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'A PERFUMED BRAIN'. CROSSMODAL CORRESPONDANCES IN TASTE AND SMELL PERCEPTION AND MEMORY

Doctoral Thesis

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CHAPTER I
INTRODUCTION

1. The crossmodal interaction in taste and smell perception and the memory for odours

Human experiences of objects and events are formed through the perception and integration of information coming from different sensory modalities. Importantly, research has shown that even information not directly related to the object itself, such as that produced by the contest where the stimulus is presented, can contribute to modulate its mental representation. This might be the case, for example, of the interaction between the evaluation of a given food and the characteristics of the plate where it is served. Despite of these observations, the presence of multisensory interactions in taste and smell perception and memory have been much less investigated by neuroscientific research as compared to interactions between other sensorial aspects of the environment. Nevertheless, this knowledge is important in order to define a more comprehensive and accurate model of human multisensory integration. Here we concentrate on this issue by investigating a number of different topics. In particular, in this thesis we investigated if the colour, weight, texture can differently modulate the evaluation of some characteristics of the liquid served in it. We also investigated crossmodal integration in the processing of odours under both ecological and computer controlled experimental conditions. Finally, we addressed the topic of olfactory memory. In this study we compared the performance of Alzheimer patients, neurologically normal elderly and young individuals. The connection among these different aspects relates to the fact that human representation of taste and olfaction, likely relies on a multimodal architecture, where unisensory perceptual aspects continuously interact with other sensorial and higher order processing systems (comprising language).

1.1 Crossmodale correspondences

The human brain in order to select and adopt the most appropriate behaviour in the world needs to select information relevant to a specific event or object from the huge amount of simultaneously presented stimuli which reach the different sensory organs. Researchers have defined the ability of the brain to unify only the relevant signals into the perception of a single object, the ‘crossmodal binding’ problem (see Spence, 2011a for a detailed review). In early studies, just as in more recent research, the temporal and spatial coincidence among the different unisensory signals were considered the more relevant factors for crossmodal integration to occur (Calvert, Spence & Stein, 2004; Engels & Singer, 2001; Frens, Van Opstal, & Van der Willigen, 1995; Klemen & Chambers, 2012; Jones, & Jarick, 2006; Macaluso & Driver 2005; Stevenson, Krueger Fister, Barnett, Nidiffer, Wallace, 2013). That is, in general, the greater the spatial and temporal proximity of the stimuli afferent in different sensory modalities, the higher their chances of being integrated into the unitary perception of a given object. However, under certain circumstances the temporal synchrony of two stimuli can generate a misleading perception. For example, in the sound-induced flash illusion, a single flash presented together with two or more audio beeps induce in the observers the perception of a double flash (Innes-Brown, & Crewther, 2009). By contrast, if two or more flashes are presented together with one beep, the observer reports the perception of a lower number of flashes (Maccora, Indovino, Baschi, Paladino, Talamanca, Cosentino, Giglia & Brighina, 2013) (see Fig. 1).

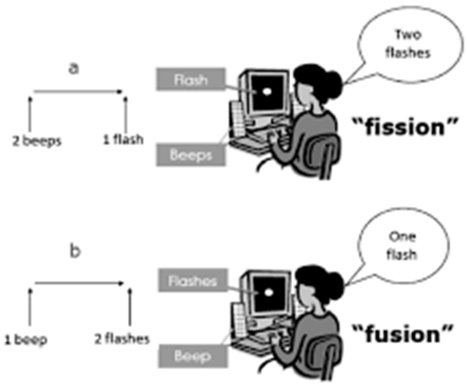


Figure 1 – Sound-induced flash illusion (from Maccora et. al., 2013)

