also provides the first empirical evidence that complex audiovisual stimuli allow highlighting IAT compatibility effects, regarding the well-established pitch-size correspondence (Experiment 1). On the relevance of combining IAT and semantic priming tasks, it appeared that further research is needed to adjust some methodological issues relative to the measure of RTs and the semantic congruency effects that might be expected with the prime and stimuli used. The result obtained in the GNAT (Experiment 2) do not allow for determining the relative effect of the two pitch-size correspondences investigated here, neither on the basis of the analysis of the RTs, nor the sensitivity in participants' responses. The sensitivity (d') was not affected by the color of the liquid, the width of the glass, or the congruency of the associations. On the other hand, the explicit measures used in both experiments suggest that the participants associate small bubbles and high-pitched pouring sounds with freshness in beverages more than big bubbles and low-pitched pouring sounds. The semantic mediation of the type of crossmodal correspondences reported here requires further investigation, especially for implicit measures. Knowing how to trigger these crossmodal correspondences, in relation to visual designs, sound symbolism, and semantics, could facilitate consumers' categorization of a given product that matches their expectations and would lead to a more pleasant overall experience.

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Supporting information

Table 1. References and volumes of food-colorings used to generate the yellow and brown visual stimuli used in Experiment 2

The final volume in each condition was completed to 200 mL with still water at ambient temperature. The bubbles were subsequently added using Photoshop.

Color	**Food-colorings references**	**Food-colorings volume** (µL)			
		No ice cubes	**4 ice cubes**	**No ice cubes + turbidity** (cloudy agent: Symrise Ref 357255=10 µL)	**4 ice cubes + turbidity** (cloudy agent: Symrise Ref 357255=6.6 µL)
Yellow	E104	200	132	240	158.4
Brown	E150d	50	33	50	33

Table 2. Pictures of the small bubbles visual stimuli used in Experiment 2

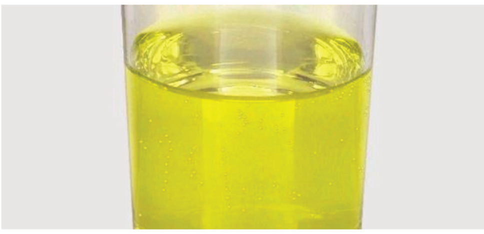
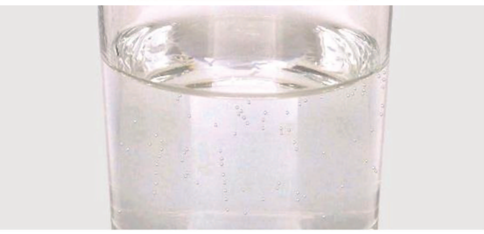
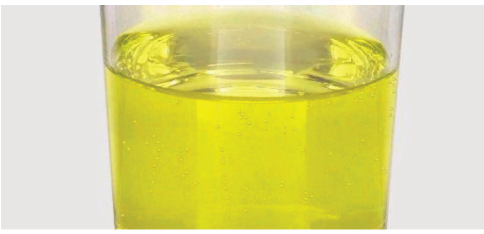
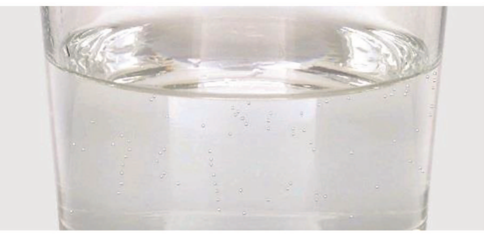
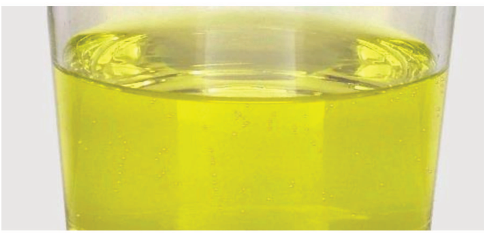
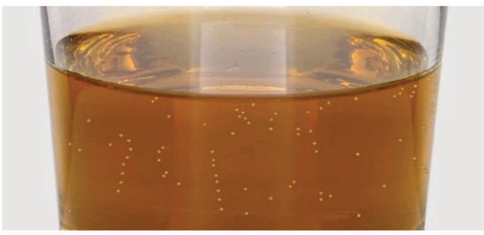
	Colorless	Yellow	Brown
Width 1			
Width 2			
Width 3			
Width 4			

Table 3. Pictures of the big bubbles visual stimuli used in Experiment 2

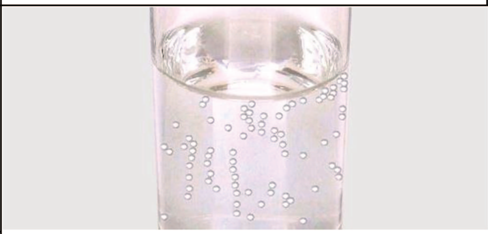
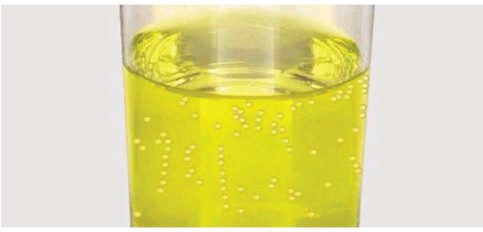
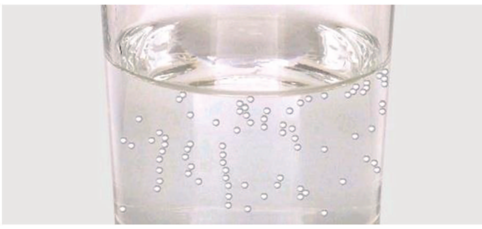
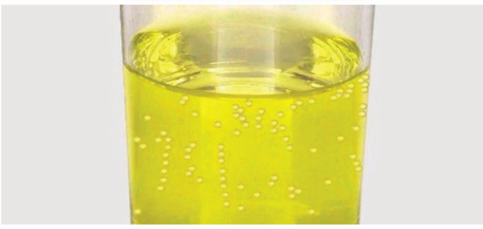
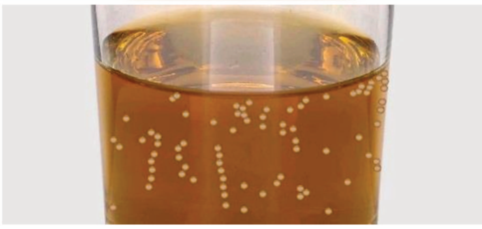
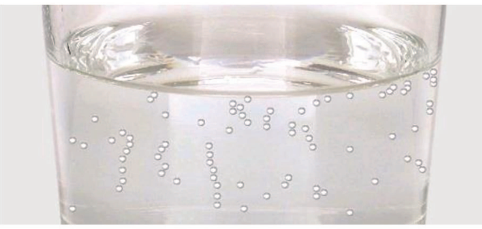
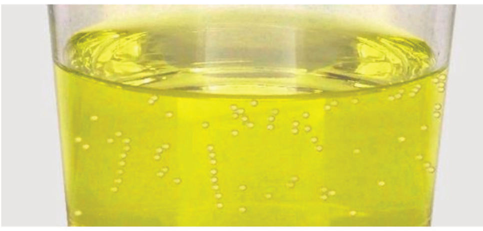
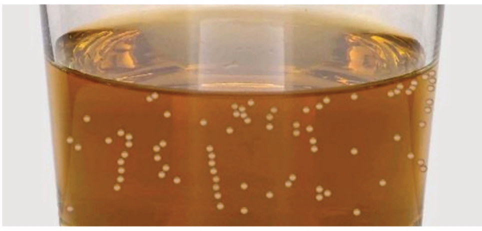
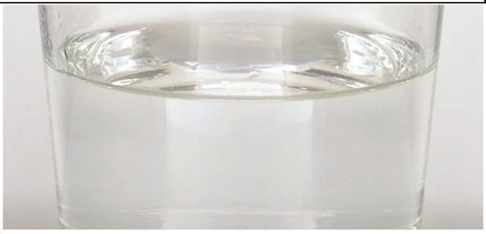
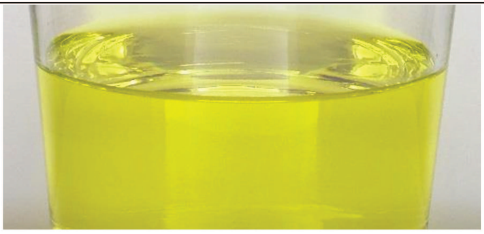
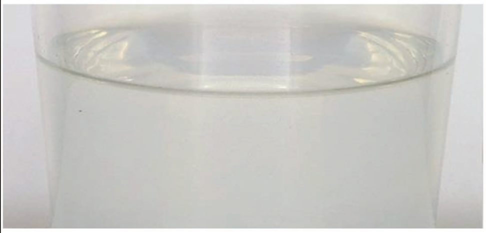
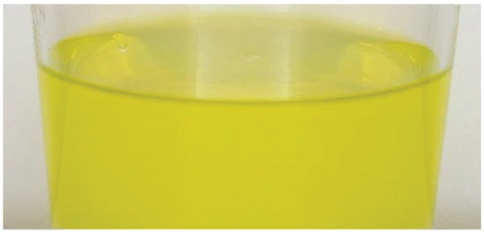
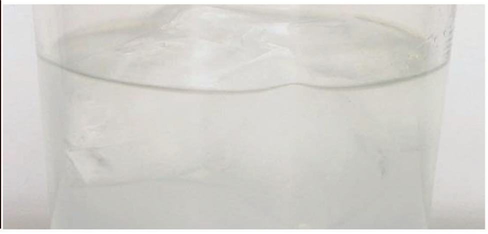
	Colorless	Yellow	Brown
Width 1			
Width 2			
Width 3			
Width 4			

Table 4. Pictures of the neutral visual stimuli used in Experiment 2

The width of the glass for all the neutral visual stimuli was width 4.

	Colorless	Yellow	Brown
No ice cubes			
Turbid			
Ice cubes			
Ice cubes + Turbid			

PART D. THE TRANSITIVITY OF CORRESPONDENCES AND ATTENTIONAL ALLOCATION EFFECTS

Chapter 6. The transitivity of correspondences: is there any relation between bubbles size, pouring sounds pitch, and spatial elevation in carbonated beverages?

This chapter presents the last experimental studies that have been conducted to investigate the relations that exist between the correspondences involving the perceptual features of bubbles size, pouring sounds pitch, and spatial elevation in carbonated beverages. The experiments reported in Chapter 5 have provided empirical evidence of Pitch-Size correspondence effects that exist between bubbles size and pouring sounds pitch. However, it remains an open empirical question whether similar stimuli would reveal: i) correspondence effects for the Pitch-Elevation and Size-Elevation correspondences, and ii) transitivity between these different correspondences.

A speeded classification paradigm was adapted from Evans & Treisman (2010) to test the existence of these correspondences and conclude on the consequences, in terms of participants' performances (e.g., facilitation effect), of a confirmation of the transitivity hypothesis. In this paradigm, two distinct task instructions were used in order to manipulate the allocation of the participants' attention toward either the same features on which the correspondences were tested (i.e., bubbles size, pouring sounds pitch, spatial elevation) or to different features from those with the hypothesized intra- or crossmodal correspondences (i.e., lateralization of the visual and auditory stimuli). This manipulation enables us to discuss the automaticity of such correspondences, a debate that is still ongoing in multisensory research (e.g., Getz & Kubovy, 2018).

From an applied perspective, we believe that a better understanding of the relations that exist between different intra- and crossmodal correspondences would help food and beverage companies in developing efficient strategies (in terms of formulation, packaging, retail experience, or ads) to better catch consumers' attention and likely increase attractiveness, acceptance, and appreciation of their products.

The relations between pouring sounds Pitch, bubbles Size, and spatial Elevation in carbonated beverages and attentional allocation effects

Jérémy Roque[a,b,c*], Malika Auvray[b], Jérémie Lafraire[c]

[a] Breakthrough Innovation Group, Pernod Ricard, 75009 Paris, France
[b] Sorbonne Université, UPMC, CNRS, Institut des Systèmes Intelligents et de Robotique (ISIR), F-75005 Paris, France
[c] Institut Paul Bocuse Research Center, 69130 Ecully, France

Manuscript in preparation

Abstract

The literature on crossmodal correspondences recently hypothesized that bidirectionality and congruency underlying correspondence effects would represent core evidence to expect transitivity among correspondences. The relations that may exist between crossmodal correspondences have been recently theorized by some researchers who refer to the notion of transitivity of implication that exists in logic; a rule governing the relationships linking different attributes that might be simply described as "If A implies B, and B implies C, then A implies C". However, the majority of studies have investigated crossmodal correspondences separately. The Pitch-Size and Pitch-Elevation crossmodal correspondences have been widely reported in the literature with very simple cues. On the other hand, the Size-Elevation intramodal correspondence has been very few investigated. Only the Pitch-Size correspondence has already been reported for more complex and ecological stimuli, namely bubbles size and pouring sounds pitch, in the case of carbonated beverages. The two experiments reported here aimed at investigating whether similar complex stimuli would reveal: i) correspondence effects for the Pitch-Elevation and Size-Elevation correspondences, and ii) transitivity between these different correspondences. In the Direct task (Experiment 1), the participants were asked to respond to the same features on which the correspondences were tested (i.e., bubbles size, pouring sounds pitch, and spatial elevation), whereas in the Indirect task (Experiment 2), the participants were asked to respond to different features from those with the hypothesized correspondences (i.e., lateralization of the auditory and visual stimuli). The allocation of the participants' attention was thus manipulated in order to conclude on the level (perceptual vs.

higher order cognitive level) at which the targeted correspondences might occur. Shorter reaction times were obtained in congruent trials (e.g., small bubbles and high pitch) than in incongruent trials, only for the Pitch-Size correspondence in the Direct task. Thus, no transitivity was observed between bubbles size, pouring sounds pitch, and spatial elevation. We hypothesize that the Pitch-Size correspondence, in the particular case of carbonated beverages, may potentially occur when higher order cognitive processes are involved (e.g., attention) and not only perceptual processing.

Keywords: crossmodal correspondences, auditory, visual, transitivity, attention, carbonated beverages

1. Introduction

A large body of research has recently explored the evidence regarding the existence, and the consequences for human information processing, of a particular form of crossmodal interactions named crossmodal correspondences. Crossmodal correspondences correspond to the non-arbitrary associations that exist between perceptual features belonging to different sensory modalities (see Parise, 2016; Spence, 2011, for reviews). Various types of crossmodal correspondences have been reported between very simple cues corresponding to pure tones for the sounds and grey circles or Gabor patches for the visual stimuli. Thus, the Pitch-Size correspondence has been one of the most reported: smaller circles are typically matched with higher pitched sounds and larger circles with lower pitched sounds (Evans & Treisman, 2010; Gallace & Spence, 2006; Parise & Spence, 2012).

The first empirical evidence of the existence of this correspondence with more complex and ecological stimuli has been provided by Roque, Lafraire, & Auvray (submitted). The authors thus replicated the Pitch-Size correspondence effects using stimuli varying for bubbles size and pouring sounds pitch in the particular case of carbonated beverages. Their results revealed shorter participants' reaction times (RTs) and higher accuracy in their responses in congruent blocks of trials (i.e., small bubbles associated to high-pitched pouring sound and big bubbles associated to low-pitched pouring sound) than in incongruent blocks (the reverse associations). Based on the collection of explicit measures, Roque et al. also showed that people generally associate more small bubbles and high-pitched pouring sounds to the consumption of fresh sparkling beverages than big bubbles and low-pitched pouring sounds. They concluded that knowing how to trigger such kind of crossmodal correspondences could facilitate consumers' categorization of a given product that matches their expectations, and would lead to a more pleasant overall experience (see Labbe, Almiron-Roig, Hudry, Leathwood, Schifferstein, & Martin, 2009; Roque, Auvray, & Lafraire, 2018a, for reviews on the multisensory perception of freshness).

In a recent review on crossmodal correspondences, Parise (2016, p.8) have highlighted that the potential consequences of manipulating perceptual features that are involved in many crossmodal correspondences (e.g., pitch that may be part of a "broader associative network") require further investigation. Interestingly, auditory pitch has been shown to match other visual attributes than size such as spatial elevation (or location) of visually-presented objects (Evans & Treisman, 2010; Patching & Quinlan, 2002). Participants generally classify visual stimuli as high and low more quickly when the visual stimulus is accompanied by a tone that is congruent rather than incongruent (e.g., high pitch with high spatial elevation rather than low).
However, few studies have investigated cases of intramodal correspondences. Noticeable exceptions are one of the experiments reported by Evans & Treisman (2010) who actually failed to reveal the supposedly natural correspondence between size and spatial elevation, even though this correspondence is considered as more than likely based on the extraction of statistical regularities in our environment (see Spence, 2011). It can though be noted that Size-Elevation correspondence effects have been shown crossmodally in Walker and Smith's study (1985) between haptic size (i.e., size of the response key) and words linked to opposite ends of the spatial elevation dimension (i.e., Top–Bottom and Up–Down). Their results showed that participants responded more quickly and accurately in the congruent condition (e.g., small size and words denoting high elevation). However, none of both of these correspondences (Size-Elevation and Pitch-Elevation) have been investigated using more complex and ecological stimuli, as it has been the case for the Pitch-Size correspondence (Roque et al., submitted).

In a review on multisensory integration, perception, and ecological validity, De Gelder and Bertelson (2003) reported that even though past research have shown that using simple cues (e.g., pure tones and circles) was sufficient to elicit robust multisensory integration, it is reasonable to question whether simple cue combinations are sufficient for the understanding of complex naturalistic situations in which humans evolve. Spence (2011) also emphasized the fact that even though perceptual effects can be demonstrated in certain tasks for certain crossmodal correspondences, this would not necessarily mean that they will be demonstrated for other tasks or crossmodal correspondences. For instance, Smith and Sera (1992) showed that adults' participants associated big objects with louder sounds whereas Gallace and Spence

(2006) found that the loudness of a sound did not actually change the perceived size of the circle it was presented with (despite the fact that participants' RTs changed significantly). Thus, replicating the effects of previously identified crossmodal correspondences with different tasks and different stimuli may provide some evidence of the robustness of the underlying mechanisms. Extending the knowledge on audiovisual multisensory integration by applying existing paradigms to more complex and ecological stimuli will also enable advances in the field of food and beverage cognition. In fact, multisensory processes and cognitive mechanisms that influence our eating and drinking behaviors have received a great deal of interest over the past decades (see Auvray & Spence, 2008; Prescott, 2015; Shepherd, 2012; Small, 2012; Spence, Auvray, & Smith, 2014; Verhagen & Engelen, 2006, for major reviews on these latter). The investigation of these mechanisms, generally with implicit measures of behavior, has enabled researchers to gain new evidence on the existence of crossmodal correspondences in the food and beverage domain.

Hypothesis 1. The existence of the Size-Elevation intramodal correspondence, the Pitch-Size, and the Pitch-Elevation crossmodal correspondences will induce that participants will respond faster and more accurately to congruent pairs of stimuli than to incongruent.

The relations that may exist between correspondences have been recently theorized by some researchers (Walker & Walker, 2012; Walker, 2016) based on previous work studying the interactions between surface brightness, odor, and auditory pitch (Hornbostel, 1931), through the notion of transitivity of implication that exists in logic. Transitivity is a rule governing the relationships linking different attributes and might be simply described as "If A implies B, and B implies C, then A implies C". The literature described above shows that the Pitch-Size and Pitch-Elevation correspondences have been often reported in the literature, and the Size-Elevation correspondence may be considered as more than likely (in some cases). Thus, based on the transitivity hypothesis, it is reasonable to hypothesize that a relation may exist between the correspondences of Pitch-Size, Pitch-Elevation, and Size-Elevation. Moreover, this same logic might be applied to the relations between Pitch, Size, and Elevation in the case of carbonated beverages: if small bubbles are associated with high-pitched pouring sound, and high-pitched pouring sound is associated with high spatial elevation, then small bubbles will be certainly associated with high spatial elevation.

Hypothesis 2. Transitivity hypothesis: If Size and Pitch share a crossmodal correspondence, if Pitch and Elevation share a crossmodal correspondence, then Size and Elevation likely share an intramodal correspondence (see Fig.1 below).

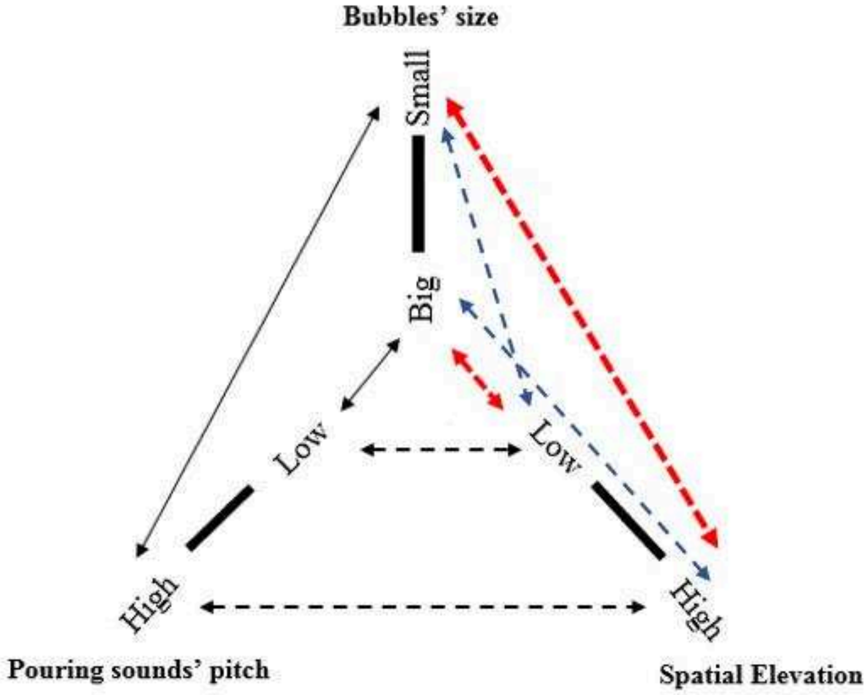


Fig. 1. Illustration of the transitivity hypothesis between bubbles size, pouring sounds pitch, and spatial elevation (retrieved from Walker, 2016).

Red arrows depict a confirmation of the transitivity hypothesis. Blue arrows depict a disconfirmation of the transitivity hypothesis.

In case of a confirmation of the transitivity hypothesis, it also remains an open empirical question whether a bidimensional congruent visual stimulus (e.g., small bubbles and high elevation in space) jointly presented with a congruent auditory stimulus (i.e., high pitch) would induce an additive facilitation effect in the participants' performances (e.g., shorter RTs). Roque, Lafraire, Spence, and Auvray (2018b) recently investigated the influence of audiovisual crossmodal interaction effects on the categorization of freshness in beverages. Their results revealed that congruent interactions between the targeted perceptual features did influence the participants' performances, and additive effects were obtained on the participants' RTs (i.e., facilitation). These additive effects were obtained when two congruent auditory cues were jointly presented and when the participants categorized the beverages as fresh.

Hypothesis 3. If the transitivity hypothesis is confirmed, it is expected that a bidimensional congruent visual stimulus (e.g., small bubbles and high elevation in space) jointly presented with a congruent auditory stimulus (i.e., high pitch) will induce a facilitation effect in the participants' performances.

Over the years, crossmodal correspondences have been investigated using different methods such as speeded classification paradigms (e.g., Evans & Treisman, 2010) or variants of the Implicit Association Test (IAT, e.g., Deroy, Fasiello, Hayward, & Auvray, 2016; Parise & Spence, 2012; Roque et al., submitted). The main difference between these two types of tasks is that the presentation of the stimuli is both unimodal and bimodal (or unidimensional and bidimensional) in classification paradigms, in which participants have to ignore one of the two modalities (or dimensions) for bimodal (or bidimensional) trials. On the other hand, the presentation of the stimuli is always unimodal in the IAT. The strengths and shortcomings of both of these implicit paradigms have been already discussed for years in the existing literature (e.g., De Houwer et al., 2009). In classification paradigms, it may be difficult to disentangle how much of the reported effects are due to the presence of the stimuli participants are instructed to respond to, or to the presence of an irrelevant stimulus instead. On the contrary, in studies using variants of the IAT, several limitations may be formulated as function of the type of stimuli used and their level of complexity. For instance, some researchers have argued that IAT compatibility effects could also arise due to other factors than the relevant features themselves, such as the similarity between stimuli in terms of shared perceptual characteristics, saliency, or the feeling of familiarity they induce (e.g., De Houwer et al., 2009).

In the two experiments reported here, the design of Evans and Treisman (2010) has been selected as the most appropriate for testing the research hypotheses on the existence of Pitch-Size, Pitch-Elevation, and Size-Elevation correspondences (Hyp1), and the transitivity hypothesis (Hyp2). Moreover, testing for an additive facilitation effect in the participants' performances during the presentation of a bidimensional congruent visual stimulus (Hyp3) will provide evidence on whether the different correspondences are revealed because i) each correspondence exist individually, or ii) a transitivity relationship enables to experimentally show their effects.
Using two distinct tasks' instructions, the allocation of the participants' attention was also manipulated toward either the same features on which the correspondences were tested ("Direct task") or to different features from those with the hypothesized intra- or crossmodal

correspondences ("Indirect task"). Thus, in addition to see whether the different correspondence effects occur in both cases of attentional allocation, the level (perceptual vs. higher order cognitive level) at which the targeted correspondences might arise is discussed in echo to the ongoing debate in the literature on the automaticity of crossmodal correspondences (e.g., Getz & Kubovy, 2018; Spence & Deroy, 2013).

2. Materials and Methods

2.1. Participants

Forty-eight French participants took part in the experiments (24 in Experiment 1: 50% female, mean age 36, ranging from 22 to 62 years old; and 24 in Experiment 2: 50% female, mean age 34, ranging from 20 to 57 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 a particular expertise in beverages in terms of leisure activities, education, or profession. In Experiment1, each individual session lasted approximately 45 min and the participants received a 10€ voucher to complete the study. In Experiment 2, each individual session lasted approximately 1 hour and the participants received a 15€ voucher to complete the study. All the participants provided written informed consent prior to taking part in the study. The experiment was approved by the local ethical committee.

2.2. Stimuli

Discriminability tasks were previously conducted with 6 participants (100% female, mean age 32) to select the visual and auditory stimuli that were well recognizable one from the other.
The visual stimuli were pictures of a 200 mL colorless carbonated-liquid (Schweppes Indian Tonic, 8.7 g/L CO_2) served in a standard glass. Only the lateral walls of the glass were kept within the picture dimension to avoid any potential association between the shape of the glass and a particular drink. Pictures were taken in the same laboratory conditions in order to control for lighting, room temperature, and liquid temperature (i.e., ambient). Pictures were taken when the liquid motion was stabilized and the foam was absent at the surface of the liquid (i.e., 2 seconds after the pouring of the 200 mL volume) since a negative effect of the foam on the participants' RTs was found in previous research (see Roque et al., 2018b). The picture in which the bubbles were the most visually identifiable and outlined was selected. Then, the picture's background was standardized by keeping only one bubble, using Microsoft's application Paint. This bubble was copied and pasted on the locations of the other bubbles that were previously

deleted. Finally, this picture was duplicated and the bubbles sizes were modified to obtain four different sizes. Hence, four pictures were obtained in which the bubbles size was the only feature that varied.

For the auditory stimuli, the sound of a 250 mL liquid (carbonated lemonade, 6.2 g/L CO2) poured in a glass was recorded for 2 sec. Then, the background noise was reduced and four pouring sounds pitch, from low-pitched to higher-pitched sounds (677 Hz, 886 Hz, 960 Hz, and 1086 Hz), were created using Audacity 2.1.3 software.

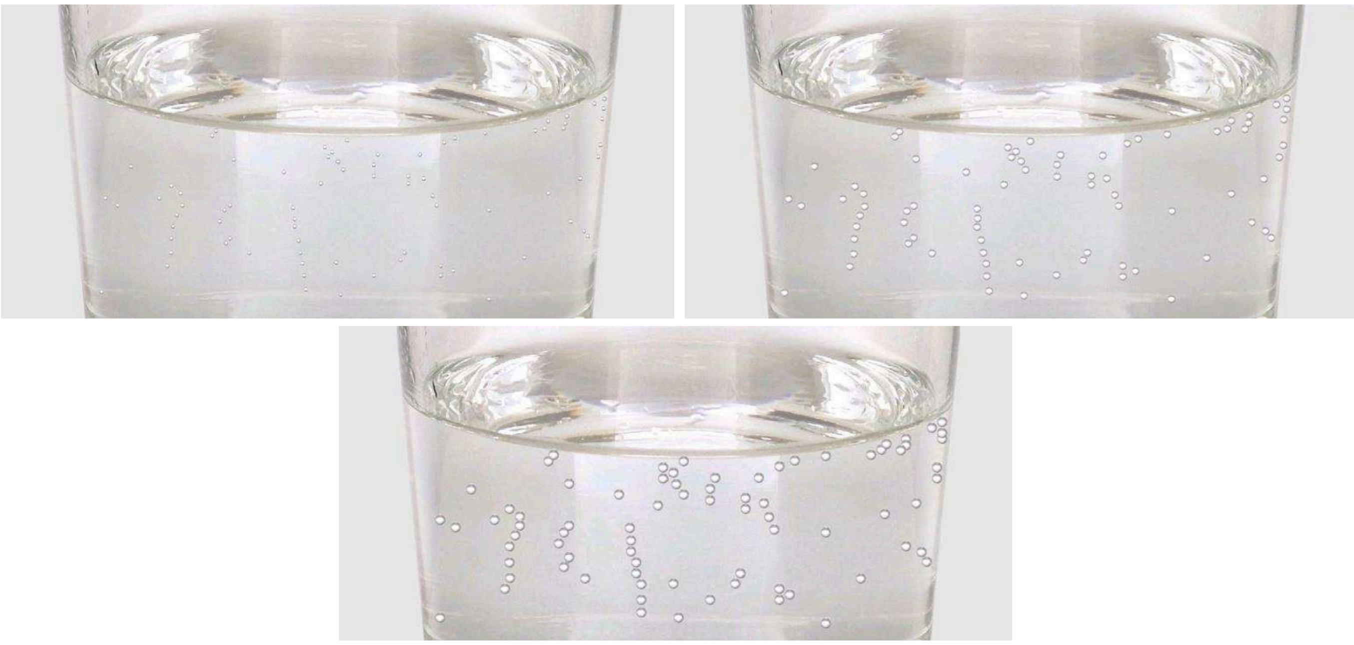


Fig. 2. Pictures of the three visual stimuli used in Experiments 1 and 2 varying bubbles size.

During the discriminability tasks (either visual or auditory), one picture or one sound was presented for 2 s, directly followed by the presentation of another picture or sound for 2 s. The participants' task was a forced-choice task in which they had to answer whether they perceived the bubbles size (or the pitch of the sound) on the second picture (of the second sound) as smaller or bigger (higher or lower) as compared to the first presented picture (sound). Error rates were calculated from the participants' responses to identify the three visual stimuli and the two auditory stimuli that were better differentiated. The visual stimuli that were better differentiated were the smallest, the second, and the third bubbles size (1-2: 9.7% error rate; 1-3: 4.2% error rate; 2-3: 4.2% error rate), represented in Figure 2. The auditory stimuli that were better differentiated were the lowest (677 Hz) and the highest-pitched (1086 Hz) sounds (7.4% error rate).

2.3. Design and procedure

Three crossmodal correspondences (Pitch-Size, Pitch-Elevation, and Pitch-Size-Elevation) and one intramodal correspondence (Size-Elevation) were investigated in two types of tasks: the "Direct tasks" in Experiment 1, and the "Indirect tasks" in Experiment 2 (see details below). The experiments were conducted in a quiet test room at the Institut Paul Bocuse Research Center. The participants sat on a chair 70 cm from a LCD computer monitor with a resolution of 1600 x 900 pixels (60 Hz refresh rate) and they wore headphones (Sony MDR-ZX110) for which the volume was adjusted to a clearly audible level.

For each correspondence tested, each experiment consisted of three conditions of which one was unimodal (i.e., stimuli were presented only in one modality, or only one dimension for Size-Elevation) and the other two were bimodal (or bidimensional), one consisting of a congruent and the other of an incongruent combination of stimuli. In any block of the experiment, participants responded only to one modality (or dimension) to which they were asked to focus on. Stimuli in the other modality (or dimension) were irrelevant to the task and the participants were asked to ignore them. The participants were instructed to press the space-bar as rapidly and accurately as possible if the picture or the sound belonged to target categories. Both visual and auditory stimuli were presented for 2 s or until the space-bar was pressed. Trials were separated by an inter-stimulus interval (ISI) of 150 ms. On-screen instructions were given before each block of trials.

The participants' level of thirst was evaluated at the beginning of each experiment on a 7-point Likert scale. Before starting each experimental session, the participants were also asked to drink a 200 mL glass of still water in order to control for their level of hydration (see Labbe et al., 2009, on the influence of thirst and hydration state on alertness and cognitive performances).

Experiment 1: *"Direct" tasks*

In the Direct tasks, the participants responded to the same features on which the correspondences were tested. Thus, for the Pitch-Size correspondence, the participants were asked to perform the speeded classification task according to the pouring sounds pitch (high pitch vs. low pitch) and the bubbles size (small bubbles vs. big bubbles). For the Pitch-Elevation, the participants had to classify the pouring sounds pitch (high pitch vs. low pitch) and the spatial elevation of the visual stimuli (high elevation vs. low elevation with a fixed intermediate bubbles size picture). The Size-Elevation correspondence tested the speeded classification of the bubbles size (small bubbles vs. big bubbles) and the spatial elevation of the visual stimuli (high elevation vs. low elevation). Finally, the Pitch-Size-Elevation correspondence tested the interaction between all these three features (see Fig. 3 with details in caption of the number of trials in each condition).

Experiment 2: *"Indirect" tasks*

In the Indirect tasks, the participants responded to different features from those with the hypothesized correspondences. Thus, for the Pitch-Size correspondence, instructions asked the participants to perform the speeded classification task according to the lateralization of the auditory stimuli (sounds heard in their left or right ear still varying for pitch, with pictures still varying for bubbles size presented at the center of the screen that the participants had to ignore) and the lateralization of the visual stimuli (pictures seen on the right or left of the screen still varying for bubbles size, with sounds still varying for pitch presented on both sides of the headphones that the participants had to ignore). For the Pitch-Elevation, the participants had to classify the lateralization of the auditory stimuli (sounds heard in their left or right ear still varying for pitch, with intermediate bubbles size picture presented at two possible locations) and lateralization of the visual stimuli (there were four possible locations of the pictures when the participants were asked to respond to the pictures and ignore the sounds: high elevation right/left vs. low elevation right/left, with a fixed intermediate bubbles size picture, and sounds still varying for pitch presented on both sides of the headphones that the participants had to ignore). The Size-Elevation correspondence tested the speeded classification of the pictures' location (four possible locations: high elevation right/left vs. low elevation right/left, pictures still varying for bubbles size). Finally, the Pitch-Size-Elevation correspondence tested the interaction between all these three features (see Fig. 4 with details in caption of the number of trials in each condition).

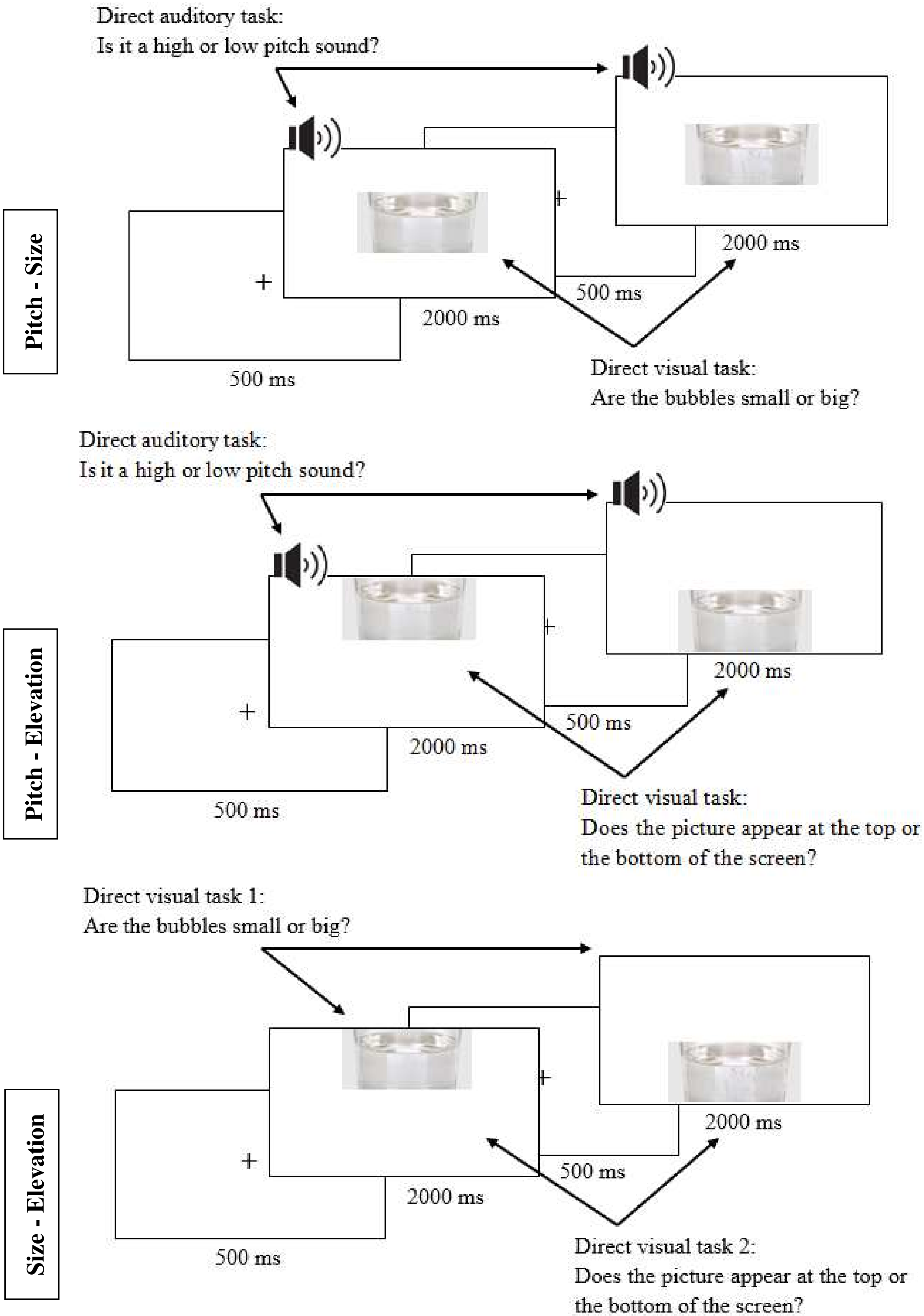


Fig. 3. The timelines in Experiment 1 (Direct tasks) for Pitch-Size, Pitch-Elevation, and Size-Elevation correspondences. One-third of the trials in each experiment were presented as unimodal stimuli for comparison. Not drawn to scale.

Pitch-Size: Unimodal auditory and visual tasks = 80 trials + Bimodal tasks = 80 trials. Pitch-Elevation: Unimodal auditory and visual tasks = 80 trials + Bimodal tasks = 80 trials. Size-Elevation: Unidimensional task on elevation = 40 trials + Bidimensional tasks = 80 trials. Pitch-Size-Elevation: Bimodal and Bidimensional tasks = 320 trials. Total = 760 trials.

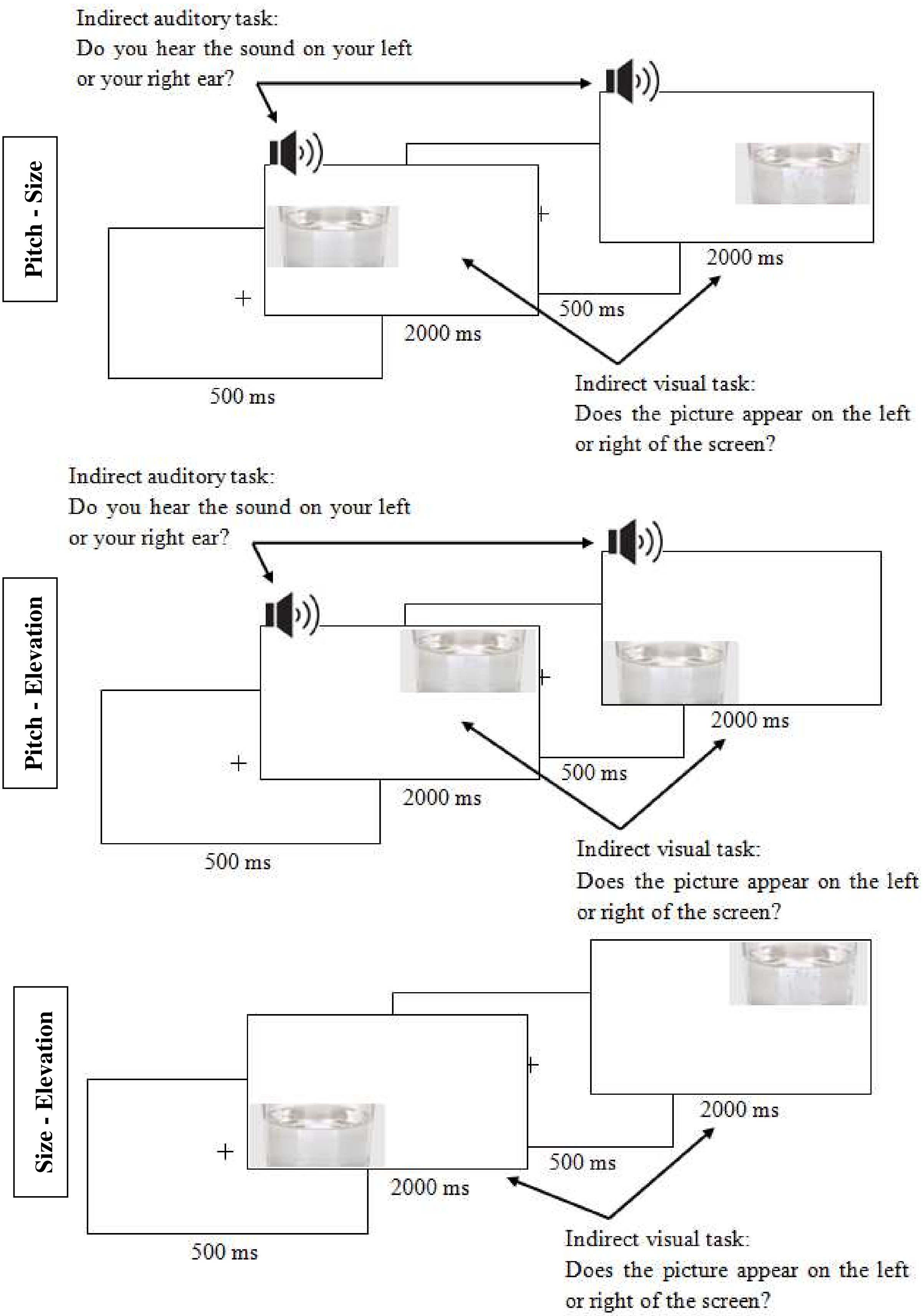


Fig. 4. The timelines in Experiment 2 (Indirect tasks) for Pitch-Size, Pitch-Elevation, and Size-Elevation correspondences. One-third of the trials in each experiment were presented as unimodal stimuli for comparison. Not drawn to scale.

Pitch-Size: Unimodal auditory and visual tasks = 160 trials + Bimodal tasks = 160 trials. Pitch-Elevation: Unimodal auditory and visual tasks = 160 trials + Bimodal tasks = 160 trials. Size-Elevation: Unidimensional task on horizontal position = 80 trials + Bidimensional tasks = 80 trials. Pitch-Size-Elevation: Bimodal and Bidimensional tasks = 320 trials. Total = 1120 trials.

At the end of both experiments (Direct and Indirect tasks), explicit measures of the association between bubbles size and pouring sounds pitch were collected. The participants were asked to indicate which bubbles size and which pouring sounds pitch they generally associate to the consumption of fresh sparkling beverages on two 7-point Likert scales ranging from "Very small bubbles" to "Very big bubbles" and from "Very low-pitched sound" to "Very high-pitched sound". The participants were also asked to complete a ranking task with 6 different pouring sounds pitch (576 Hz; 677 Hz; 886 Hz; 960 Hz; 1086 Hz; 1187 Hz) that they had to classify from 'Not fresh at all' to 'Very fresh'.

2.4. Data analysis

Six participants (2 males, 4 females) appeared as outliers in the data distribution of the Indirect task due to more than 40% of unanswered trials (Mean 48.8%; Mean of unanswered trials for the remaining eighteen participants: 3.2%) and were removed from the subsequent analyses due to their weak performances that might reflect a poor understanding and/or involvement in the task. Data from one participant (male) of the Direct task were not analyzed due to a dysfunction of the software during the test period. In order to normalize the RTs distributions, the RTs data were log-transformed. The RTs from those trials in which participants responded correctly were submitted to mixed model analyses of variances (ANOVAs) with the within-participants factors of Correspondence (Pitch-Size, Pitch-Elevation, Size-Elevation, Pitch-Size-Elevation), Congruency (congruent, incongruent, and unimodal/unidimensional) for each correspondence, Attended Modality (the modality to which the participants were asked to focus for a given set of trials; visual vs. auditory), and the between-participant factor of Task (Direct vs. Indirect). The same analysis was performed considering the participants' mean error rates (%) as the dependent variable. Tukey post-hoc analyses were subsequently performed. Effects were considered significant when $p<.05$. Statistical analyses were performed using R 3.5.0.

3. Results

When considering the participants' RTs as the dependent variable, the mixed model ANOVA revealed significant main effects of Task ($F=9.2$, $p=0.004$), Correspondence ($F=16.5$, $p<.0001$), Pitch-Size Congruency (F=11.8, p<.0001), Size-Elevation Congruency (F=3.7, p=0.02), and Attended Modality (F=102, p<.0001). Significant interaction effects were also revealed between Task and Correspondence (F=25.3, p<.0001), and Task and Pitch-Size Congruency (F=3.7, p=0.03).

Overall, the participants' RTs were shorter in the Indirect task (m=417 ms ± 1.7 SEM) than in the Direct task (m=531 ms ± 2.6 SEM). A Tukey post-hoc analysis on Size-Elevation congruency revealed that the participants' RTs were shorter in unidimensional trials (m=516 ms ± 3.8 SEM) than in congruent bidimensional trials (m=542 ms ± 6.2 SEM). However, there were no significant differences in mean RTs between bidimensional congruent and incongruent trials (p=0.7).

Regarding the two-way interaction effect between Task and Pitch-Size Congruency, a Tukey post-hoc analysis revealed that the participants' RTs were shorter in congruent trials (m=537 ms ± 5.3 SEM) than in incongruent trials (m=551 ms ± 5.5 SEM), in the Direct task only (see Fig. 5), p=0.02. However, there were no significant differences in mean RTs between congruent and incongruent trials according to the Attended Modality (Visual vs Auditory) independently of the task (Direct vs Indirect). The mean percentage of error rates were not significantly different between conditions of Pitch-Size Congruency neither in the Direct task nor in the Indirect task.

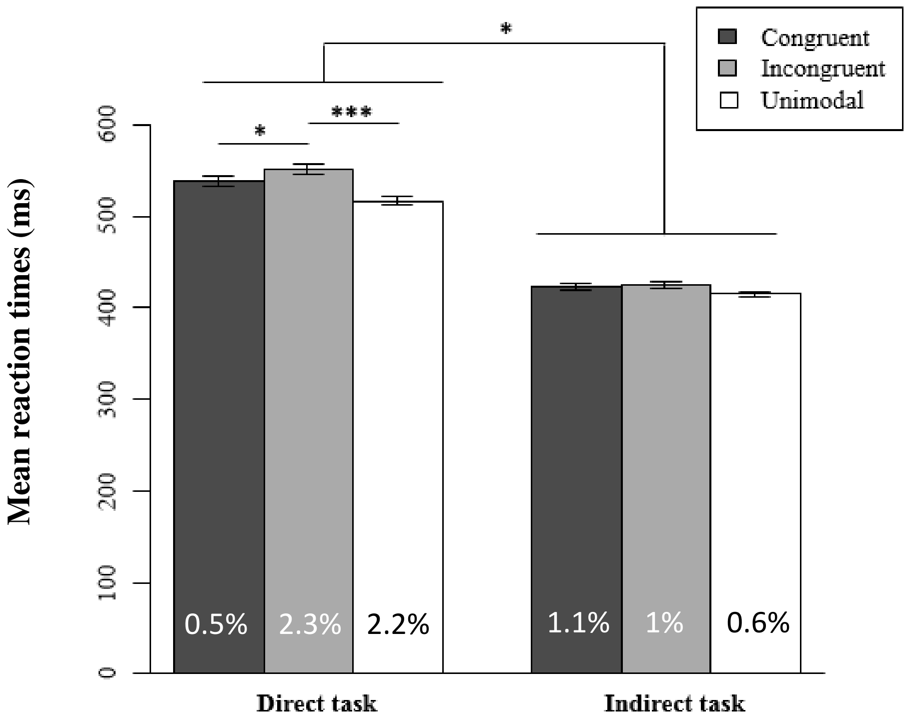


Fig. 5. Mean reaction times according to the task and the congruency of the interaction for the Pitch-Size correspondence. Direct task: N=23. Indirect task: N=18. The mean percentage of errors for each condition is shown at the foot of each column. Error bars represent the standard error of the mean across participants and the asterisks indicate significant statistical difference (*p<.05, ***p<.001).

Regarding the Pitch-Size-Elevation correspondence, the mixed model ANOVA revealed a significant effect of Congruency on the participants' RTs only in the Direct task (F=3, p=0.03). A Tukey post-hoc analysis revealed that the participants responded faster to bimodal stimuli that were congruent in Pitch and Size (m=527 ms ± 8.2 SEM) than to bimodal stimuli that were congruent in Pitch and both Size and Elevation (m=542 ms ± 8.8 SEM). The third hypothesis is thus rejected since a bidimensional congruent visual stimulus (e.g., small bubbles and high elevation in space) jointly presented with a congruent auditory stimulus (i.e., high pitch) did not induce an additive facilitation effect in the participants' performances.

In speeded classification tasks, such as in the two experiments reported here, there is empirical evidence of correspondence effects when there is both a facilitation (between congruent and either unimodal or incongruent conditions) and an interference (between incongruent and unimodal conditions) in the participants' RTs. When there is no evidence of intra- or crossmodal correspondence effects, the greater the mean interference value, the more difficult it is to attend selectively to the relevant dimension (Ben-Artzi & Marks, 1995). To be noted that the interference reported here (see Table 1) differs from the Garner interference (Garner, 1974, 1976) because in past experiments on Garner interference, researchers typically used as baseline a neutral stimulus on the irrelevant dimension rather than the absence of any irrelevant stimulus. Similar to Evans & Treisman (2010), the purpose of this absence of an irrelevant stimulus in baseline in our experiments was to avoid any crossmodal interaction.

The results reported in the Table 1 below show that the Pitch-Elevation and the Size-Elevation correspondences were not revealed neither in the Direct task nor in the Indirect task. The second hypothesis is thus not verified.

Table 1. Mean reaction times differences (ms) between bimodal congruent, bimodal incongruent, and unimodal stimuli.

Facilitation is indicated by negative differences between congruent and unimodal conditions and positive differences between incongruent and congruent conditions. Interference is indicated by positive difference between incongruent and unimodal conditions. For Size-Elevation: congruent and incongruent correspond to bidimensional stimuli (variation in bubbles size and spatial elevation) and unimodal to unidimensional stimuli (i.e., variation in spatial elevation only). The asterisks indicate significant statistical difference between the two means RTs in each column (*p<.05, ***p<.001).

	Direct task			**Indirect task**		
	Congruent minus unimodal	**Incongruent minus unimodal**	**Incongruent minus congruent**	**Congruent minus unimodal**	**Incongruent minus unimodal**	**Incongruent minus congruent**
Pitch-Size						
Auditory	-79	-64.6	14.4	22.8	27.8	5
Visual	67.2	79.4	12.2	-13.9	-14.9	-1
Mean	**-5.9**	**7.4*****	**13.3***	4.45	6.45	2
Pitch-Elevation						
Auditory	-66.4	-74.4	-8	19.4	18.9	-0.5
Visual	57.3	44.6	-12.7	-11.8	-25.3	-13.5
Mean	-4.55	-14.9	-10.35	3.8	-3.2	-7
Size-Elevation						
Mean	26.6*	21.9	-4.7	2.7	11.1	8.4

Similarly to results of previous research (e.g., Ratcliff, Spieler, & McKoon, 2000; Roque et al., submitted), a Spearman correlation between the participants' age and the participants' RTs revealed that the more the participants were old, the more they performed slower independently of the task and the correspondence (rho=0.24, p<.0001). Since this pattern was observed in all conditions of the two experiments reported here, it is unlikely that this age effect prevented all correspondence effects to occur.

Finally, regarding the analysis of the explicit measures collected, it appeared that the more the participants associated the consumption of fresh sparkling beverages with small bubbles, the more they also associated it with high-pitched pouring sounds (Spearman correlation: rho=0.21, p<.0001). The data of 39 participants were analyzed for the freshness ranking task on pouring sounds pitch and no significant effect of the rank of the sounds was obtained. However, it can be noted that the two lowest sounds' pitch were ranked as not fresh by more than 38% of the participants. These results are in line with those obtained by Roque and colleagues (submitted) and confirm that bubbles size and pouring sounds pitch may have an influence on the perceived freshness in beverages, at least when the participants' attention is directed toward those perceptual features.

4. Discussion

The two experiments reported aimed at investigating whether complex and ecological stimuli, namely pictures of beverages varying for bubbles size and pouring sounds pitch, would reveal correspondence effects between Pitch and Size, Pitch and Elevation, and Size and Elevation. The transitivity hypothesis between these three correspondences was also tested to determine whether the existence of two of the targeted correspondence would imply the existence of the last. In case the transitivity hypothesis would be verified, we hypothesized that a bidimensional congruent visual stimulus (e.g., small bubbles and high elevation in space) jointly presented with a congruent auditory stimulus (i.e., high pitch) will induce a facilitation effect in the participants' performances. Finally, the two experiments differed in the instructions that were provided to the participants: in the Direct task, the participants responded to the same features on which the correspondences were tested (i.e., bubbles size, pouring sounds pitch, and spatial elevation), whereas in the Indirect task, the participants responded to different features from those with the hypothesized correspondences (i.e., lateralization of the auditory and visual stimuli). To do so, a speeded classification task was adapted from Evans & Treisman (2010) in order to conclude on the level (perceptual vs. higher order cognitive level) at which the targeted correspondences might occur.

The results revealed that the participants' RTs were shorter in the Indirect task than in the Direct task, independently of the tested correspondence. It is possible that the duration of the Indirect task (around 1h), together with the repetitive characteristic of the task, led the participants to respond faster in the Indirect task in order to shorten the total duration of the experiment. Nevertheless, there was no evidence of a speed-accuracy trade-off: a significant congruency effect (shorter RTs for bimodal congruent than incongruent trials) was always associated with no statistically significant difference between the mean error rates of congruent and incongruent trials.

Only Pitch-Size correspondence effects were partially found in the Experiment 1 reported here, using a Direct task. In fact, the existence of a correspondence is generally assumed when there is shorter RTs for both visual and auditory stimuli (e.g., Parise & Spence, 2012). Even though further investigation is needed, this result provides a first evidence that Pitch-Size correspondence effects would occur only when the participants' attention is directed toward the same features on which the correspondence is tested (i.e., bubbles size and pouring sounds pitch). In the Direct task, the visual and auditory stimuli that the participants had to discriminate were presented in the task's instructions. It is thus possible that during the processing of these stimuli along the task, the participants' cognitive system formed higher order associations between the target stimuli and the corresponding category to which they might relate (e.g., freshness perception in beverages, or positively correlated psychophysiological concept such as thirst-quenching, see Roque et al., 2018a,b). As a consequence, the Pitch-Size correspondence effects reported in the case of beverages would be not purely based on bottom-up processing.

The fact that Pitch-Size correspondence effects are only revealed in the Direct task is also consistent with the results obtained by Roque and colleagues (submitted). The authors reported the existence of Pitch-Size correspondence effects between bubbles size and pouring sounds pitch using a variant of the Implicit Association Test (IAT) and a Go/No-go Association Task (GNAT). In both tasks, the participants' attention was always directed toward the same features on which the correspondence was tested. It is possible that the different design used here (i.e., speeded classification paradigm), in addition to the complexity of the target stimuli, was not appropriate in order to reveal complete Pitch-Size correspondence effects experimentally for both modality separately. In fact, the participants might have had difficulties to attend selectively to only one of the modality while ignoring the other.

We also hypothesized that Pitch-Elevation correspondence effects would occur between the complex stimuli used here given that the same stimuli were already shown to be involved in Pitch-Size correspondence effects (Roque et al., submitted). Even though Pitch-Elevation correspondence effects have been widely reported in the literature (e.g., Chiou & Rich, 2012), our experiments failed to replicate these effects. It is possible that the stimuli and/or the design used require some adjustments (e.g., carbonation intensity for the visual stimuli, height of the spatial elevation). Moreover, the fact that the audiovisual stimuli used in our experiments directly relate to the domain of beverages might have trigger specific sensory expectations for the participants. For instance, the pouring sounds pitch of a beverage may elicit sensory expectations toward the temperature and the perceived freshness in mouth of the beverage, as well as associations with different types of drinks (see Roque et al., 2018b; Spence & Wang, 2015). These sensory expectations might be well modulated by the level of familiarity of each participant with the stimuli used. We hypothesize that the feeling of familiarity with the stimuli could thus also modulate the expected crossmodal correspondence effects. Given the fact that some crossmodal correspondences depend on both perceptual (e.g., saliency) and higher order cognitive levels (e.g., linguistic), Deroy & Spence (2013) pointed out that transitivity should not be expected in every case.
Chiou & Rich (2012) used a modified version of Posner's attention-cuing paradigm (Posner, 1980), and their results showed that the process of mapping pitch to location would occur only after participants recognize whether the sound represents a high or low tone. They suggested that post-sensory processing (e.g., semantic labeling or polarity mapping) would be necessary for correspondence effects between auditory pitch and spatial elevation to occur. Other authors have also argued that many of audiovisual crossmodal correspondences would be influenced by cognitive processes rather than purely the result of perceptual encoding (Chen & Spence, 2017; Parise, 2016). This hypothesis could also partly explain why we obtained evidence, at least partial, of Pitch-Size correspondence effects in the Direct task only since the participants' attention was manipulated toward the perceptual features of interest in this task.

Finally, the null effect of the Size-Elevation correspondence is consistent with the results obtained by Evans and Treisman (2010), and this result brings an additional evidence that the putative intuitive relation that may exist between size and elevation is actually not straightforward and require further research. Once again, we hypothesize that the complexity and more ecological character of the stimuli used here might require adjustments and supplementary testing. However, Parise (2016) has justly warned that while the use of complex stimuli might be more ecological, it is likely that the multidimensionality of such stimuli will increase the difficulty for researchers to identify what are the relevant stimulus dimensions that drive the corresponding crossmodal correspondences.

Regarding the characteristics of the participants that took part in the experiments reported here, it also has to be noted that they were all French residents, and that further experiments would be necessary in order to more fully explore cultural differences in these particular intra- and crossmodal correspondences. In fact, the Pitch-Elevation correspondence has been generally considered as semantically-mediated since common terms are used to describe both pitch and elevation, namely high and low. However, it is worth highlighting that this dichotomy is not at stake in French common language in which the verbal labels used to describe pitch and elevation are different (i.e., “aigu” and “grave” for pitch, “haut” and “bas” for elevation). The fact that Pitch-Elevation correspondence effects did not occur in the two experiments reported here could thus be partly explained by this absence of semantic mediation. Against this hypothesis, several cross-cultural (e.g., Parkinson, Kohler, Sievers, & Wheatley, 2012) and developmental (e.g., Walker, Bremner, Mason, Spring, Mattock, Slater, & Johnson, 2010) works have shown that the Pitch–Elevation correspondence was not purely semantic in nature as infants and individuals, from cultures who use other terms to describe pitch, still show effects of pitch directionality on elevation judgments. Further cross-cultural studies would enable to confirm whether the Pitch-Elevation correspondence is culturally-mediated, according to the stimulus context.

5. Conclusion

The results of the experiments reported here provide the first empirical evidence that Pitch-Size correspondence effects in beverages is more likely to occur when the participants’ attention is directed toward the same features on which the correspondence is tested (i.e., bubbles size and pouring sounds pitch). However, it would seem that no transitivity exists between bubbles size, pouring sounds pitch, and spatial elevation. Further research is needed in order to evaluate the appropriateness of both the design and stimuli used.

In terms of applications, even if the research works reported here require further investigation, the results obtained for the Pitch-Size correspondence, both implicitly (in the Direct task) and explicitly, suggest that if companies aim at increasing beverages’ attractiveness and perceived freshness of their products, they would better have to direct the consumers’ attention toward the features of interest. This could be done, for instance, by using labels such as “thin bubbles” together with an increase in saliency of the perceptual features associated with bubbles size and pouring sounds pitch (e.g., in ads, or during multisensory tasting events).

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GENERAL DISCUSSION

Innovation in beverages has reached an important market that pushes companies to continuously improve their products' formulation and their marketing campaigns. Increasing beverages' attractiveness and insuring the most pleasurable experience that will fit the consumers' expectations are of principal importance. Among these expectations, freshness represents one of the current strong consumers' demands. Despite the efforts of companies, many innovations fail due to a lack of understanding of consumers' expectations and their modulation (Dijksterhuis, 2016a). In fact, food and beverages' expectations and their underlying cognitive mechanisms are much more complex than just what the consumers explicitly declare about their expectations for a given product.

Meanwhile, over the past years, research in the food and beverage domain has provided evidence on the multisensory integration processes that characterize our everyday experience as consumers. However, the complexity of the cognitive mechanisms involved in multisensory perception, in particular during the actual consumption of a product, has conducted to inconsistencies and ongoing debates in the literature. For instance, it is likely that the respective contributions of the various sensory inputs, the subjective location of the final percept, and whether these mechanisms are more driven by bottom-up or top-down modulating factors will vary from one multisensory representation associated to food and beverages (e.g., fruitiness) to another (e.g., freshness).

Nevertheless, the development of new or at least improved experimental paradigms has enabled researchers to identify specific cognitive mechanisms, such as crossmodal correspondences, allowing the collection of implicit measures of behavior (e.g., reaction times, error rates). In particular, the influence of visual and auditory cues and their interaction effects have been extensively studied in cognitive science. However, these investigations remain fairly minor in the food and beverage domain whereas they may trigger sensory expectations that will in turn influence subsequent experiences of a particular food or beverage. In particular, it is still unknown whether more complex and ecological audiovisual stimuli would reveal intra- and crossmodal correspondence effects, which have been shown to induce measurable perceptual effects (Spence, 2011). Multisensory information processing in a particular context, such as beverages, and how crossmodal interactions may modulate perceiver's performances require new evidence. Moreover, the allocation of participants' attention may help to determine the level (perceptual vs. higher order cognitive level) at which the targeted mechanisms might occur. Consequently, these investigations could benefit to a better understanding of consumers' expectations and their modulation.

In this context, the five main objectives of the present thesis were:

(i) To explore the influence of congruent and incongruent audiovisual interactions, with perceptual features cuing temperature, carbonation, and color of the liquid on the categorization of freshness in beverages.

(ii) To test the existence of audiovisual crossmodal correspondence effects between specific cues related to carbonation, namely between bubbles size and pouring sounds pitch.

(iii) To disentangle the relative effects of the two associations involved in the Pitch-Size correspondence, and see whether these effects are robust enough to variations of the stimulus context (i.e., color of the liquid and width of the glass).

(iv) To test the existence of the intra- and crossmodal correspondences that may exist between bubbles size, pouring sounds pitch, and spatial elevation, and determine whether a transitivity relationship exists.

(v) To test the robustness of the tested correspondences i) using more complex and ecological stimuli than those used in the literature, ii) replicating their effects with different experimental paradigms.

The general discussion summarizes the main findings that have been obtained for each experiment conducted during this PhD project and sheds light on the theoretical and empirical advances reported. The limits of the present research work are also presented and discussed. Finally, three general perspectives are presented as promising research avenues that could extend the findings of the present thesis.

1. Freshness expectations, crossmodal congruency, and consequences on participants' attention and performances

One of the first aim of the present PhD project was to identify specific audiovisual perceptual features associated to beverages that could induce crossmodal correspondence effects and potentially increase perceived freshness, upstream of the consumption phase. To do so, a first set of experiments (chapter 4) has been conducted to investigate the crossmodal interaction effects of bimodal 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 (manipulated between-participants) on freshness ratings and freshness categorization in beverages.

The online experiment on freshness ratings, conducted with American participants, aimed at investigating the potential influence of the targeted stimuli on the perception of freshness.
The results have shown that the increase in freshness ratings was mainly driven by the sight of ice cubes in the drink, followed by the sound and sight of carbonation. Moreover, this effect was additive when these two perceptual features were presented together. However, the sound of ice cubes unexpectedly decreased the participants' freshness ratings. Finally, the color of the beverage had no effect on the freshness ratings.

Even if the participants were explicitly asked to wear headphones and to fix the volume of their computer at a clear audible level, the online setting of this experiment did not allow us to control for a potential variability of the quality of the sound heard or the quietness of the test room. Nonetheless, given that both the sight of ice cubes and the congruent association between visual and auditory carbonation did increase the freshness ratings, it is possible that a positive effect of the sound of ice cubes on the freshness ratings would arise by varying the pitch of the pouring sound and/or the number of ice cubes that could be heard. Further research toward the influence of the sound of ice cubes on the perception of freshness in beverages with participants from the same cultural area is thus needed.
Regarding the null effect of color on freshness ratings, several explanations have been formulated in the limitation section of the experimental paper presented in chapter 4. Among them, it is likely that a color effect did not occur due to the manipulation of this variable as a between-participants factor, which did not allow visual comparisons of the different colored beverages in our study.

This first online experiment laid the groundwork for a second experiment to investigate the influence of the same bimodal stimuli, but this time using a freshness categorization task for which more objective implicit measures (i.e., RTs) of behavior were analyzed. This second experiment was conducted in a laboratory setting with French participants. Given that the existence of crossmodal correspondences is generally inferred from implicit measures using variants of speeded categorization paradigms (see chapter 2), this second experiment aimed at showing how the relation of congruency between the different perceptual features could influence the participants' performances (i.e., RTs). We expected 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 a tendency for the participants to categorize these congruent stimuli as fresh. The main findings are summarized below and introduce our further research hypotheses on audiovisual crossmodal correspondences in the case of beverages.

Overall, the participants' RTs were significantly shorter for congruent bimodal stimuli that displayed the perceptual features of interest (e.g., both the sight and sound of ice cubes) than for incongruent pairs of auditory and visual stimuli. Among this main effect of congruency, our results showed that the modulation of the participants' RTs might also depend on both the type and number of perceptual features involved in the audiovisual interaction: When the participants categorized the beverages as fresh, congruent audiovisual interactions that displayed both visual and auditory ice cubes induced an additive effect in decreasing the participants' RTs. However, this additive effect was no longer obtained when there was visible carbonation in the drink. Congruent bimodal interactions also resulted in the participants categorizing more 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. An additive effect of the targeted audiovisual perceptual features was also observed on the inclination for participants to categorize the beverages as fresh (vice versa for not fresh in the absence of visual and auditory ice cubes and carbonation).

As evoked in the discussion section of the experimental paper presented in chapter 4, it is possible that the complexity of our stimuli might have influenced the participants' attention and consequently pushed them to focus more on the foam on the surface of the liquid rather than on the bubbles present within the liquid itself. Moreover, the relevance of the different stimuli to the targeted category of freshness in beverages to which they might belong potentially varied in the experiment from one stimulus to another. In fact, even if the definition of freshness was constrained by the task's instructions in our experiment, it is possible that this latter varied (multisensory experience versus time delay) when the participants categorized the stimuli. In particular, when the participants answered to a beverage that contained visual ice cubes (or visual carbonation) and subsequently answered to visual stimuli with the same color but for which visual ice cubes (or bubbles) were absent, it is possible that they interpreted this sequence as ice cubes' melting (or bubbles vanishing). In this case, the meaning of freshness could have been associated to the time delay between the preparation and the consumption of the drink, and it is possible that the subsequent participants' expectations might have been affected.

Consequently, this potential variability might also have an influence on the participants' attention and performances. Seriès and Seitz (2013) reported that when the available sensory inputs are ambiguous or when there are multiple competing interpretations for the sensory input, expectations can alter the content of perception and induce changes in perceptual appearance, at least of visual stimuli. For instance, the well-known Rabbit-Duck illusion (Jastrow, 1899) illustrates how an ambiguous and bistable percept can be influenced by the spatial context in which it is placed. Seriès and Seitz refer to the concept of contextual expectations explaining that in the case of the Rabbit-Duck illusion, observer would be more likely to perceive a duck than a rabbit if a picture of a flock of ducks is also presented.

This alteration of the content of perception may also relate to the notion of wishful seeing (e.g., Dunning & Balcetis, 2013; see also Mayor Poupis, 2018 on wishful hearing) that has been shown to emerge when people form representations of the dimensions of the natural environment. Balcetis and Dunning (2009) have shown that perceivers' desires could serve as internal psychological states that will shape perception of the physical environment. Recent evidence has suggested that people's desires influence their estimates of size, length, and slope in the environment. For instance, the desirability of an object can influence perceptual estimates involving it. Van Koningsbruggen, Stroebe, and Aarts (2011) have shown that a delicious chocolate muffin appeared larger to dieters than to non-dieters after both groups observed pictures of tempting desserts. In our freshness categorization task, even though the initial level of thirst of the participants was controlled before taking part in the experiment, it is possible that some perceptual estimates of our stimuli were influenced by the individual internal states of the participants. We may hypothesize that, for instance, specific diets on sugar intake could lead some participants to perceive as more salient perceptual features of our stimuli (e.g., red color of the liquid that is generally automatically processed as a cue for higher energy density, see Foroni, Pergola, & Rumiati, 2016).

It is interesting to note that people's internal states may also be influenced by individual preferences or motivation (Dunning & Balcetis, 2013). It has been shown that, for instance, the recognition of stimuli can be enhanced if one individual is motivated to see them. This phenomenon may be observed at early stages of visual processing and it provides evidence that cognitive penetrability may occur relatively early while being influenced by higher-order cognitive factors (e.g., motivational influences). Pylyshyn (1999, p.343) have stated that "if a system is cognitively penetrable then the function it computes is sensitive, in a semantically coherent way, to the organism's goals and beliefs, that is, it can be altered in a way that bears some logical relation to what the person knows". For instance, Radel and Clement-Guillotin (2012) have shown that hungry participants more accurately recognized words that were related to food than words that were not, at short (33-millisecond) durations, as compared to participants who were well fed. However, further research is necessary to examine how far and how much perceptual processes are influenced by motivational influences or preferences.

The relative contributions that are attributed to different sensory inputs during a multisensory experience, consciously or not, might also be explained in terms of Bayesian statistics principles (Ernst & Banks, 2002; Ernst & Bülthoff, 2004; Körding, Beierholm, Ma, Quartz, Tenenbaum, & Shams, 2007) which are based on the notion that each sensory modality by itself provides the central nervous system with imperfect and variable sensory inputs. According to Bayesian inference principles, the imperfect estimate obtained from one sensory input can be improved by taking into account the probabilities of signals from another sensory modality. It is thus likely that the brain will often minimize the uncertainty of imperfect and noisy sensory inputs by combining probabilities of multiple sensory signals to refine sensory estimates. In these optimal estimates, prior experiences are also taken into account and the nervous system gives more weight to the less variable estimate. In ambiguous or incongruent conditions, the sensory modality that affords the most precise estimate at that moment will probably contribute more to the final percept than the other sensory modalities do.

In addition, Piqueras-Fiszman and Spence (2015) have reported that attention may play a role even before the stimuli are interpreted based on our previous experiences and before expectations are shaped. Thus, expectations likely depend on the processing of a particular stimulus. The latter authors refer to the notion of selective attention which is the mechanism by which our brain prioritizes its limited neural resources toward the processing of certain more relevant information over other putatively less-important information. It has also been shown that those stimuli that we attend to may also be perceived slightly earlier in time relative to other unattended, or less well attended, stimuli (Spence & Parise, 2010; von Békésy, 1964).

Beyond the Bayesian approach, it has for long been shown that some sensory modalities may dominate over others. In particular, this is the case for the visual modality that has been shown to overcome many of the other sensory modalities in different type of tasks. This visual dominance was discovered by Colavita (1974). In speeded discrimination tasks, participants were asked to press a designated button when they detected a visual stimulus (flash), another button for an auditory stimulus (sound), and both buttons (or a third button) when both stimuli were presented together. In some of the bi-sensory trials participants failed and responded by pressing only one of the buttons as if only a single stimulus was presented. Remarkably, however, these erroneous responses were significantly biased towards the visual sensory modality, i.e., in the bi-sensory trials participants pressed only the visual button more often than they pressed only the auditory button (Colavita, 1974; Colavita, Tomko, & Weisberg, 1976). Interestingly, it has been shown that the Colavita effect persisted despite matching the subjective intensity of the two stimuli, or doubling the subjective intensity of the tone relative to that of the light (Colavita 1974). It has also been shown that the visual dominance persisted irrespective of the semantic congruency between the auditory and the visual stimuli in bimodal trials (Koppen, Alsius, & Spence, 2008).

In our experiment, 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 could thus partly explain that the participants responded faster in categorizing beverages that contained ice cubes as fresh. However, further research is needed to disentangle the specificity of this effect toward freshness since congruent stimuli generally facilitate participants' performance independently of the task.

Even though the results obtained in our first set of experiments (chapter 4) have some limitations, as described above, they provide the first empirical evidence that audiovisual crossmodal interaction effects can influence participants' performances in the categorization of freshness in beverages. Moreover, the congruency of the interactions in relation with the number of perceptual features involved has showed additive effects in

some conditions. The relative contributions of the visual and auditory perceptual features seem to be mediated both by bottom-up and top-down (e.g., attention) modulating factors that are involved in multisensory processing.

Following from these results, other types of paradigms were considered in order to determine whether some of the perceptual features previously identified as having a positive influence on freshness categorization, could induce crossmodal correspondence effects. The theoretical and methodological limits of the implicit paradigms used for this purpose are discussed in the next section.

2. Theoretical and methodological limits of the implicit paradigms used to measure intra- and crossmodal correspondence effects

2.1. The Implicit Association Test (IAT)

The Implicit Association Test used in the first experiment presented in chapter 5 aimed at investigating the existence of audiovisual crossmodal correspondence effects between specific cues related to carbonation in beverages, in particular between bubbles size and pouring sounds pitch.

Even though our two previous experiments (chapter 4) revealed a main influence of ice cubes on perceived freshness in beverages, we chose to test crossmodal correspondence effects with perceptual features of carbonated beverages for several reasons: i) one of the most reported audiovisual correspondence is the Pitch-Size correspondence that is generally tested with simple cues corresponding to circles and pure tones (e.g., Evans & Treisman, 2010), ii) since the Pitch-Size correspondence has never been reported with more complex and ecological stimuli, we had to select stimuli that appear to be good ecological counterparts of the above-mentioned circles and pitch, iii) several studies have reported the influence of visual and auditory carbonation on freshness perception and/or participants' performances (Guinard et al.,1998; McEwan & Colwill, 1996; Peyrot des Gachons, Avrillier, Gleason, Algarra, Zhang, Mura, …, & Breslin, 2016; Roque et al., 2018b).

Given that our IAT experiment was the first investigation of Pitch-Size correspondence effects in beverages and that we did not obtain any significant effect of the color of the liquid on freshness perception in our previous experiments (chapter 4, though manipulated between-participants), the visual stimuli used in our IAT experiment corresponded to pictures of a colorless carbonated soft drink. It was also a way to control for any potential effect of confounding variable.

The results of the IAT experiment revealed shorter RTs and higher accuracy in congruent blocks and confirmed the existence of the crossmodal correspondence effects between bubbles size and pouring sounds pitch in carbonated beverages.

Since its publication (Greenwald et al., 1998), the IAT has been extensively used in social psychology in order to test the existence of implicit attitudes towards categories (e.g., gender, race) and attributes (valenced words). The amount of data collected have enabled researchers to formulate hypotheses regarding the possible mechanisms of the IAT effects.
For instance, Fazio and Olson (2003) reported several possible mechanisms of the IAT effects that shed light on the potential limitations of this paradigm. One possible mechanism of the IAT effects is linked to the figure-ground asymmetry model that focuses on participants perceiving one response category as figure on the ground of the opposing response category (Rothermund & Wentura, 2001). The authors assume that participants simplify, either spontaneously or strategically, the congruent block in which the salient categories are matched onto one response key, by recoding both categorization tasks as figure-ground discriminations. Thus, all salient stimuli (i.e., figure) are assigned to one key and all non-salient stimuli (i.e., ground) to the other, so that the salient stimuli constitute the figure against the background of the less salient stimuli. Another possible mechanism suggested of the IAT effects is a task-set switching account for which respondents could simplify the task's instructions in congruent blocks (i.e., targeting the most evident association) by classifying the stimuli according to only one dimension (e.g., pleasant vs. unpleasant). This simplification of the task is no longer possible in incongruent blocks since the participants inevitably have to consider the two categories (e.g., flowers vs. insects) and the two groups of attributes (pleasant vs. unpleasant). Thus, the participants who adopt this simplification strategy in congruent blocks will have to inhibit it in incongruent blocks. This task-set switching account would induce an additional cognitive cost that may vary from one individual to another (Mierke & Klauer, 2001). These types of executive controls are independent of the association strength between the targeted concepts and could thus lead to misinterpretation of the IAT effects (Blaison, Chassard, Kop, & Gana, 2006).

Because the IAT effect is based on a comparison of performance in the two separate IAT blocks, the different possible mechanisms described above may have a direct impact on the IAT effects.

Teige-Mocigemba, Klauer and Sherman (2010) have suggested that the elimination of the IAT's block structure could prevent from a misinterpretation of the IAT effects, as it has been done in two paradigms called Single Block IAT (SB-IAT; Teige-Mocigemba, Klauer, & Rothermund, 2008) and Recoding Free IAT (IAT-RF; Rothermund, Teige-Mocigemba, Gast, & Wentura, 2009). The basic principle of both the SB-IAT and the IAT-RF is that the mapping of categories onto response keys may randomly change from trial to trial instead of blockwise. However, more research is still needed to evaluate the potential of both the SB-IAT and the IAT-RF.

In the crossmodal version of the IAT used in the experiment presented in chapter 5, the fact that only two visual and two auditory stimuli were used may question whether the participants would have the possibility to use learning strategies during the task that would explain their performances (i.e., shorter RTs and higher accuracy in congruent blocks). The fact that the Pitch-Size correspondence is likely based on the extraction of statistical regularities from the environment rules out the possibility that the participants' performances would have resulted only from task-induced memory processes, that could ease a particular stimulus–response assignments for one association (i.e., congruent) as opposed to the other (i.e., incongruent).

However, in social psychology, some criticisms have emerged suggesting that the IAT effects could also arise due to other factors than the relevant features themselves, such as the similarity between stimuli in terms of shared perceptual characteristics or saliency (e.g., De Houwer et al., 2009 for a review). Saliency has been defined as "the degree to which a stimulus pops out within a background of other stimuli" (p. 353). In the modified version of the IAT we used, we think that saliency does not appear as a limitation of the results because the fact that the congruent associations between bubbles size and pouring sounds pitch appeared as potentially more salient to the participants could be a consequence of the existence of the underlying statistical correspondence.

The results obtained in the IAT experiment reported in chapter 5 provide the first empirical evidence that more complex and ecological audiovisual stimuli may reveal IAT compatibility effects toward the well-established Pitch-Size correspondence.

The way such crossmodal correspondence effects may interact with the perception of freshness in beverages has been investigated in parallel with the IAT by including a semantic prime to the design. Results and limitations of this approach are presented in the sub-section below.

The semantic priming merged with the IAT

A semantic priming on freshness was also tested in the IAT experiment presented in chapter 5 in order to investigate whether IAT compatibility effects could be enhanced by a congruent semantic prime. In other words, the affiliation's level of the targeted audiovisual stimuli to the freshness category was implicitly tested in order to see whether it could induce any facilitation in the participants' performances. In our study, we expected that a congruent semantic prime (i.e., related to freshness as opposed to neutral) would shorten participants' RTs and increase their accuracy in congruent blocks, in particular for small bubbles and high-pitched pouring sound that likely more refer to freshness.

The semantic priming related to freshness that was merged with the IAT design did not significantly influence neither the participants' RTs nor the participants' mean error rates, independently of the targeted associations between the visual and auditory stimuli.

As already evoked in the discussion section of the experimental paper presented in chapter 5, the overlap between the prime-words and the target-stimuli is crucial to evaluate in order to potentially obtain semantic congruency effects. It is possible that in our experiment, this overlap was not strong enough with regard to the stimuli used. In fact, the carbonation intensity was fixed all along the experiment. We may thus hypothesize that another bubbles density would strengthen the relation of semantic congruency between the freshness prime and the target-stimuli (i.e., small bubbles and high-pitched pouring sound). However, the affiliation's level to the freshness category of the audiovisual stimuli related to carbonation still remain to be explored, for instance by manipulating the different perceptual features through a gradient of intensity.

On the priming itself, two types of priming may be distinguished: the perceptual and the conceptual priming which differ in the relation between primes and targets and the level of information processing. Perceptual priming focuses on how similar prime and target are whereas conceptual priming focuses on how related prime and target are. McNamara and Holbrook (2003) reported that conceptual priming focuses on meaning, while perceptual priming focuses on the form of the stimulus. Over the past years, semantic priming, which belong to conceptual priming, has been studied extensively because it is thought to provide insight into the structure of people's mental lexicon (e.g., see McNamara, 2005 for a review).

The relation of congruency that is generally investigated is very straightforward: for instance, it is a well-known finding that the presentation of a related word (e.g., cat) enhances processing of a subsequently presented target (e.g., picture of a cat) compared to when the preceding word is unrelated (e.g., car). Heyman, Van Rensbergen, Storms, Hutchison, and De Deyne (2015) have reported that priming effects arise as a result of automatic pre-activation processes and/or the use of strategies such as expectancy generation and semantic matching. As a consequence, automatic priming emerges when the presentation of a related prime (partially) activates the target's representation, thereby lowering its recognition threshold. Whether the relation that exists between freshness perception and the audiovisual sensory cues related to carbonation is sufficient to reveal semantic congruency effects require further investigation.

In terms of methodology, the null effect of the prime in our experiment (chapter 5) may also depend on the time of presentation of either the semantic prime, the target-stimuli, or both of them. In fact, the prime-words were presented for 250 ms directly followed by the presentation of the target stimulus to categorize that was displayed for 2 seconds. At this time of presentation, the prime-words were thus expected to be consciously perceived by the participants. In fact, research that conduct subliminal or unconscious semantic priming generally set the time presentation of the prime-words around 30 ms, to which are added a pre- and a post-mask (e.g., Ortells, Kiefer, Castillo, Megías, & Morillas, 2016).

As a first investigation of the potential impact of semantic priming in an IAT experiment, and given the fact that the overlap between the prime-words (i.e., freshness) and the target-stimuli (i.e., bubbles size and pouring sounds pitch) was not straightforward, a conscious semantic priming seemed to be more reasonable than an unconscious one. Moreover, different theories and models are still matter of debates both in the literature in marketing (e.g., Minton, Cornwell, & Kahle, 2016) and cognitive psychology (e.g., Kiefer, Liegel, Zovko, & Wentura, 2017) regarding the appropriate prime and target set sizes, the familiarity of both primes and stimuli, or else the influence of personal characteristics such as individuals' awareness, motivation, and capacity for evaluation.

The eligibility of the concept of freshness as an efficient prime per se may also be questioned since the freshness representational content is broad and heterogeneous among people (see Fenko et al., 2009; Zhang et al., 2016). As a consequence, this variability may potentially reduce the possibility to reveal semantic congruency effects when the word 'freshness' is used as a semantic prime.

In the food and beverage domain, Dijksterhuis (2016b) highlighted the complexity of "flavor priming" given that there are many different components of flavor that can presumably be primed, or that can themselves act as primes.

Part from the semantic congruency effects that may be observed using semantic priming paradigms and that could indirectly influence crossmodal correspondence effects, the relative effects of the two associations involved in the Pitch-Size correspondence identified in the IAT experiment remained to be investigated. This is what has been subsequently tested in a second experiment using a dedicated paradigm presented in the next section.

2.2. The Go/No-go Association Task (GNAT)

Following from the results obtained in the IAT experiment (chapter 5), a subsequent experiment was conducted in order to disentangle the relative effects of the two associations previously uncovered between bubbles size and pouring sounds pitch in carbonated beverages. The experimental design used (GNAT, see Nosek & Banaji, 2001) has been suggested as a good alternative to the IAT in order to restrain some of the limitations of the IAT above-mentioned in section 2.1 (e.g., the shift in response criteria due to an increase difficulty of response for the participants in incongruent blocks, see Blaison et al., 2006).

Given that the GNAT task is easier to perform for the participants than the IAT task, the color of the beverage as well as the width of the glass were manipulated in order to increase the difficulty of the task and get more chances to obtain finer discriminability performances (measured with the sensitivity d') in the participants' responses. These variations in the visual stimuli also enabled us to extend the results obtained in the IAT experiment (with colorless stimuli) and see whether the Pitch-Size correspondence effects previously identified were robust enough to variations of the stimulus context. Only two colors (yellow and brown; colorless as control) were tested. These two colors were chosen based on the consumer science literature on freshness perception in beverages (see Table 1, page 11), as well as on previous results obtained in the experiments presented in chapter 4 (see supplementary results on color typicality for sparkling beverages). No semantic priming relative to freshness was tested in the GNAT experiment given the above-mentioned limitations of using such complex concept as a prime, and the null effect of this latter in the previous IAT experiment.

The results of the GNAT experiment revealed shorter RTs and higher accuracy in congruent blocks. These results are in line with the results on RTs obtained in the IAT experiment and confirm the existence of the Pitch-Size correspondence effects between

bubbles size and pouring sounds pitch. The interactions of the color of the liquid and the width of the glass with congruency were not significant, meaning that the Pitch-Size correspondence effects observed seem to be robust enough to variations of these aspects of the stimulus context.
Regarding the analysis of the participants' sensitivity in their responses (d'), no significant effects of congruency, color of the liquid, and width of the glass appeared. On the basis of our results, it is not possible to conclude on the relative effects of the two associations involved in the Pitch-Size correspondence reported in the IAT and the GNAT experiments.

Despite our careful consideration for designing a GNAT experiment that would be difficult enough to reveal differences in sensitivity (d'), the participants' mean error rates were overall less than 4%. Thus, we hypothesized that the disentanglement of the relative effects of the two associations involved in the Pitch-Size correspondence was not possible due to i) an equal strength of the two associations according to the conditions of our GNAT experiment (e.g., stimuli used), ii) the fact that the task was too easy to perform for the participants to reveal any differences in sensitivity (d'), or iii) the combination of both of these parameters.
Similarly to the IAT experiment, the carbonation intensity was kept constant all along the GNAT experiment. It is possible that this fixed bubbles density, together with variations in the color of the liquid created perceptual mismatch between the expected versus the actual attributes of our stimuli during the task. For instance, if one individual expects brown carbonated drinks to have a high bubbles density, then the discrepancy with the actual bubbles density of our stimuli might interfere with the relation of congruency between the visual stimuli and the auditory stimuli. It could be interesting to further investigate the extent to which a disconfirmation of expectations relative to one perceptual feature in one sensory modality may interfere with the congruency of a targeted crossmodal interaction, in a particular task.

Since its publication, the reliability of the GNAT (at least its original version used in social psychology to study implicit attitudes) has been discussed, and some researchers have provided methodological advices as well as statistical approaches for estimating the reliability of a particular GNAT. For instance, Nosek and Banaji (2001) have suggested that the reliability of a GNAT could be improved by increasing the number of trials in order to obtain more data points for the calculation of sensitivity (based on the recommendations of Williams & Kaufmann (2012), the number of trials in our GNAT experiment was fixed to 72 trials in critical combined blocks). Nosek and Banaji (2001) also stated that using a variable response deadline, instead of the fixed deadlines in GNAT studies, could eliminate irrelevant variation due to individual differences in ability to discriminate signal from noise irrespective of the category pairings. Since no empirical evidence have shown that using variable response deadlines could significantly reduce irrelevant variations in participants' performances and improve the calculation of sensitivity, and in order to avoid fatigue due to the duration of the experiment, response deadlines were kept constant in our GNAT experiment. Williams and Kaufmann (2012) reported that the timeout which is generally used in GNAT experiments is less than 1 second in order to limit the influence of conscious processing. Thus, in order to increase the difficulty of the task, the time presentations of the stimuli (i.e., 2 sec timeout in our experiment) could be shortened. However, we kept the time presentation of our stimuli to 2 sec due to their complexity and because this same time-out enabled us to show Pitch-Size correspondence effects in the IAT experiment.

In regard to the reliability of a GNAT experiment, Williams and Kaufmann (2012) suggested that the method of test-retest would not be very appropriate for estimating the reliability of GNAT results since implicit measures are prone to substantial practice effects because of the novel nature of the task, rapid learning of the response format, stimuli sets, and priming effects. A repeated GNAT administration is, thus, not properly an independent trial. The authors suggested that one way of avoiding practice effect contamination would be to develop parallel or alternate-forms of the test. The split-half method (i.e., cutting a test in half to create two tests and correlating these) has been suggested as a good alternative to the test-retest even though some limitations are still at hand.

Williams and Kauffman (2012) finally suggested a statistical approach based on Cronbach's alpha (i.e., a lower-bound estimate of reliability) that would be the most appropriate for the estimation of GNAT studies reliability. The authors argued that a GNAT could be more precisely designed by collecting first pilot data with 40–50 trial blocks, and then using the alpha-based procedure to estimate the appropriate block length for a chosen level of reliability. Though, they acknowledge that their approach has some limitations and that a model for the cognitive processes underlying GNAT responses is still needed. Nevertheless, given their observations and the flexibility of the GNAT, the authors concluded that similar levels of reliability would be readily achieved by any well-designed GNAT.

In our case, the GNAT experiment was adapted from the literature in social psychology in order to provide evidence of the relative effects of the two associations involved in the Pitch-Size correspondence in carbonated beverages. Based on the results described above and their limitations, it seems that further research is needed in order to estimate the reliability of such crossmodal GNAT-related paradigms.

Beyond the implicit associations that may be observed between perceptual features of two sensory modalities for a particular dimension (pitch and size), it is clear that in our everyday environment the various sensory inputs integrated may vary for several dimensions within a single modality (e.g., objects processed visually may vary for their size and their spatial elevation). Given the widespread network that may be formed from the inter-relations between various types of intra- and crossmodal correspondences, the notion of transitivity of correspondences was subsequently investigated using a different implicit paradigm for which main results and limitations are presented in the next section. In particular, we investigated whether the visual characteristic of spatial elevation could interfere with the Pitch-Size correspondence. Here again, this last experiment presented in chapter 6 enabled us to test the robustness of the crossmodal correspondence effects previously reported between bubbles size and pouring sounds pitch in carbonated beverages, in both the IAT and the GNAT experiments.

2.3. Speeded classification tasks and attentional allocation effects through task's instructions

The results obtained in the IAT and the GNAT experiments (chapter 5) provided empirical evidence of Pitch-Size correspondence effects between bubbles size and pouring sounds pitch in carbonated beverages. These effects were revealed with two different experimental designs and occurred even when variations of the stimulus context were applied (namely color of the liquid and width of the glass, at least for those tested), showing the robustness of the Pitch-Size correspondence in carbonated beverages.

Within the framework of audiovisual correspondences, Parise (2016) has recently suggested that the potential consequences of manipulating perceptual features that are involved in many crossmodal correspondences (e.g., pitch that may be part of a broader associative network) require further investigation. For instance, besides visual size, auditory pitch has been shown to match to other visual attributes such as the spatial elevation (or location) of visually-presented objects (Evans & Treisman, 2010; Patching & Quinlan, 2002). Participants generally classify visual stimuli as high and low more quickly when the visual stimulus is accompanied by a tone that is congruent rather than incongruent (e.g., high pitch with high spatial elevation rather than low).

Through the notion of transitivity of implication that has been recently outlined in the domain of correspondences (Walker & Walker, 2012; Walker, 2016), we hypothesized that a relation could exist between the correspondences of Pitch-Size, Pitch-Elevation, and Size-Elevation. However, it remained an open empirical question whether the perceptual features of bubbles size and pouring sounds pitch would reveal i) correspondence effects for the Pitch-Elevation and Size-Elevation correspondences, and ii) transitivity between these different correspondences. One of the objective of these last experiments (chapter 6) was also to conclude on the consequences, in terms of participants' performances (e.g., facilitation effect), of a confirmation of the transitivity hypothesis.

Through the adaptation of a speeded classification paradigm used by Evans and Treisman (2010), two distinct task's instructions were used in order to manipulate the allocation of the participants' attention toward either the same features on which the correspondences were tested or to different features from those with the hypothesized intra- or crossmodal correspondences. This manipulation enabled us to discuss the automaticity of such correspondences, a debate that is still ongoing in multisensory research (e.g., Getz & Kubovy, 2018).

Our results did not reveal any Pitch-Elevation nor Size-Elevation correspondence effects between bubbles size and pouring sounds pitch. The transitivity hypothesis was thus not confirmed.

Nevertheless, partial Pitch-Size correspondence effects were obtained, which was consistent with the results obtained in our previous experiments. Moreover, The manipulation of the participants' attention through task's instructions provided the first empirical evidence that the Pitch-Size correspondence effects in beverages are more likely to occur when the participants' attention is directed toward the same features on which the correspondence is tested (i.e., bubbles size and pouring sounds pitch). Even if further research is needed, this result suggest that the present Pitch-Size correspondence might be more driven by top-down influences such as attentional processes.

At which level the investigated correspondences might occur? What are the respective contributions of bottom-up and top-down influences? These questions are still debated in the literature in order to determine how each type of crossmodal correspondences affect performance; either in an automatic manner, or in a strategic manner, emerging as a function of the specific task demands and instructions imposed on the participant by the experimenter.

Spence and Deroy (2013, p.249) suggested that researchers should be more precise in defining what exactly automaticity entails. In fact, the authors highlighted that researchers have used different criteria for assessing the automaticity of a given cognitive process (“goal-independence, non-conscious, load-insensitivity, and speed”) and that different answers to the automaticity question may be revealed depending on the type of correspondence under consideration (e.g., statistical, structural, and semantic).

More recently, Getz and Kubovy (2018) investigated the degree of “bottom-upness” and “top-down-ness” present in a variety of audiovisual correspondences. In their speeded classification task, they manipulated both congruency and compatibility. The compatibility criterion referred to the instructions given on each bock of trials to the participants (they were told to select either the large shape/low pitch or small shape/high pitch associations in the compatible blocks, whereas they had to select the reverse associations in the incompatible blocks). Getz and Kubovy (2018) thus created measures of “bottom-up-ness” (BU) and “top-down-ness” (TD) based on the participants’ RTs to the various conditions. “Bottom-up-ness” referred to the ease with which participants completed the task on compatible as opposed to incompatible blocks. According to the authors, slower RTs on incompatible blocks are evidence that it is hard to pair together the incongruent dimensions and thus show a stronger bottom-up association. “Top-down-ness” referred to how well participants followed the instructions on compatible and incompatible blocks. Getz and Kubovy (2018, p.102) stated that “If participants can just as quickly and accurately pair the dimensions in the opposite, non-consensus direction, this is evidence of a stronger top-down, goal-directed influence of the instructions.”

With these two measures, Getz and Kubovy propose a first experimental approach that would enable researchers to quantify the degree of automaticity for different crossmodal correspondences. In their investigation of audiovisual correspondences, they defined automaticity “in terms of a bottom-up association between the auditory and visual modalities that exists without the necessity for intentional learning and outside the influence of attention or motivation.” (p. 102). Their results showed that top-down influence was present to varying degrees according to the tested correspondence. They found a stronger top-down influence on Pitch-Size but also small bottom-up effects for all the correspondences with the strongest bottom-up effect on Pitch-Elevation. These results cannot be really compared to the results we obtained in the experiment reported in chapter 6 since the experimental paradigms and the stimuli are different. Moreover, it seems that Getz and Kubovy (2018) took mainly into account the goal-independence criterion in their measures of the degree of automaticity of the tested correspondences, which likely simplified the complexity of the cognitive mechanisms at stake. Nevertheless, their results are in line with our hypothesis that the Pitch-Size correspondence might be more driven by top-down influences (e.g., attention). In particular in our case with the use of more complex and ecological stimuli in the domain of beverages for which we hypothesized that they could trigger specific sensory expectations, in relation to the memory of the observer, and consequently induced a more top-down driven effect on the participants' performances.

Regarding the particular influence of attention, we already reported in our literature review presented in chapter 1 that two different modes of attention have been distinguished, namely the exogenous and the endogenous modes of attention. On the one hand, the exogenous mode of attention refers to an attentional processing that occurs in a bottom–up manner, for instance when a salient perceptual feature pops-out from its background. In this case, the participants' attention is directed toward it even though she/he was not planning to focus on it. On the other hand, attentional processing operates in a top–down (endogenous) manner in which the observer may voluntarily control what is attended and what not, in order to extract relevant information relatively early from a rich and complex stimulus environment.

In our experiments reported in chapter 6, it is possible that the presentation of the stimuli that the participants had to classify in the instructions of the Direct task only, activated both endogenous and exogenous attentional processes toward the perceptual features of interest during the task. Consequently these attentional processes could be involved in the fact that the Pitch-Size correspondence effects occurred in the Direct task.

Using an attentional cuing paradigm, Chiou and Rich (2012) have shown that the pitch-induced cuing effect on spatial location was primarily mediated by cognitive processes taking place after initial sensory encoding, that would thus occurred at a relatively late stage of voluntary attention orienting. Their results also showed that the recognition of relative pitch height (rather than an intrinsic crossmodal scale between pitch and location) was critical. In other words, the process of mapping pitch to location would occur only after participants recognize whether the sound represents a high or low tone. This might be consistent with the results from past studies (e.g., Ben-Artzi and Marks, 1995) that have shown that increasing the size of the difference in the pitch of the tones improved performance on the auditory classification.

Even if the two sounds pitch used in the experiment reported in chapter 6 were well differentiated one from the other, we may wonder whether we would obtain different results by increasing the size of the differences between the two. Nonetheless, the use of one lower pitched sound and one higher pitched sound in the GNAT experiment (chapter 5) did not reveal any significant effect according to the congruency of the interaction between bubbles size and pouring sounds pitch.

In terms of measurement, Marks (2004) pointed out that response times are used more often than errors as a primary measure of performance because response times generally prove more sensitive. However, it is worth mentioning that using more traditional psychophysical paradigms that induce either no or less time constraint on responding, would also enable to quantify crossmodal correspondence effects within the framework of Signal Detection Theory. Based on the results obtained in our GNAT experiment (chapter 5), we argue that combining both measurements of RTs and accuracy may still provide more evidence of the underlying mechanisms at hand.

Beyond the knowledge on the multisensory processes and their interactions that we may grasp from implicit measures (see chapter 2), complementary information can also be provided by explicit measures, as it is generally done in the consumer science literature. In order to gain a more comprehensive understanding of the consumers' behavior in the case of complex perception such as freshness in beverages, it may be worth combining results from both implicit and explicit measures (Maison, Greenwald, & Bruin, 2004; Piqueras-Fiszman & Spence, 2011). The convergence and divergence that may emerge from both of these measures are discussed in the next section.

3. Relationships between implicit and explicit measures

In all of our experiments reported in chapters 4, 5, and 6, we collected implicit and explicit measures in order to see whether both measures would provide consistent, though not comparable, results with regard to the influence of audiovisual perceptual features linked to temperature and/or carbonation on perceived freshness in beverages.

In the first set of experiments in which we investigated the influence of audiovisual perceptual features cuing temperature, carbonation, and color on the categorization of freshness in beverages, the analysis of the participants' RTs and their inclination to categorize the stimuli as fresh showed that the perceptual features of interest did positively influence the categorization of freshness in beverages.
In parallel, the explicit measures collected were consistent with the implicit ones since the participants selected cold and sparkling as one of the most important characteristics that could be found in a fresh alcoholic beverage.

It is nonetheless important to note that the reference to alcoholic beverages was explicitly mentioned for the collection of explicit data regarding the general characteristics the participants associated to fresh beverages. It thus remains an open empirical question whether consistent results would have also been obtained for implicit measures if we mentioned to the participants in the task's instructions that the audiovisual stimuli corresponded to alcoholic beverages. It is likely that similar consistency between implicit and explicit measures would be obtained since the perceptual features linked to coldness and carbonation in beverages have already been reported in the literature both for soft drinks and alcoholic beverages (Guinard et al., 1998; McEwan & Colwill, 1996; Peyrot des Gachons et al., 2016).

The results obtained from the implicit and the explicit measures collected in the IAT and the GNAT experiments reported here are less evident to compare. On one side, the link between bubbles size, pouring sounds pitch, and the perception of freshness in beverages was explicitly mentioned to the participants for explicit measures. On the other side, the influence of a putative semantic mediation of the Pitch-Size correspondence was implicitly investigated only in the IAT experiment, using a semantic priming. Our results did not reveal any significant effect of the semantic prime on the participants' performances with regard to the perceptual features of interest. Nonetheless, the explicit measures collected in both experiments confirmed our hypotheses that the participants associate more small bubbles and high-pitched pouring sound to the consumption of fresh sparkling beverages.

In the field of social psychology in which the IAT (Greenwald et al., 1998) and the GNAT (Nosek & Banaji, 2001) paradigms have been developed to asses implicit attitudes of people toward target concepts and attributes, correlational analyses have been often conducted by researchers to see whether implicit and explicit measures were consistent. For implicit measures collected with a GNAT paradigm, Williams and Kaufmann (2012) though reported that little can be concluded about the meaning of correlations between implicit GNAT results and other measures since the GNAT reliability has not been systematically studied.

Correlational analysis between implicit and explicit measures could be performed by researchers in social psychology because the same concepts and attributes were used for both measures without any link to another concept or perception, as opposed to our case in which the explicit measures were on the same perceptual features but also explicitly introduced the link with the perception of freshness in beverages.

Several interpretations of a convergence or a divergence between the results obtained with implicit and explicit measures have since been proposed in the literature. If there is no implicit-explicit correlation, one of the possible interpretations is that the implicit measures have not been “contaminated” by the inherent biases that belong to the explicit measures (i.e., self-observation bias, limited introspective abilities). In this case, the dissociation between implicit and explicit measures can be interpreted as an index of discriminant validity. However, if there is an implicit-explicit correlation, researchers may interpret it as an index of convergent validity showing the reliability of the paradigm they used.

In one of the review dealing with the IAT and related tasks, Teige Mocigemba, Klauer, and Sherman (2010) reported that one debate is on whether low (implicit-explicit correlation of .24, see Hofmann, Gawronski, Gschwendner, Le, & Schmitt, 2005) to moderate (implicit-explicit correlation of .37, see Nosek, 2005) correlations between the IAT and explicit measures should be interpreted as indices of discriminant or convergent validity. Nevertheless, several models have been proposed during the last 20 years in order to explain different cases of convergence and divergence between implicit and explicit measures (see Blaison, Chassard, Kop, & Gana, 2006 for a review).

Two main classes of models can be distinguished as function of whether implicit and explicit measures are supposed to underlie the same construct or two different constructs. On the one hand, for instance, the model of dual attitudes (Wilson, Lindsley, & Schooler, 2000) distinguishes the implicit construct and the explicit construct on several criteria such as the fact that the implicit construct can be activated automatically whereas the explicit construct requires additional cognitive resources and motivations to be activated. On the other hand, the MODE model of attitude-behavior processes (Fazio & Towles-Schwen, 1999) suggests that there is only one construct that differ according to the processing of the information during its measure.

A dissociation between implicit and explicit measures could be explained by the fact that an implicit measure would be underlined by a spontaneous processing of the information whereas an explicit measure would be underlined by controlled processes (Blaison et al., 2006).
All these models have been elaborated and discussed with regard to the original version of the IAT supposed to capture implicit attitudes towards self-esteem, racial prejudice, or else stereotypes. Thus, it is unclear how far these models may be applied to crossmodal versions of the IAT in which this is the crossmodal correspondence between perceptual features of different sensory modalities that is investigated. For instance, it is unlikely that the self-observation bias of explicit measures, which correspond to what the participants accept to say on their own perception, attitudes, or behaviors, might entirely explain the dissociations between implicit and explicit measures in a crossmodal version of the IAT. In our case for example, the participants had no reasons to hide or to be ashamed of a particular behavior with regard to the bubbles size and the pouring sounds pitch they associate to the consumption of fresh sparkling beverages.

Correlational analyses between implicit and explicit measures and the computation of other indices showing the reliability of the paradigm used represent promising research avenues in the food and beverage domain. In fact, the combination of approaches would likely enable researchers to provide a more fully comprehensive model of the consumers' perception and behaviors, for instance in the case of complex multisensory perception such as freshness in beverages.

4. Perspectives

The present thesis offers an original approach for the investigation of crossmodal interactions and correspondences involving visual and auditory perceptual features in the domain of beverages. Consumers' freshness expectations, congruency of the crossmodal interactions, and consequences on the participants' attention and performances in different types of experimental paradigms have been addressed. The results reported provide interesting conclusions and pave the way for further empirical research dealing with multisensory perception in food and beverage cognition that could take into account other sensory inputs of interest (section 4.1), inter-individual variability linked to taste phenotypes (section 4.2), or else bringing new evidence through the use of neurocognitive approaches (section 4.3).

4.1. Examples of other audiovisual crossmodal correspondences that could positively influence freshness perception in beverages

The experiments reported in the present thesis have provided evidence of Pitch-Size correspondence effects between bubbles size and pouring sounds pitch in carbonated beverages. Given the variety of perceptual features that have been reported in the consumer science literature as increasing the expected or actual perceived freshness in beverages (see Table 1, page 11), it is likely that some of them might be involved in other audiovisual crossmodal correspondences.

On the basis of the literature, we provide some examples below of audiovisual crossmodal correspondences that could exist between other perceptual features than those investigated in the present thesis. We argue that if such correspondences could be revealed in the domain of beverages, it could extend the results reported here toward the perceptual and cognitive mechanisms that companies could use in order to increase the perceived freshness and attractiveness of their products, upstream of the consumption phase.

4.1.1. Pitch-Shape correspondence

Beyond size and spatial elevation, auditory pitch (of nonsense words) has also been shown to match to other visual attributes such as shape. Köhler (1929) was one of the first to demonstrate that people associate the nonsense word “Baluma” with rounded shapes and the word “Takete” with angular shapes. Ramachandran and Hubbard (2001) replicated Köhler’s results showing that around 95% of the population tend to map the name “Kiki” onto the figure on the left and “Bouba” onto the figure on the right (Figure 18). This has been called the Bouba/Kiki effect.

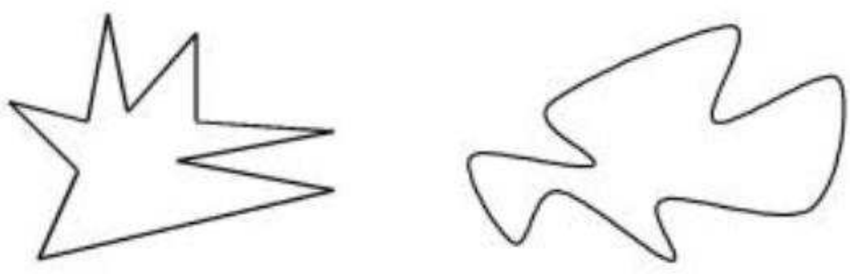

Figure 18: Visual shapes associated to Kiki on the left and Bouba on the right (retrieved from Ramachandran & Hubbard, 2001)

Ramachandran and Hubbard (2001) provided several hypotheses of the underlying mechanisms for the Bouba/Kiki effect such as the fact that the rounded and angular shapes of Bouba and Kiki could match with sound contour, motor lips, and tongue movements.

In a series of experiments designed to investigate shape and sound symbolism in a range of commercial fruit pulps/juices, Ngo, Velasco, Salgado, Boehm, O'Neill, and Spence (2013) recently showed that British and Colombian participants matched juices that were considered sweet and low in sourness with rounder shapes and speech sounds (i.e., Bouba), as well as lower-pitched sounds. However, the participants matched juices that were rated as tasting sour with angular shapes and sharper speech sounds (i.e., Kiki), as well as higher-pitched sounds. This experiment has some limitations since the corresponding crossmodal correspondences have been inferred from explicit measures using pencil-and-paper line scales that are known to be biased by limited introspective abilities of participants. Moreover, the type of sound (low-pitched versus high-pitched) that the participants had to match to the flavor of the fruit juices was not specify to the participants. It is possible that they interpreted it as the pouring sound of the corresponding beverage or as other sounds in general (e.g., music).

In the present thesis, we investigated the existence of audiovisual crossmodal correspondences using perceptual features of carbonated beverages, namely bubbles size and pouring sounds pitch. However, the results of our first set of experiments (chapter 4) have shown that the sight of ice cubes in a drink as well as the pouring sound of a beverage that contain ice cubes were two sensory inputs that positively influenced the participants' performances (i.e., RTs), and led them to categorize more the stimuli as being fresh.

From the literature on the Bouba/Kiki effect and the potential associations that have been shown with the pitch of the sounds in the domain of beverages (e.g., Ngo et al., 2013), we may hypothesize that crossmodal correspondence effects between the shape of ice cubes and the pouring sounds pitch of a beverage may exist. Since high-pitched sound and angular shapes have been associated to higher ratings of sourness in fruit juices, we may expect that a particular beverage containing angular ice cubes associated to a high-pitched pouring sound would likely increase the perceived freshness (see also Deroy & Valentin, 2011). To be noted that sourness is one of the basic tastes that generally increase the perceived freshness in beverages (see Table 1, page 11). However, in Ngo et al.'s study, the fruit juices that were rated as tasting sour were less liked by the participants. Thus, according to the level of sourness and the type of beverage, freshness expectations based on ice cubes' visual shapes and pouring sounds pitch may be disconfirmed after tasting. In order to efficiently manipulate such kinds of crossmodal correspondences, when the latter exist, food and beverage companies have to identify the particular type of products for which the audiovisual crossmodal correspondence effects will be congruent with the other (chemo)sensory attributes that come to play during tasting (see section 4.2.1) together with some relevant participants' characteristics (see section 4.2.2).

4.1.2. Pitch-Brightness correspondence

The audiovisual crossmodal correspondence between auditory pitch and visual brightness of simple stimuli has been reported many times in the literature (e.g., between sawtooth waveforms' sounds and visual rectangles; Marks, 1987, see also Spence, 2011). However, the Pitch-Brightness correspondence has never been investigated using more complex and ecological stimuli such as the ones used in our experiments, namely pictures of a beverage served in a glass and pouring sounds pitch.

Interestingly, Zellner and Durlach (2003) have shown that clear beverages were often rated as most refreshing because of the association between clarity and water. By extension, and according to the different aspects of color (e.g., hue, intensity), clarity of a beverage may also refer to limpidity and perceived brightness. Thus, it could be interesting to investigate whether Pitch-Brightness correspondence effects exist between pouring sounds pitch and different visual stimuli corresponding to beverages varying for color intensity/hue, or degree of transparency/turbidity.

Interestingly, there is currently an extensive market for natural fruit juices (Rajauria & Tiwari, 2018) that may have a turbid appearance due to the organic components of the fruits. Consequently, a divergence may emerge for consumers between these drinks composed of "fresh fruits" and their corresponding perceived freshness based solely on visual appearance. This dichotomy relates to the semantic ambiguity related to the term fresh evoked in the literature review presented in chapter 1, and it represents a real challenge both for researchers (crosslevel correspondences involving higher order level of processing such as linguistic or emotional) and companies in terms of product formulation and marketing strategies.

In parallel, Cao (2013) reported that turbidity corresponds to the cloudiness or haziness of a fluid caused by particles that are generally invisible to the naked eye. It has been shown that consumers often associate dark color (i.e., less transparent and potentially perceived as more cloudy) with stronger flavor intensity, higher alcohol content, and greater heaviness in beers (e.g., O'Brien, 2006). An intramodal correspondence may also exist between the brightness and the weight of objects (Walker, Francis, & Walker, 2010). Thus, the transitivity of correspondences investigated in the present thesis (chapter 6) could also be tested for the relations that may exist between pouring sounds pitch, visual brightness, and visual viscosity in the domain of beverages. In other words, do consumers associate a high-pitched pouring sound with both a clearer/more transparent beverage and a fluid texture (i.e., low viscosity)? Though, it would remain to disentangle whether consumers associate the heaviness of a particular drink to its post-ingestion effect or to the viscosity of the liquid.

Spence and Wang (2015) recently investigated whether people are able to discriminate different liquid viscosities based on their pouring sounds. The participants heard one of three pouring sounds, associated with water, water with 25 % sugar by weight added and water with 50 % sugar by weight added, and had to rate on two seven-point scales how “thick and sticky” the pouring sounds were. Their results showed that the participants were unable to discriminate any difference in viscosity based on sound alone. Spence and Wang hypothesized that discrimination performances of the liquids’ viscosity could have been better if the three sounds were displayed as within-participants factor instead of between. The authors also investigated whether people could hear any difference between the sounds of a low-alcohol white wine (Tesco’s Vinho Verde 2013, 9 % alcohol) and a high-alcohol red wine (Ridgy-Didge Shiraz 2012, 14.5 % alcohol) since liquids with a lower alcohol content are less viscous than liquids with a higher alcohol content. The experiment conducted online with 43 participants revealed that they did discriminate the viscosity of the two wines based on their pouring sounds pitch that might trigger expectations toward the viscosity of the liquids, actually due to their alcohol content.

Beyond the influence of audiovisual sensory cues and their interaction effects, it is clear that our perception of beverages (alcoholic or not) as well as our drinking behaviors are influenced by many other bottom-up and top-down factors. Even if the results reported in the present thesis provide new empirical evidence on the influence of audiovisual crossmodal interaction effects on perceived freshness in beverages and the existence of a Pitch-Size correspondence, the introduction and the impact of other sensory modalities that occur during the actual tasting step remain to be investigated.

4.2. Increasing the ecological validity of the experimental results

4.2.1. Trimodal interactions with taste, smell, and somatosensory system

What is the real impact of audiovisual interactions and crossmodal correspondence effects when the act of consumption comes to play?

As far as we are aware, no study has been conducted until now targeting this question as to whether the audiovisual interaction effects that may be observed upstream of the consumption phase, in terms of participants' performances, still hold during the consumption phase of a food or drink. It is clear that such an investigation is challenging since it would have to be conducted in controlled conditions using a rigorous experimental design that would deal with i) the physiological saturations associated to chemosensory and somatosensory systems, ii) the crossmodal interactions and correspondences that are embedded within the corresponding multisensory context.

Few studies have investigated the influence of trimodal interactions on participants' performances using different types of speeded classification paradigms. The majority of the studies identified in the literature have considered the interactions between taste, smell, and tactile attributes, using simple stimuli that do not directly apply to the domain of food and beverages. Nonetheless, these studies reported interesting results with regard to the multisensory integration processes that could also occur during a multisensory drinking experience.

For instance, Diederich and Colonius (2004) have shown that participants' RTs to trimodal stimulus combinations were shorter than to bimodal combinations. Thus, a trimodal facilitation effect was observed between visual flash, sinusoidal tones, and tactile vibrations. Another study from Hecht and Reiner (2009) has shown that the occurrence of Colavita's visual dominance (General discussion, section 1) was limited to bisensory combinations when a visual signal was synchronized with an auditory or a haptic signal, whereas in tri-sensory combinations of audio–visual–haptic signals there was no bias towards vision. Finally, Misselhorn, Daume, Engel, and Friese (2016) found that crossmodal congruency improved performance in a trimodal paradigm if both the attended modalities and the task-irrelevant distractor were congruent. They also showed that according to the attentional conditions of the experiment, crossmodal congruency had the strongest effects on visual–tactile pairs, intermediate effects for audio–visual pairs, and weakest effects for audio–tactile pairs. The results are discussed in terms of the statistical

regularities that our cognitive system may extract from the environment in relation to the different patterns of functional connectivity in multisensory neural networks. We hypothesize that similar research approach could be considered in the food and beverage domain in order to better understand the multisensory processes underlying complex experiences of consumers.
Nonetheless, several research works in the food and beverage domain have provided evidence of the influence of visual or auditory perceptual features on taste, smell, or somatosensation, as well as how the latter three sensory modalities may interact with each other (e.g., Verhagen & Engelen, 2006 for a review). Some examples of crossmodal interactions with taste, smell, and somatosensation that could interact with the audiovisual crossmodal correspondence effects reported in the present thesis are described below.

(i) Interactions with taste

Even though we did not find any significant effect of the color of the beverage on the Pitch-Size correspondence effects (chapter 5), we may wonder how these effects would be modulated in a trimodal matching paradigm involving the tasting phase. In fact, it is possible that during or after tasting, the participants' responses (in terms of performances, subjective ratings of taste intensity, or preferences) might be influenced by both the expectations triggered by the audiovisual correspondence, and the actual perception of the targeted beverage modulated by its color.

Indeed, handful of studies have reported an influence of color on taste. For instance, taste thresholds are generally increased and taste discrimination decreased by the addition of different colors to aqueous solutions (Maga, 1974; Pangborn, 1960; Pangborn, Berg, & Hansen, 1963 for seminal studies).
It is interesting to note that red, one of the colors that have often been shown to generate strong expectations concerning a food's taste, odor, and flavor (e.g., Koch & Koch, 2003; Demattè et al., 2006), also happens to be one of the colors that are most often reported as having an effect in terms of influencing flavor, taste, and odor perception (in terms of both identity and intensity judgments; e.g., Morrot, Brochet, & Dubourdieu, 2001). It has been shown that the intensity of red color generally enhances sweetness intensity in aqueous solutions (e.g., Johnson & Clydesdale, 1982). It remains to be investigated how the Pitch-Size correspondence effects in carbonated beverages, which may potentially increase the perceived freshness, interact with taste intensity judgments of different colored beverages.

Beyond the influence of visual cues, such as color on taste and flavor perception, the literature in crossmodal perception of flavor has also reported the influence of some auditory cues (e.g., Spence & Shankar, 2010 for a review). Zampini and Spence (2005) have shown that the perceived level of carbonation of a beverage was influenced by the loudness and/or frequency composition of the auditory feedback emitted by carbonated beverages. However, their results also suggested a dominance of oral-somatosensory and nociceptive cues over auditory cues in the perception of carbonation of beverages in the mouth. Thus, it would appear that the Pitch-Size correspondence effects shown in the present thesis might have a little influence on the perception of carbonation in the mouth. Nonetheless, our results have shown that this crossmodal correspondence between bubbles size and pouring sounds pitch could also trigger freshness expectations for consumers. The loudness and frequency composition of the auditory feedback were not manipulated in our experiments. Thus, it would be interesting to further investigate how these auditory modulations could influence the Pitch-Size correspondence effects, as well as the expected and actual perception of freshness in carbonated beverages.

(ii) Interactions with smell

Orthonasal olfaction may be used in order to detect and identify surrounding olfactory cues of food and beverage products. This may help to avoid ingesting poisonous substances or else driving consumers to choose their most preferable food item (Shepherd, 2012). Crossmodal interactions between orthonasal olfactory cues and some visual cues have been reported in the literature as having a significant influence on olfactory identification, and therefore on flavor perception.

Regarding multisensory integration that takes place during the experience of a particular food or drink, some studies have shown that the temporal and spatial presentation of color cues differentially affect the influence of color on participants' orthonasal olfactory identification responses. For instance, Shankar, Simons, Levitan, Shiv, Mcclure, and Spence (2010) have shown that color cues of particular drinks significantly influenced flavor perception when these color cues were simultaneously presented with the orthonasal olfactory cues or when the visual access of the color of the beverage was possible after smelling. On the contrary, only being exposed to color cues prior to the olfactory components of the drinks did not necessarily influence flavor perception.

Thus, in a trimodal matching paradigm considering the influence of both audiovisual correspondence (e.g., Pitch-Size) and olfactory cues, with beverages varying in color, it appears that the presentation of the targeted perceptual features would have to be done concomitantly or within a specific time range in order to obtain a possible crossmodal facilitation effect.

The influence of some olfactory compounds may also be driven through the proxy of temperature. Indeed, it has been shown that some odors could be perceptually associated with a temperature. Verhagen & Engelen (2006) reported that some odor compounds have been described as warm and are present in foods varying from dairy products to coffee. These compounds may be found in spices, such as anethole, a constituent of the volatile compound mix present in aniseed products. Consequently, if consumers expect a beverage to be fresh based on audiovisual sensory cues, the relation of congruency with paired odors would likely influence the perceived freshness.

As reported in the literature review presented in chapter 1, there is a general consensus on the fact that (i) retronasal smell is the main sensory contributor to the experience of flavor even if its implication is generally not consciously perceived, and (ii) the localization of flavor perception has an illusory component due to the mouth capture phenomenon.

In the case of freshness perception in beverages, it is unclear whether a similar mouth capture phenomenon occurs or not. In particular, a different pattern of subjective location of the final percept of freshness might be expected according to the beverage composition. If we stick to the case of cold and carbonated beverages, the trigeminal component is likely one of the main contributors to freshness due to i) the processing of coldness by the trigeminal cold-sensing neurons (Labbe et al., 2009a), and ii) the excitation of trigeminal neurons involved in signaling oral irritant sensations due to processing of CO2 contained in bubbles (Carstens, Carstens, Dessirier, O'Mahony, Simons, Sudo, & Sudo, 2002). However, the corresponding receptors are widely distributed (on the tongue, in the nasal cavity, and in the peripheral nervous system). Thus, it remains to be investigated i) whether consumers are conscious or not of the involvement of these trigeminal cues in their perception of freshness in beverages, and ii) whether some audiovisual correspondences, such as the Pitch-Size correspondence in carbonated beverages, might modulate the trigeminal sensitivity and the perceived freshness.

(iii) Interactions with somatosensation

The somatosensory system contributes to the identification of the texture, shape, and size of foods via active oral exploration of the food, including mastication and tongue movements (Cardello, 1996). Somatosensation may also be influenced by olfactory signals since somatosensory fibers in the nose may be activated by certain kinds of volatile chemicals, such

as the vapor of ammonia or by physical properties such as those of carbonated drinks (Shepherd, 2012). The sense of smell may thus in itself be considered as a multimodal sense given that smell receptor cells can also respond to mechanical stimulation by the air stream.
According to the carbonation intensity in a particular drink, Pitch-Size correspondence effects may occur and could consequently influence the expected somatosensation provided by bubbles during the consumption of the beverage. It could be interesting to test whether the participants' attentional allocation (as investigated in the experiments reported in chapter 6) differently impacts somatosensation induced by a carbonated drink, when the latter is preceded or not by the triggering of audiovisual Pitch-Size correspondence effects.

It is also worth mentioning that sounds that people produce while consuming food and drink may also influence their perception of what they actually consume (e.g., Spence & Shankar, 2010). If we consider complex beverages such as particular cocktails constituted of fresh fruits, ice cubes, and carbonated waters or soft drinks, we may expect that the crispness sound associated to fruits' chewing (or ice cubes cracking) will likely influence the actual perceived freshness. An interesting follow-up of the present thesis would be to test whether the pairing of the Pitch-Size correspondence effects linked to carbonation with somatosensory cues linked to the experience of the texture of fruits in a beverage, may induce an enhancing effect or not on the perceived freshness. It could also enable researchers to acquire new data about the semantic ambiguity of the term "fresh" that may convey different meanings (see chapter 1).

To summarize, the last three sections present some of the research perspectives that could be relevant to pursue when increasing the complexity of the stimulus context further than what has been done in the present thesis. In particular, how the audiovisual crossmodal correspondence effects may interact with the sensory modalities of taste, smell, and somatosensation during the dynamic experience of drinking have been addressed. It opens new research avenues toward the multisensory integration processes associated to the perception of freshness in beverages.

4.2.2. *Participants' characteristics*: inter-*individual variability linked to the taster's status*

Beyond the influence of culture and expertise of the participants that we already discussed in the literature review presented in chapter 1, some physiological aspects have been shown to directly impact the individuals' sensitivity to particular taste compounds and consequently their taste and flavor preferences. As one of the perspectives of the present thesis is to make more complex the stimulus context by integrating other sensory modalities such as taste, smell, and/or somatosensation, taking into account such participants' characteristics appears relevant in future research. We hypothesize that some audiovisual crossmodal correspondence effects might be modulated by i) the individuals' sensitivity to bitter-tasting compounds and ii) the thermal taster status of the consumers, when other sensory modalities are involved during the tasting step.

A lot of studies have shown that 25% of the population can be more sensitive to bitter-tasting compounds, such as phenylthiocarbamide (PTC) or the chemically-related 6-n-propylthiouracil (PROP) and they are called "supertasters" (e.g., Bartoshuk & Beauchamp, 1994). Around 50% would be "medium tasters" and 25% "non-tasters" (Bartoshuk, 2000). PROP sensitivity is associated with a higher taste sensitivity in general, and with a larger number of taste buds on the tongue. Non-tasters to PROP appear to like fat, sweet foods, and alcoholic beverages (Duffy, Peterson, & Bartoshuk, 2004). On the contrary, supertasters seem to be more sensitive to (or at least rate more intensely the sensation elicited by) other (non-bitter) taste stimuli (Bajec & Pickering, 2008) and are also more sensitive to the oral-somatosensory attributes of foods, such as the fat in a salad dressing (Eldeghaidy, Marciani, McGlone, Hollowood, Hort, Head, et al., 2011). Finally, it has been shown that supertasters are significantly less influenced by inappropriate coloring of a beverage than were medium tasters who, themselves, were less influenced than were the non-tasters (Zampini, Wantling, Phillips, & Spence, 2008).

Thus, depending of the perceptual features of interest (e.g., carbonation in beverages) and the type of beverage (e.g., alcoholic beverages) that are considered, it would be interesting to test whether the Pitch-Size correspondence effects reported in the present thesis might have an influence during the tasting phase of the product on freshness perception and liking of the product, according to the taster status of the participants.

Another interesting taste phenotype has also been reported recently. Cruz & Green (2000) showed that cooling or warming of small areas of the tongue could result in weak taste sensations. Another study has shown that the heat-activated cation channel TRPM5 would act downstream from the activation of taste receptors by depolarizing taste cells, and consequently this mediates the phenomenon of 'thermal taste' (Talavera, Yasumatsu, Voets, Droogmans, Shigemura, Ninomiya, et al., 2005). People experiencing the thermal-taste illusion tend to experience other tastes as more intense such as sourness or sweetness (e.g., Pickering, Bartolini, & Bajec, 2010). Consequently, it is likely that the thermal taster status may be an important determinant of individual differences in the perception of flavor. Regarding freshness perception in beverages, it remains to be investigated whether the thermal taster status of consumers would have a significant influence on i) the audiovisual crossmodal correspondence effects between perceptual features cuing temperature or carbonation that might trigger freshness expectations, and ii) the actual perception of freshness during the tasting step.

In the purpose of increasing the ecological validity of the experimental results, it is important to highlight that the context of consumption will also largely influence the way consumers perceive a product and how they adapt their behavior. However, such perspective would lead us far beyond the scope of the immediate perspectives of the present thesis given the amount of confounding variables, and their potential interaction effects involving both bottom-up and top-down modulating factors. Nonetheless, we invite the interested readers to have a look on relevant literature reviews as well as some experimental studies dealing with the influence of context, covering several dimensions from the size, shape, weight, and even the color of a wine glass (Spence & Wan, 2015), to ambient lighting (e.g., Oberfeld, Hecht, Allendorf, & Wickelmaier, 2009), background color (e.g., Spence, 2018), background music (e.g., Wang, Knoeferle, & Spence, 2017), and background noise (e.g., Spence, 2014) that have all been shown to influence taste and flavor perception (see also Spence & Piqueras-Fiszman, 2014; Spence, Velasco, & Knoeferle, 2014; Velasco et al., 2013).

4.3. Neurocognitive approach

Based on the works conducted and the results obtained in the present thesis, the last research perspective suggested here clearly has other implications in terms of the targeted research questions and methodology used. Nonetheless, we argue that the use of neurocognitive approach could considerably extend the results reported on the integration processes at stake during the multisensory experience of freshness in beverages. Moreover, it could provide new evidence to some unanswered questions: At what level of processing crossmodal correspondence effects that likely influence freshness perception occur? Are these effects involved in the unification of the experience of freshness in beverages? Is it possible to dissociate the impact of freshness on arousal and reward in neuroimaging or neuronal responses? Does a specific oropharyngeal perception generally perceived as not fresh can be later on considered as fresh through learning?

From EEG to fMRI, different techniques may be used to provide evidence of cortical activation or neural responses in specific brain regions associated with taste/flavor perception, language, emotion, and reward (e.g., Small, 2012).

In a review on the psychophysiological factors that may influence refreshing perception, Labbe and colleagues (2009a) have reported interesting EEG studies providing evidence of changes in alertness after water consumption. For instance, recordings of EEG during water consumption revealed a greater enhancement of cortical activation in water-deprived subjects than in thirst-quenched subjects (e.g., Hallschmid, Molle, Wagner, Fehm, & Born, 2001).

Some studies have also shown that specific compounds stimulating the olfactory or trigeminal pathways may also induce cortical activation. Nasal stimulation with peppermint has been shown to increase both cortical activation (Klemm, Lutes, Hendrix, & Warrenburg, 1992) and subjective alertness (Moss, Hewitt, Moss, & Wesnes, 2008). It is also likely that activation of the trigeminal pathway through a combination of cold and cooling stimulations would trigger specific brain mechanisms leading to an increased level of arousal and cortical activation (e.g., Labbe et al., 2011).

Considering higher order levels of processing, some studies have also shown that linguistic processing can have a fundamental influence on how the hedonic value of the taste and flavor of a food is represented early in cortical processing, and how it may drive the selection and consumption of foods (Grabenhorst, Rolls, & Bilderbeck, 2008). Even reading the word salt, for example, has been shown to activate many of the same areas as when a salty taste is actually experienced in mouth (Barrós-Loscertales, González, Pulvermüller, Ventura-Campos, Bustamante, Costumero, Parcet, & Àvila, 2012).

Regarding the ‘reward value’ of food and drink, several studies have shown that an activity detected in the orbitofrontal cortex was associated to pleasantness (e.g., Small, 2012). Given that freshness perception is perceived as pleasurable by consumers, it would be interesting to investigate whether the Pitch-Size correspondence effects reported in the present thesis may activate this particular brain region. The influence of congruent and incongruent combinations of stimuli in a trimodal matching paradigm involving for instance, visual, auditory, and somatosensory cues, would provide interesting results toward the multisensory integration processing associated to freshness perception in beverages.

GENERAL CONCLUSION

The present PhD project has been set up in order to explore the sensory and cognitive factors that underlie the multisensory perception of freshness in beverages, which is perceived as pleasurable and represents one of the current strong consumers' demands. Over the last thirty years, freshness (or positively correlated psychophysiological terms such as refreshing, thirst-quenching) has been investigated only in the field of consumer science, mainly through the collection of declarative data with self-administered questionnaires or visual analog scales (e.g., Fenko et al., 2009; Labbe et al., 2009b). Thanks to these methodologies, several studies have provided evidence of the sensory descriptors that could positively or negatively influence expectations and actual perception of freshness in beverages or semi-solid products. Even though companies gather knowledge on consumers' expectations, a large majority of products' innovations do not integrate the market place (Dijksterhuis, 2016a). We think that these failures can be due to a lack of understanding of consumers' expectations since the complexity of the cognitive mechanisms involved in multisensory perception of food and beverages cannot be entirely extracted from declarative data only. Thus, this approach needed to be completed by more objective measures of behavior (i.e., categorization or recognition tasks). To do so, experiments were conducted in the field of cognitive science in order to increase knowledge on the multisensory integration processes and the audiovisual crossmodal interaction effects that might influence the perceived freshness in beverages, upstream of the consumption phase.

After having reviewed the existing literature on the cognitive mechanisms of flavor perception (chapter 1), we argued that similarly to flavor, freshness perception is characterized by hybrid content, both perceptual and semantic, but that freshness has a higher-degree of specificity than flavor. In particular, contrary to flavor, freshness is characterized by specific functions (e.g., alleviation of oropharyngeal symptoms such as mouth-dryness). This higher degree of specificity for freshness prevents us from assuming that freshness does not differ from flavor with respect to the weighting of each sensory contributor, as well as to its subjective location (e.g., mouth capture phenomenon in the case of flavor). The respective contributions of taste, smell, and somatosensation to flavor perception as well as the complexity of the corresponding cognitive mechanisms that underlie the unified percept of flavor are still under ongoing debates in the literature (General Introduction, section 2). Thus, as a first investigation of the crossmodal interaction effects that may influence perceived freshness in beverages, we decided to orient our investigations on the influence of visual and auditory cues that may indirectly influence the subsequent consumers' experiences by triggering specific sensory expectations. This approach has the advantage i) to avoid the effects of confounding variables when the act of consumption comes to play, and ii) to bring new evidence on the audiovisual interaction effects in the field of food and beverage cognition.

The first set of experiments conducted and reported in chapter 4 aimed at investigating the influence of specific audiovisual perceptual features – temperature, carbonation, and color of the liquid – on freshness ratings (online with American participants) and freshness categorization in beverages (implicit measures collected in the laboratory with French participants). Explicit data were also collected regarding consumption habits of the participants, as well as the alcoholic beverage group, the general characteristics, and the aromas they associate more with freshness. The main results from implicit measures of the laboratory experiment revealed that the audiovisual perceptual features cuing the likely temperature (the presence versus absence of ice cubes), as well as the likely level of carbonation (the presence versus absence of bubbles) did influence the participants' performances. In fact, the participants' RTs were shorter in the freshness categorization task for congruent combinations of auditory and visual stimuli that displayed the perceptual features of interest (e.g., presenting both visual and auditory ice cubes) than for incongruent ones. Moreover, the participants categorized more the congruent stimuli as fresh. The sight and sound of simultaneously presented ice cubes and carbonation in the beverage had an additive effect on the participants' performances (shorter RTs and increased categorization of the stimuli as fresh). These results provide the first empirical evidence that audiovisual interaction effects, between perceptual features previously reported to influence the perceived freshness, can influence the participants' performances in a speeded (freshness) categorization task. Given the hedonic dimension elicited by the perception of freshness, we argued that these results could have important applications for beverage companies that could exploit these sensory levers to facilitate the categorization of their products as fresh.

From these results, we decided to pursue in the investigation of crossmodal interaction effects and their consequences on participants' performances using controlled paradigms. The literature on crossmodal correspondences has been reviewed and appeared as relevant to consider in the food and beverage domain due to their effects that can be quantified with implicit measures such as RTs and psychophysics indices (Spence, 2011). The majority of crossmodal correspondences reported in the literature was between visual and auditory cues, for which researchers used very simple stimuli (e.g., Parise & Spence, 2012). Among these audiovisual crossmodal correspondences, the Pitch-Size correspondence was one of the most reported: smaller circles are typically matched with higher-pitched sounds and larger circles with lower-pitched sounds.

We investigated whether the Pitch-Size correspondence effects still exist when using more complex and ecological stimuli in the beverage domain. Given the positive influence of carbonation on perceived freshness in beverages, found in our previous experiments and in the literature (e.g., Peyrot des Gachons et al., 2016), we selected bubbles size and pouring sounds pitch in carbonated beverages as good ecological counterparts of the simple audiovisual stimuli generally used to investigate Pitch-Size correspondence effects.

A first experiment was conducted using a modified version of the Implicit Association Test (Greenwald et al., 1998), which has been used in many other studies investigating the existence of crossmodal correspondence effects in the food and beverage domain (e.g., Crisinel & Spence, 2009). The results revealed shorter RTs and more accurate responses in congruent blocks (small bubbles and high-pitched pouring sound; big bubbles and low-pitched pouring sound) as compared to incongruent blocks (the reverse associations). Thus, this study provides the first empirical evidence of Pitch-Size crossmodal correspondence effects using more ecological and complex audiovisual stimuli. In order to replicate these results and to be able to disentangle the relative effects of the two associations involved in this Pitch-Size correspondence, we designed a second experiment using a Go/No-go Association Task (Nosek & Banaji, 2001). We also tested whether the Pitch-Size correspondence effects were robust enough to variations of the stimulus context (i.e., color of the liquid and width of the glass). The results from the participants' RTs confirmed the existence of the Pitch-Size correspondence effects in beverages, and showed that these effects were independent of the color of the liquid and the width of the glass targeted. This additional result thus provides evidence of the robustness of the effects. However, on the basis of the analysis of implicit measures, we were not able to disentangle the relative effects of the two associations involved in the Pitch-Size correspondence effects (small bubbles and high-pitched pouring sound; big bubbles and low-pitched pouring sound). The explicit measures collected in both experiments have shown that the participants associate more the pairing between small bubbles and high-pitched pouring sound to the consumption of fresh sparkling beverages. We believe that these results provide promising applications for the beverage industry, as triggering such kind of audiovisual crossmodal correspondences, upstream of the consumption phase, can positively influence the perceived freshness and may ultimately increase beverages' attractiveness.

Following from this evidence of Pitch-Size correspondence effects in beverages, we hypothesized that it is likely that other correspondences exist involving other visual dimensions. In particular, based on the literature, we wondered whether the visual dimension of spatial elevation could be involved in a triangular relationship with bubbles size and pouring sounds pitch. This constituted our hypothesis of transitivity of correspondences. In other words, we tested whether people would also match small bubbles and high-pitched pouring sound with high spatial elevation. Thus, this last experiment enabled us to i) replicate the Pitch-Size correspondence effects, and ii) test the existence of Pitch-Elevation and Size-Elevation correspondence effects. Moreover, using two distinct tasks' instructions, the allocation of the participants' attention was manipulated toward either the same features on which the correspondences were tested (i.e., bubbles size, pouring sounds pitch, and spatial elevation), or to different features from those with the hypothesized intra- or crossmodal correspondences (i.e., lateralization of the visual and auditory stimuli). This manipulation enabled us to discuss at which level (perceptual vs. higher order cognitive level) the targeted correspondences might occur.

The results of this last experiment only revealed partial evidence of Pitch-Size correspondence effects that were already found in our two previous experiments (chapter 5). Interestingly, the effects were found only when the participants' attention was manipulated toward the same features on which the correspondence was tested. However, no correspondence effects were obtained for Pitch-Elevation and Size-Elevation correspondences, independently of the task. Thus, no transitivity was observed between bubbles' size, pouring sounds' pitch, and spatial elevation. We hypothesized that the Pitch-Size correspondence, in the particular case of carbonated beverages, may potentially arise when higher order cognitive processing (e.g., attention) than just perceptual is involved. The partial results obtained for the Pitch-Size correspondence in this last experiment suggest that if companies aim at increasing beverages' attractiveness and perceived freshness of their products, they would better have to direct the consumers' attention toward the features of interest. The use of specific labels such as "thin bubbles" together with an increase in saliency of the perceptual features associated with bubbles' size and pouring sounds' pitch (e.g., in ads, or during multisensory tasting events) could be promising ways to achieve these goals.

Three general perspectives that could extend the findings of the present thesis have been presented. First, one of the immediate perspectives presented is the investigation of other audiovisual crossmodal correspondences that could influence freshness perception in beverages. In particular, we report the examples of Pitch-Shape and Pitch-Brightness correspondences, for which different perceptual features as those used in the experiments of this thesis could be used. For instance, we suggested that a correspondence between the shape of ice cubes and pouring sounds pitch could be investigated. It could lead to the development of original ice-based cocktails. On the other hand, whether consumers associate a particular color intensity/hue, or a certain degree of transparency/turbidity with a pouring sound pitch, and by extension with a particular texture (viscosity) of the beverage could represent promising research avenues.

Second, it is clear that one of the perspective of this PhD work is to investigate the real impact of audiovisual interactions and crossmodal correspondence effects when the act of consumption comes to play. As exposed in perspectives (General Dicsussion, section 4), this would enable to investigate whether the introduction of taste, smell, and/or somatosensation would induce enhancing or inhibiting/masking effects on participants' performances, as well as the impact in terms of the crossmodal congruency effects of such trimodal interactions.

The fact that participants would have to consume beverages in these putative future studies imply to take into account the inter-individual variability that has been often reported toward the PROP, and less often, thermal taster status. In fact, it has been shown that these particular phenotypes could influence the perceived intensity of particular basic tastes and consequently impact the perception of the products, as well as the subsequent behaviors of consumers.

Finally, the last research perspective that has been suggested relates to another field of research which is cognitive neuroscience. In fact, based on neuroimaging or neuronal responses, further research could extend the results reported here toward the multisensory integration processes at stake during the experience of freshness in beverages.

To conclude, the present thesis offers an original research approach in the investigation of the multisensory perception of freshness in beverages. Empirical evidence has been provided on the audiovisual crossmodal interaction and correspondence effects that influence participants' performances in specific controlled tasks. These results have opened promising research avenues in terms of the variety of crossmodal interactions that could be further investigate, the respective contributions of the different sensory inputs contributing to freshness, and the influence of higher-order cognitive processes (e.g., attention) on participants' performances. The present thesis has also important practical implications for beverage companies that wish to launch new product formulation or attractive marketing campaigns.

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ANNEXES

Annex 1: Methodology of the online consumer survey (2015)

- Participants: N=299, French nationality, 62% Female, 70% between 25 and 35 years old and 30% more than 36 years old. 46% of employees, 23% of executives or professionals, 11% of retired, 9% without professional activity. The participants have to be consumers of at least one type of alcoholic beverages.

- Questionnaire: 4 parts, total duration ≈ 15 min.

Themes of the questions	Collected data	Type of questions
1. Socio-demographic	Age, gender, socio-professional category, consumption or not of alcoholic beverages	4 closed-ended questions
2. Expectations for fresh alcoholic beverages	Appreciated and ideal characteristics, flavor expectations (taste, texture…)	1 open-ended question, 6 Check All That Apply (CATA) questions, 3 liking scales (11 points Likert scales)
3. Particular types of fresh alcoholic beverages	Examples of alcoholic beverages considered as fresh, aromas and general characteristics	4 closed-ended questions, 8 open-ended questions, 4 CATA
4. Consumption habits	Frequency of consumption, places…	3 closed-ended questions

<u>Annex 2:</u> Methodology of the experts interviews (2015)

- <u>Participants:</u> 6 bartenders from Paris (5 males, 1 female), 4 bartenders from Lyon (3 males, 1 female) with at least 5 years of experience and a particular interest and/or expertise in cocktails.

- <u>Procedure:</u> semi-directive interviews with questions relative to products, ingredients, expected sensations of the consumers, consumers' expectations toward fresh drinks, and finally the concept of freshness from the bartenders' point of view: practice, general characteristics, and types of drinks.

Annex 3: Methodology of the consumer test (2016)

- Participants: N=110 clients of restaurant, French nationality, 48% Female, mean age 44.7 ± 16 ranging from 19 to 75 years old. 32% of executives or professionals, 21% of retired, 20% of employees or workers, 18% of students, and 9% of craftsmen, shopkeepers, or heads of a company.

- Products: Three cocktails of 40 mL: 1 reference, 1 sparkling, and 1 with thick texture.

Ingredients	Reference	Sparkling	Thick
Gin (Gordon's London Dry Gin)	7.3 mL	7.3 mL	7.3 mL
Ginger liquor (Ginger of the Indies, Giffard)	7.3 mL	7.3 mL	7.3 mL
Concomber juice	7.3 mL	7.3 mL	7.3 mL
Lime juice	3.6 mL	3.6 mL	3.6 mL
Still mineral water (Castalie)	14.5 mL	X	14.5 mL
Sparkling mineral water (Castalie)	X	14.5 mL	X
Thickener (CMC)	X	X	0.12 g

The basic mixed preparation of the cocktails were stored in fridge at 3°C for 4 hours. The adjusted volume of mineral water (either still or sparkling) was added just before being proposed to the participants.

- Procedure: The experiment took place in the Living lab of the Institut Paul Bocuse Research Center during 5 days at the diner (controlled conditions for restaurant setting, light, musical playlist). The three cocktails were simultaneously presented to the participants on a slate plate, each numbered by three random digits. They were asked to respond to several questions for each cocktail and thereby they had to taste them step by step and not with a single swallowing action.

Figure 19: The living lab of the Institut Paul Bocuse Research Center and the three cocktails served during the consumer test

- Questionnaire:

Collected data	Type of questions
1. Comparison of the three cocktails for the perceived freshness	Ranking task
2. Overall liking and comments	Liking scales (9 points Likert scales), 1 open-ended question
3. Perceived intensity of sourness, sweetness, and bitterness	3 Just About Right (JAR) questions in 5 points
4. Socio-demographic and consumption habits	6 closed-ended questions

Annex 4: Socio-professional categories of the participants in the online and the laboratory experiment (Chapter 4)

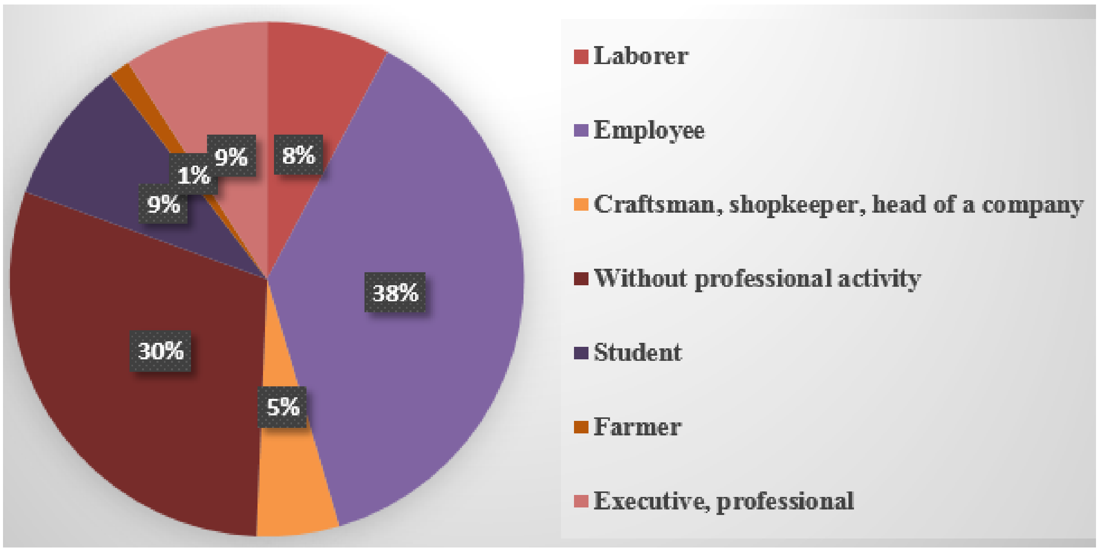

Figure 20: Socio-professional categories of the American participants in the online experiment

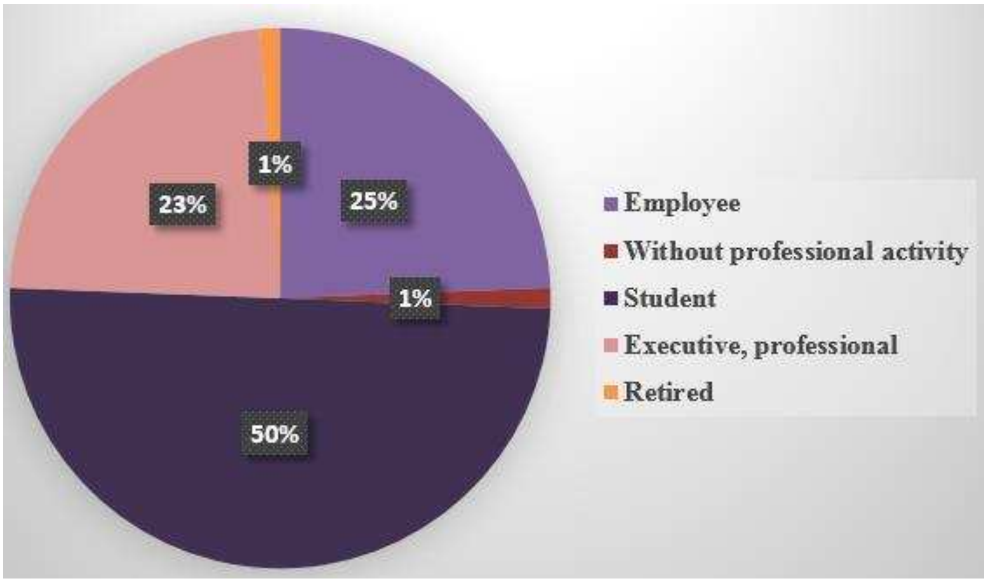

Figure 21: Socio-professional categories of the French participants in the laboratory experiment

Annex 5: Timeline procedure of the online experiment (Chapter 4)

The participants were asked 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 quickly as possible. The audiovisual stimuli were displayed for 2000 ms (time-out). If the participants failed to answer within the stimulus presentation, a second response scale without the audiovisual stimulus was displayed until a response was made.

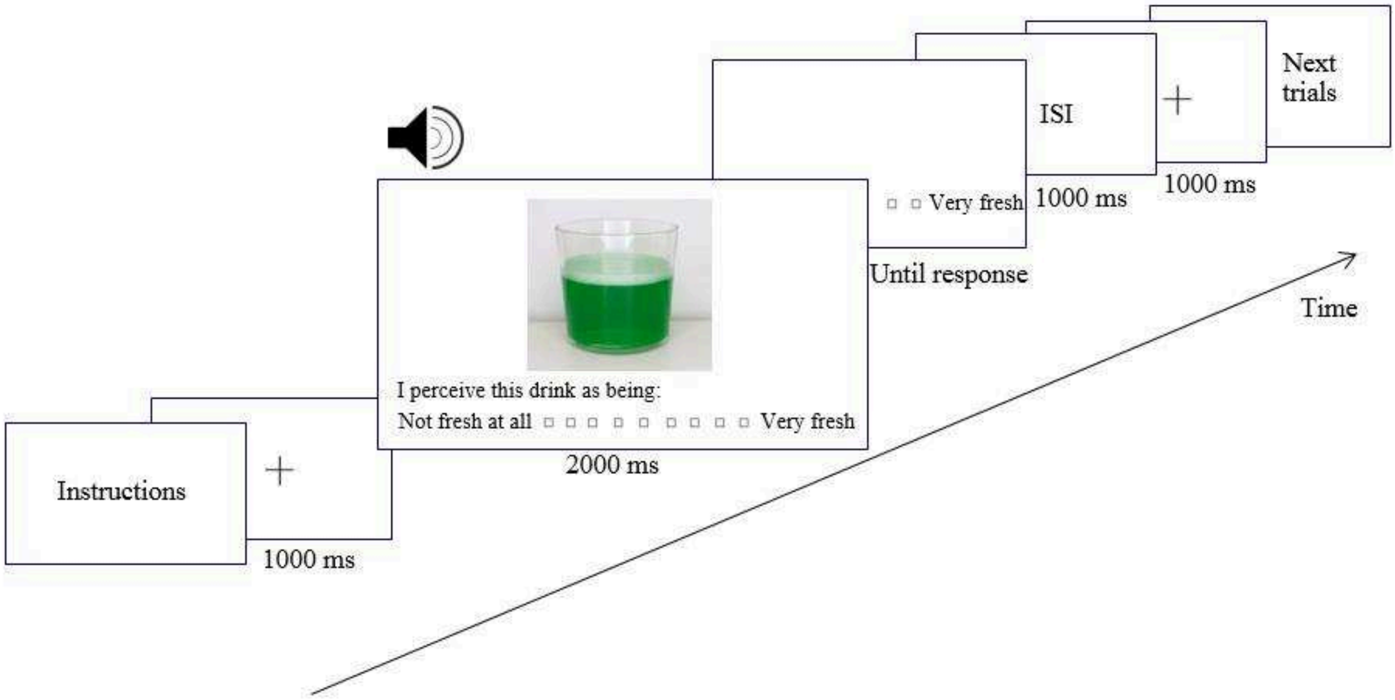

Figure 22: Timeline procedure of the online experiment

<u>Annex 6:</u> Questionnaire of the online experiment (Chapter 4)

<u>1. Socio-demographic questionnaire:</u>

- Your country of residence: France, USA, other
- You are: a female, a male
- Indicate your year of birth format (19XX)
- Indicate your socio-professional category: Farmer; Craftsman, shopkeeper, head of a company; Executive, professional; Employee; Worker; Student; Without professional activity; Retired

<u>2. Consumption habits and liking questionnaire:</u>

Q1- How much do you like the consumption of sparkling beverages?

Not at all ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ Very much

Q2- How much do you like the consumption of sweet beverages?

Not at all ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ Very much

➔ Q1 and Q2 randomized

Q3- Among these colors, which color is the most representative of a sparkling beverage?

☐ Colorless	☐ Orange
☐ Blue	☐ Brown
☐ Yellow	☐ Red
☐ Green	

➔ Q3: randomized order of the different colors

Q4- On average, how many times do you consume the following beverages?

(Put a cross in the corresponding case)

	Several times a day	Once a day	Once a week or more	Two or three times during a month	Less than once a month	Never
1. Sparkling water						
2. Sparkling soda						
3. Fruit juices						
4. Beers						
5. Alcoholic cocktails						
6. Spirits						
7. Wine						

Q5- Which group of alcoholic beverages do you associate the most to fresh alcoholic beverages?

☐ Spirits or liquor-based cocktails
☐ Spirits or liquors (neat)
☐ Beers
☐ Ciders
☐ Ready to drink mixed beverages
☐ Wines
☐ Other

➔ Q5: randomized order of the different groups of alcoholic beverages

Q6- Within this group of alcoholic beverages, please quote the particular drink you associate the most to a fresh alcoholic beverage:

/______ /

Q7- According to you, which characteristics make this drink fresh?

/______ /

Q8 – According to you, what aromas could be found in a fresh alcoholic beverage?

- ☐ Citrus fruits
- ☐ Woody
- ☐ Coffee
- ☐ Caramel
- ☐ Chocolate
- ☐ Spice (cinnamon, pepper, vanilla…)
- ☐ Floral (honeysuckle, violet, jasmine…)
- ☐ Yellow fruits
- ☐ Red fruits
- ☐ Tropical fruits
- ☐ Fresh herbs (dill, thyme, mint…)
- ☐ Vegetables
- ☐ Honey
- ☐ Nuts
- ☐ Other, precise: /_____ /

➔ Q8: randomized order of the different aromas (except “Other”)

Q9 – According to you, a fresh alcoholic beverage should be:

- ☐ At room temperature
- ☐ Sour
- ☐ Bitter
- ☐ Hot
- ☐ Colored
- ☐ Thirst-quenched
- ☐ Thick
- ☐ Strong in alcohol
- ☐ Cold
- ☐ Freezing
- ☐ Sparkling
- ☐ Slightly thick
- ☐ Low in alcohol
- ☐ Still
- ☐ Salty
- ☐ Sweet
- ☐ Transparent
- ☐ Other, precise: /_____ /

➔ Q9: randomized order of the different general characteristics (except “Other”)

Annex 7: Questionnaire of the laboratory experiment (Chapter 4)

1. Socio-demographic questionnaire:

- Votre pays de résidence: France, Etats-Unis, Autre
- Vous êtes: une femme, un homme
- Indiquez votre année de naissance (format 19XX)
- Indiquez votre catégorie socio-professionnelle: Agriculteur, exploitant; Artisan, commerçant ou chef d'entreprise; Cadre ou profession libérale; Employé; Ouvrier; Etudiant; Sans activité professionnelle; Retraité

2. Consumption habits and liking questionnaire:

Q1- A quel point appréciez-vous la consommation de boissons pétillantes?

Je n'aime pas du tout ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ J'aime beaucoup

Q2- A quel point appréciez-vous la consommation de boissons sucrées ?

Je n'aime pas du tout ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ J'aime beaucoup

➔ Q1 and Q2 randomized

Q3- Parmi ces couleurs, quelle couleur associez-vous le plus à la consommation de boissons pétillantes ?

☐ Incolore ☐ Orange
☐ Bleu ☐ Marron
☐ Jaune ☐ Rouge
☐ Vert

➔ Q3: randomized order of the different colors

Q4- En moyenne, combien de fois consommez-vous les boissons suivantes?

(Mettre une croix dans la case correspondante)

	Plusieurs fois par jour	Une fois par jour	Une fois par semaine ou plus	Deux ou trois fois par mois	Moins d'une fois par mois	Jamais
1. Eaux pétillantes						
2. Sodas pétillants						
3. Jus de fruits						
4. Bières						
5. Cocktails alcoolisés						
6. Spiritueux						
7. Vins						

Q5- Quel groupe de boissons alcoolisées vous évoque le plus des boissons alcoolisées fraîches?

☐ Cocktails à base de spiritueux et alcools forts

☐ Vins

☐ Spiritueux at alcools forts (purs)

☐ Apéritifs anisés

☐ Bières

☐ Cidres

☐ Apéritifs alcoolisés de type Aperol, Martini, Porto…

➔ Q5: randomized order of the different groups of alcoholic beverages

Q6- Dans ce groupe de boissons alcoolisées, pouvez-vous citer une boisson qui vous évoque le plus une boisson alcoolisée fraîche ?

/_______ /

Q7- A votre avis, quelles caractéristiques la rendent fraîche ?

/_______ /

Q8 – Selon vous quels sont les arômes que l'on pourrait retrouver dans une boisson alcoolisée fraîche ?

- ☐ Agrumes
- ☐ Boisé
- ☐ Café
- ☐ Caramel
- ☐ Chocolat
- ☐ Epices (cannelle, poivre, vanille…)
- ☐ Floral (chèvrefeuille, violette, jasmin…)
- ☐ Fruits jaunes
- ☐ Fruits rouges
- ☐ Fruits tropicaux
- ☐ Herbes fraîches (aneth, thym, menthe…)
- ☐ Légumes
- ☐ Miel
- ☐ Noix
- ☐ Autre, précisez: /_____ /

➔ Q8: randomized order of the different aromas (except "Autre")

Q9 – Pour vous, une boisson alcoolisée fraiche devrait être :

- ☐ A température ambiante
- ☐ Acide
- ☐ Amère
- ☐ Chaude
- ☐ Colorée
- ☐ Désaltérante
- ☐ Epaisse
- ☐ Forte en alcool
- ☐ Froide
- ☐ Glacée
- ☐ Pétillante
- ☐ Peu épaisse
- ☐ Peu forte en alcool
- ☐ Plate
- ☐ Salée
- ☐ Sucrée
- ☐ Transparente
- ☐ Autre, précisez: /_____ /

➔ Q9: randomized order of the different general characteristics (except "Autre")

Annex 8: Thesis' valorization

Publications in peer-reviewed journals

Roque, J., Auvray, M., & Lafraire, J. (in preparation). The relations between pouring sounds Pitch, bubbles Size, and spatial Elevation in carbonated beverages and attentional allocation effects.

Roque, J., Lafraire, J., & Auvray, M. (submitted). Audiovisual crossmodal correspondence between bubbles size and pouring sounds pitch in carbonated beverages. Manuscript submitted for publication in Acta Psychologica.

Roque, J., Lafraire, J., Spence, C., & Auvray, M. (2018). The influence of audiovisual stimuli cuing temperature, carbonation, and color on the categorization of freshness in beverages. Journal of Sensory Studies, e12469.

Roque, J., Auvray, M., & Lafraire, J. (2018a). Understanding Freshness Perception from the Cognitive Mechanisms of Flavor: The Case of Beverages. Frontiers in Psychology, 8:2360.

Oral communications in international conferences

Roque, J. (2018, September). Implicit associations between bubbles size and pouring sounds pitch in carbonated beverages: a promising way to increase freshness perception and categorization. Presentation at Eurosense, Verona, Italy.

Roque, J. (2018, April). Audiovisual crossmodal correspondences: the case of carbonation in beverages. Presentation at the British Feeding and Drinking Group (BFDG), Lyon, France.

Roque, J. (2017, May). Multimodal perception of alcoholic beverages: the particular case of freshness perception. Presentation at the Symposium of the European Sensory Science Society (E3S), Paris, France.

Oral communications in research seminars or business symposium

Roque, J. (2018, November). Multisensory perception of beverages: the particular case of freshness perception. Presentation at the International Research & Innovation Committee, Institut Paul Bocuse Research Center, Ecully, France.

Roque, J. (2018, May). Implicit associations between bubbles size and pouring sounds pitch in carbonated beverages: a promising way to increase freshness perception and categorization.

Presentation at the International research seminar, Institut Paul Bocuse Research Center, Ecully, France.

Roque, J. (2018, January). Multimodal perception of alcoholic beverages: the particular case of the complex perception of freshness. Presentation at the Sensolier, Paris, France.

Roque, J. (2016, July). Investigating the cognitive mechanisms underlying freshness perception. Presentation at the International research seminar, Institut Paul Bocuse Research Center, Ecully, France.

Roque, J. (2016, March). Multimodal perception of alcoholic beverages: the particular case of freshness and lightness perceptions. Presentation at the Pernod Ricard Science and Technology for Innovation Community meeting, Paris, France.

Graphic communications in international conferences

Roque, J., Lafraire, J., & Auvray, M. (2018, June). Audiovisual crossmodal correspondences between bubbles size and pouring sounds pitch in carbonated beverages. Poster presented at the International Multisensory Research Forum (IMRF), Toronto, Canada.

Roque, J., Lafraire, J., & Auvray, M. (2017, April). The influence of audio-visual interactions on freshness perception and categorization: the case of beverages. Poster presented at the British Feeding and Drinking Group (BFDG), Reading, UK.

Roque, J., Lafraire, J., & Auvray, M. (2017, May). Investigating the multisensory perception of freshness in beverages: the case of audio-visual interactions. Poster presented at the International Multisensory Research Forum (IMRF), Nashville, US.

Roque, J., Auvray, M., Garrel, C., & Lafraire, J. (2016, April). The multisensory perceptions of flavour and freshness: a new perspective. Poster presented at the British Feeding and Drinking Group (BFDG), London, UK.

Roque, J., Lafraire, J., Giboreau, A., Brit, A.-C., Petit, E., Garrel, C. (2016, September). Consumers’ perception of freshness in alcoholic beverages and the influence of somesthetic parameters. Poster presented at Eurosense, Dijon, France.

TABLE OF ILLUSTRATIONS

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RÉSUMÉ

Le présent projet de thèse a pour objectif d'explorer les facteurs sensoriels et cognitifs qui sous-tendent la perception multisensorielle de fraîcheur dans les boissons, perçue comme plaisante et faisant partie des demandes actuelles des consommateurs. Au cours des trente dernières années, la fraîcheur (ou termes psychophysiologiques positivement corrélés tels que rafraîchissant, désaltérant) a été étudiée uniquement dans le domaine des sciences du consommateur, principalement par la collecte de données déclaratives avec des questionnaires ou des échelles analogiques visuelles (e.g., Fenko et al., 2009; Labbe et al., 2009b). Grâce à ces méthodologies, plusieurs études ont mis en évidence les descripteurs sensoriels pouvant influencer positivement ou négativement les attentes et la perception avérée de la fraîcheur dans les boissons ou les produits semi-solides. Même si les entreprises collectent des informations sur les attentes des consommateurs, une grande majorité des innovations produit ne parviennent pas à intégrer le marché (Dijksterhuis, 2016a). Nous pensons que ces échecs peuvent être dus à un manque de compréhension des attentes des consommateurs car la complexité des mécanismes cognitifs impliqués dans la perception multisensorielle des aliments et des boissons ne peut être entièrement extraite à partir de données déclaratives uniquement. Ainsi, cette approche avait besoin d'être complétée par des mesures plus objectives du comportement (e.g., tâches de catégorisation ou de reconnaissance). Pour cela, des expérimentations ont été menées dans le domaine des sciences cognitives afin d'accroître les connaissances sur les processus d'intégration multisensorielle et les effets d'interactions intermodales audiovisuelles susceptibles d'influencer la fraîcheur perçue dans les boissons, en amont de la phase de consommation.

Après avoir examiné la littérature existante sur les mécanismes cognitifs de la perception de la flaveur (chapitre 1), nous avons défendu le fait que, tout comme la flaveur, la perception de la fraîcheur est caractérisée par un contenu hybride, à la fois perceptif et sémantique, mais que la fraîcheur présente un degré de spécificité supérieur à celui de la flaveur. En particulier, contrairement à la flaveur, la fraîcheur est caractérisée par des fonctions spécifiques (e.g., l'atténuation des symptômes oro-pharyngés tels que la sécheresse en bouche). Ce degré de spécificité supérieur pour la fraîcheur nous empêche de supposer que la fraîcheur ne se différencie pas de la flaveur en ce qui concerne la pondération de chaque contributeur sensoriel, ainsi que sa localisation subjective (e.g., le phénomène de capture orale dans le cas de la flaveur). Les contributions respectives du goût, de l'odeur et des sensations somatosensorielles

à la perception de la flaveur, ainsi que la complexité des mécanismes cognitifs qui sous-tendent la perception unifiée de la flaveur, font encore l'objet de débats dans la littérature (Introduction générale, section 2). Ainsi, en tant que première étude des effets d'interactions intermodales susceptibles d'influencer la fraîcheur perçue dans les boissons, nous avons décidé d'orienter nos recherches sur l'influence des signaux visuels et auditifs susceptibles d'affecter indirectement les expériences ultérieures des consommateurs en déclenchant des attentes sensorielles spécifiques. Cette approche ayant l'avantage i) d'éviter les effets de variables confondantes lors de la phase de consommation, et ii) d'apporter de nouvelles preuves empiriques quant aux effets d'interaction audiovisuels dans le domaine de la cognition des aliments et des boissons.

La première série d'expériences menées et rapportées au chapitre 4 visait à examiner l'influence de caractéristiques perceptives audiovisuelles spécifiques - température, carbonatation et couleur du liquide - sur les évaluations de fraîcheur (en ligne avec des participants américains) et sur la catégorisation de fraîcheur dans les boissons (mesures implicites collectées en laboratoire avec des participants français). Des données explicites ont également été recueillies sur les habitudes de consommation des participants, ainsi que sur le groupe de boissons alcoolisées, les caractéristiques générales et les arômes qu'ils associaient à la fraîcheur. Les principaux résultats des mesures implicites de l'expérience conduite en laboratoire ont révélé que les caractéristiques perceptives audiovisuelles indiquant la température probable (présence ou absence de glaçons), ainsi que le niveau probable de carbonatation (présence ou absence de bulles) ont influencé les performances des participants. En effet, les temps de réaction (RTs) des participants étaient plus courts dans la tâche de catégorisation de la fraîcheur pour des combinaisons congruentes de stimuli auditifs et visuels présentant les caractéristiques perceptives ciblées (e.g., présentant des glaçons en visuel et en auditif), par rapport aux combinaisons incongruentes. De plus, les participants ont davantage classé les stimuli congruents comme frais. Le fait de voir des glaçons et des bulles et d'entendre simultanément un son de glaçons et de carbonatation a eu un effet additif sur les performances des participants (RTs plus courts et catégorisation accrue des stimuli comme étant frais). Ces résultats fournissent la première preuve empirique que les effets d'interaction audiovisuelle, entre des caractéristiques perceptives précédemment identifiées comme modulant la fraîcheur perçue, peuvent influencer les performances des participants dans une tâche de catégorisation rapide sur la fraîcheur. Compte tenu de la dimension hédonique suscitée par la perception de fraîcheur, nous suggérons que ces résultats ont d'importantes applications pour les entreprises de boissons qui pourraient exploiter ces leviers sensoriels pour faciliter la catégorisation de leurs produits comme étant frais.

À partir de ces résultats, nous avons décidé de poursuivre l'étude des effets d'interaction intermodale et de leurs conséquences sur les performances des participants à l'aide de paradigmes contrôlés. La littérature sur les correspondances intermodales a été examinée et est apparue comme pertinente à considérer dans le domaine des aliments et des boissons en raison des effets générés par ces correspondances pouvant être quantifiés via des mesures implicites comme les RTs et des indices psychophysiques (Spence, 2011). La majorité des correspondances intermodales rapportées dans la littérature ont été étudiées entre des indices visuels et auditifs, pour lesquels les chercheurs ont utilisé des stimuli très simples (e.g., Parise & Spence, 2012). Parmi ces correspondances intermodales audiovisuelles, la correspondance entre hauteur du son et taille des objets circulaires est l'une des plus rapportées : les petits cercles sont généralement associés à des sons aigus et les grands cercles à des sons graves.

Nous avons étudié si les effets de correspondance hauteur du son-taille existaient toujours lorsque des stimuli plus complexes et plus écologiques étaient utilisés dans le domaine des boissons. Compte tenu de l'influence positive de la carbonatation sur la fraîcheur perçue des boissons, constatée dans nos expériences précédentes et dans la littérature (e.g., Peyrot des Gachons et al., 2016), nous avons sélectionné la taille des bulles et la hauteur des sons de versement dans les boissons gazeuses comme les homologues écologiques des stimuli audiovisuels simples généralement utilisés pour étudier les effets de correspondance hauteur du son-taille.

Une première expérience a été réalisée en utilisant une version modifiée du test d'association implicite (IAT, Greenwald et al., 1998), qui a également été utilisé dans de nombreuses autres études cherchant à démontrer l'existence d'effets de correspondance intermodales dans le domaine des aliments et des boissons (e.g., Crisinel & Spence, 2009). Les résultats de notre étude ont révélé des RTs plus courts et des taux de réponses correctes plus élevés dans les blocs congruents (petites bulles et son de versement aigu; grosses bulles et son de versement grave) par rapport aux blocs incongruents (associations inverses). Ainsi, cette étude fournit la première preuve empirique d'effets de correspondance intermodale hauteur du son-taille en utilisant des stimuli audiovisuels plus écologiques et plus complexes. Afin de répliquer ces résultats et de pouvoir démêler les effets relatifs des deux associations impliquées dans cette correspondance hauteur du son-taille, nous avons conçu une deuxième expérience utilisant une tâche d'association Go/No-Go (Nosek & Banaji, 2001). Nous avons également vérifié si les effets de correspondance hauteur du son-taille étaient suffisamment robustes pour résister à des variations du contexte du stimulus (c'est-à-dire la couleur du liquide et la largeur du verre). Les résultats des RTs des participants ont confirmé l'existence d'effets de correspondance hauteur du son-taille des bulles dans les boissons et ont montré que ces effets étaient indépendants de la couleur du liquide et de la largeur du verre ciblés. Ce résultat supplémentaire atteste donc de la robustesse des effets. Cependant, sur la base de l'analyse des mesures implicites, nous n'avons pas pu démêler les effets relatifs des deux associations impliquées dans les effets de correspondance hauteur du son-taille (petites bulles et sons de versement aigu ; grosses bulles et son de versement grave). Les mesures explicites recueillies dans les deux expériences ont montré que les participants associaient davantage l'association petites bulles - sons de versement aigus à la consommation de boissons pétillantes fraîches. Nous pensons que ces résultats offrent des applications prometteuses pour l'industrie des boissons, car le déclenchement de ce type de correspondances intermodales audiovisuelles, en amont de la phase de consommation, peut influencer de manière positive la fraîcheur perçue et ainsi accroître l'attractivité des boissons.

Suite à ces effets avérés de correspondance hauteur du son-taille des bulles dans les boissons, nous avons émis l'hypothèse que d'autres correspondances pouvaient exister, impliquant d'autres dimensions visuelles. En particulier, sur la base de la littérature, il est apparu que la dimension visuelle de l'élévation spatiale pouvait potentiellement être impliquée dans une relation triangulaire avec la taille des bulles et la hauteur des sons. L'hypothèse de transitivité des correspondances a ainsi émergé. En d'autres termes, nous avons testé si les personnes associaient également des petites bulles et un son de versement aigu, avec une élévation spatiale élevée. Ainsi, cette dernière expérience nous a permis de i) reproduire les effets de correspondance hauteur du son-taille des bulles, et ii) vérifier l'existence d'effets de correspondance hauteur du son-élevation spatiale et taille des bulles-élévation spatiale. De plus, en utilisant deux instructions distinctes de la tâche, l'attention des participants a été manipulée soit sur les mêmes caractéristiques sur lesquelles les correspondances ont été testées (i.e., taille des bulles, hauteur du son de versement, et élévation spatiale), soit sur des caractéristiques différentes de celles des correspondances intra- ou intermodales supposées (i.e., latéralisation des stimuli visuels et auditifs). Cette manipulation nous a permis de déterminer à quel niveau (perceptif ou cognitif d'ordre supérieur) les correspondances ciblées pourraient survenir.
Les résultats de cette dernière expérience n'ont révélé que des preuves partielles des effets de correspondance hauteur du son-taille des bulles qui avaient déjà été constatés lors de nos deux

expériences précédentes (chapitre 5). Il est intéressant de noter que les effets n'ont été constatés que lorsque l'attention des participants était dirigée sur les mêmes caractéristiques sur lesquelles la correspondance a été testée. Cependant, aucun effet de correspondance n'a été obtenu pour les correspondances hauteur du son-élévation et taille des bulles-élévation, indépendamment des instructions de la tâche. Ainsi, aucune transitivité n'a été observée entre la taille des bulles, la hauteur des sons de versement et l'élévation spatiale. Nous avons émis l'hypothèse que la correspondance hauteur du son-taille des bulles, dans le cas particulier des boissons gazeuses, pourrait potentiellement survenir lorsqu'un traitement cognitif supérieur (e.g., impliquant des processus attentionnels) est impliqué plutôt qu'un simple processus perceptif. Les résultats partiels obtenus pour la correspondance hauteur du son-taille des bulles de cette dernière expérience suggèrent que pour les entreprises cherchant à accroître l'attractivité de leurs boissons et la fraîcheur perçue de leurs produits, il serait plus efficace d'orienter l'attention des consommateurs sur les caractéristiques perceptives d'intérêt. L'utilisation de termes spécifiques tels que "fines bulles", associée à une augmentation de la saillance des caractéristiques perceptives associées à la taille des bulles et à la hauteur des sons (e.g., dans des publicités ou lors d'événements de dégustations multisensorielles) pourrait constituer un moyen prometteur pour augmenter la fraîcheur perçue des produits.

Trois perspectives générales susceptibles d'étendre les résultats de la présente thèse ont été présentées. Tout d'abord, l'une des perspectives immédiates présentées est l'étude d'autres correspondances intermodales audiovisuelles qui pourraient influencer la perception de la fraîcheur dans les boissons. En particulier, nous rapportons les exemples de correspondances entre hauteur du son et forme et hauteur du son et clarté, pour lesquelles des caractéristiques perceptives différentes à celles utilisées dans les expériences de cette thèse pourraient être utilisées. Par exemple, nous avons suggéré d'étudier une correspondance entre la forme des glaçons et la hauteur des sons. Cela pourrait mener à l'élaboration de cocktails originaux dont les glaçons constitueraient un aspect important. D'autre part, le fait que les consommateurs associent une intensité/une teinte de couleur particulière, ou un certain degré de transparence à une hauteur de son de versement et, par extension, à une texture particulière (viscosité) de la boisson peut représenter des pistes de recherche prometteuses.

Deuxièmement, il est certain que l'une des perspectives de cette thèse est d'étudier l'impact réel des interactions audiovisuelles et des effets de correspondances intermodales lorsque l'acte de consommation intervient. En d'autres termes, peut-on s'attendre à ce que l'introduction de stimuli gustatifs, olfactifs et/ou somatosensoriels induisent des effets de renforcement ou au

contraire d’inhibition/masquage sur les performances des participants ? La question se pose aussi de savoir ce que cela impliquerait en termes d'effets de congruence intermodale lorsque de telles interactions trimodales sont en jeu.
Le simple fait que les participants soient amenés à consommer des boissons dans ces supposées futures études implique de prendre en considération la variabilité interindividuelle qui a souvent été rapportée en ce qui concerne la sensibilité aux composés amers, et plus récemment, le statut du dégustateur lié aux sensations thermiques. En effet, il a été démontré que ces phénotypes particuliers pouvaient influencer l'intensité perçue de goûts particuliers et, par conséquent, cela peut moduler la perception des produits, ainsi que les comportements ultérieurs des consommateurs.
Enfin, la dernière perspective de recherche suggérée concerne un autre domaine de recherche, celui des neurosciences cognitives. En effet, à partir de données de neuroimagerie ou de réponses neuronales, des recherches supplémentaires pourraient étendre les résultats rapportés ici concernant les processus d’intégration multisensorielle en jeu lors de l’expérience de fraîcheur dans les boissons.

En conclusion, la présente thèse propose une approche de recherche originale pour l’étude de la perception multisensorielle de fraîcheur dans les boissons. Les expérimentations menées ont démontré l’existence d’effets d’interactions intermodales audiovisuelles et de correspondances pouvant influencer les performances des participants dans des tâches contrôlées. Ces résultats ont ouvert des pistes de recherche prometteuses en ce qui concerne la diversité des interactions intermodales pouvant faire l’objet d’autres études, les contributions respectives des différents signaux sensoriels favorisant la perception de fraîcheur, ainsi que l’influence des processus cognitifs d’ordre supérieur, comme l’attention, sur les performances des participants. La présente thèse a également des implications pratiques importantes pour l’industrie des boissons puisque les résultats générés permettent de fournir des recommandations en termes d’innovation pour la formulation des produits et le développement de campagnes marketing.

Am I expecting this drink to be fresh? The influence of audiovisual interactions on perceived freshness in beverages

The concept of freshness has received recent consideration in the field of consumer science, mainly due to its hedonic dimension, assumed to influence consumers' preference and behavior. Previous studies concluded that freshness could be defined as the result of the multisensory integration of olfactory, gustatory, trigeminal, visual, and auditory cues. In the case of beverages, freshness is also complex at a semantic level since it conveys different meanings. Up to now, most studies focused on consumers' expectations by a collection of declarative data. Given the complexity of the perceptual and cognitive mechanisms involved, this approach needed to be completed by more objective measures of behavior. In this thesis, we focus on the influence of audiovisual interactions from which consumers can perceive a beverage as fresh, before tasting. The first experiments revealed that audiovisual stimuli cuing temperature and carbonation positively influence the perception and categorization of freshness in beverages. The second experiments revealed the existence of audiovisual crossmodal correspondence effects between bubbles size and pouring sounds pitch in carbonated beverages that were robust to variations of the stimulus context as well as the experimental design used. A final experiment revealed that the Pitch-Size correspondence effects in beverages are more likely to occur when the participants' attention is directed toward the same features on which the correspondence is tested. Applications such as the triggering of perceptual and cognitive mechanisms underpinning the multisensory perception of freshness could help to increase beverages' attractiveness and appreciation.

Keywords: freshness, multisensory perception, expectations, audiovisual, crossmodal correspondences, categorization, implicit measures, beverages

Est-ce que je m'attends à ce que cette boisson soit fraîche ? L'influence des interactions audiovisuelles sur la fraîcheur perçue dans les boissons

Le concept de fraîcheur a été récemment étudié en sciences du consommateur en raison de sa dimension hédonique influençant les préférences des consommateurs. Les études antérieures ont conclu que la fraîcheur pouvait résulter d'une intégration multisensorielle des signaux olfactifs, gustatifs, trigéminaux, visuels et auditifs. Dans les boissons, la fraîcheur est également complexe au niveau sémantique puisqu'elle peut avoir des significations différentes. La plupart des études se sont concentrées sur les attentes des consommateurs à partir de données déclaratives. Compte tenu de la complexité des mécanismes cognitifs impliqués, des mesures plus objectives du comportement sont apparues nécessaires. Dans cette thèse, nous avons ciblé l'influence des interactions audiovisuelles à partir desquelles les consommateurs perçoivent une boisson comme fraîche, avant la dégustation. Nos résultats révèlent que des stimuli audiovisuels liés à la température et la carbonatation influencent positivement la fraîcheur perçue. L'existence d'effets de correspondance audiovisuelle entre la taille des bulles et la hauteur des sons dans les boissons pétillantes ont également été montré et se sont avérés être robuste à des variations du stimulus ainsi qu'au paradigme expérimental utilisé. Enfin, les effets de correspondance observés entre taille des bulles et hauteur du son seraient plus susceptibles de se produire lorsque l'attention des participants est dirigée sur les caractéristiques pour lesquelles la correspondance est testée. Certains mécanismes cognitifs sous-tendant la perception multisensorielle de fraîcheur pourraient aider à augmenter l'attractivité et l'appréciation des boissons.

Mots-clés : fraîcheur, perception multisensorielle, attentes, audiovisuel, correspondances intermodales, catégorisation, mesures implicites, boissons