More recently, researchers have investigated how higher level or cognitive factors (such as semantic and synaesthetic aspects) can also modulate the integration of sensory signals in the brain. Spence (2011a) defined 'semantic congruence/incongruence' the conditions in which two simultaneously presented stimuli (auditory and visual) vary with respect to their identity or meaning. For example, a speaker's voice can be matched to the same gender face or not (Lachs & Pisoni, 2004), or, an odour (coffee) can be semantically congruent with a sound (drinking coffee) or not (eating potato chips) (Seo & Hummel, 2011). Instead, 'synesthetic congruence' is based on some sort of 'similarities' between the two interacting senses (Gallace, Boschin & Spence, 2011; Gallace & Spence, 2006) and, in general, is intended as the correspondence between basic stimulus features in different modalities (e.g. pitch in audition and brightness in vision) (Spence, 2011a). Nevertheless, among researches there is not full agreement on the distinction between the concepts of crossmodal correspondence, synaesthetic congruence and full blown synaesthesia. Some researchers consider synesthetic associations just as a weak form of synaesthesia and base their assumptions on the fact that these phenomena share the same neural basis (Martino & Marks, 2001; Simmer, Ward, Lanz, Jansari, Noonan, Glover, Oakley, 2005; Ward, Huckstep, Tsakanikos, 2006). However, it is important to underlie that in synaesthetes the stimulation of a given sensory channel (i.e., vision) is associated to an additional response in a sensory modality that was not directly stimulated (i.e., audition). For example, in grapheme-colour synaesthesia different numbers or letters can induce the experience of colours (the vision of a blue 'O', or a red '5') (Ramachandran, & Hubbard, 2001) (see Fig. 2). Another important distinction is that synaesthetes are a very small portion of the population, while crossmodal correspondence effects are shared by a wide number of (if not all) people (synaesthetes included).

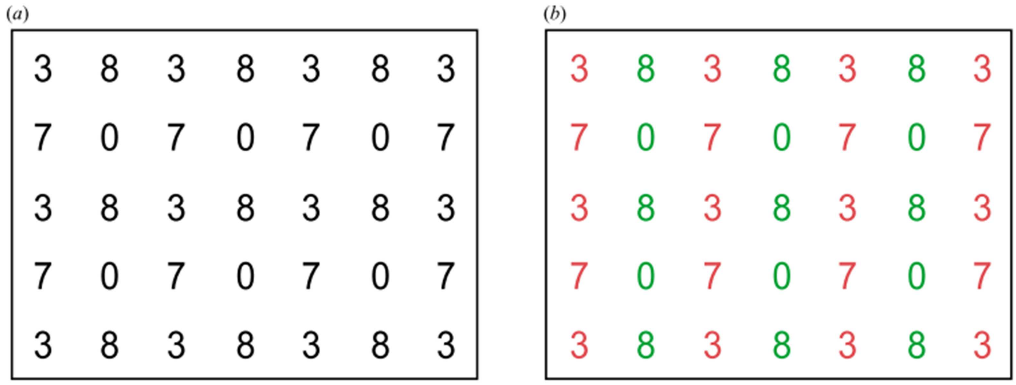


Figure 2 – (a) A matrix number view from a non synaesthetes. (b) The same matrix number view from a synaesthetes (from Ramachandran & Hubbard, 2001)

Other authors simply postulate that synaesthesia is a normal phase of the development of multimodal integration processes in children (Baron-Cohen, 1996; Spector & Maurer, 2009).

The debate on the processes at the basis of crossmodal interaction, recently received some contributions from the Bayesian theory **(**Bernardo & Smith, 1997). In particular, some authors (Ernst, 2006; Ernst & Bülthoff, 2004) postulated that perception is a probabilistic process, that is, an optimal integration of different sensory information due to a reduction in variance of the final perceptual estimate. In other words, the greater the number of times in which a person integrate several signals from the same object, the lower the perception of differences in the final percept estimate. According to Bayesian integration theories, crossmodal integration relies on the combination of prior knowledge and sensory information weighted on the basis of their reliability in a given situation (Spence, 2011a).

On the subject of audio-visual multisensory integration, Parise and Spence (2009) investigated the role of synesthetic correspondences in a series of experiments based on Bayesian models in which pairs of temporally or spatially conflicting auditory and visual stimuli were presented. The task consisted of a series of unspeeded audiovisual temporal order judgment (TOJs) and participants were requested to establish which stimulus was presented first in a sequence. The results demonstrated that the reliability of the available perceptual information is reduced by the intersensory conflicts. That is, when couples of matched stimuli (i.e., high pitched tones with small visual objects), as compared to couples of mismatched stimuli (i.e., high pitched tones with large visual objects) were presented performance deteriorated. Parise and Spence argued that the lower participant's performance in TOJs task with synesthetically congruent auditory and visual stimuli is due to a strong coupling between unisensory signals and reflect the cost of multisensory integration.

1.2 Neural correlates of crossmodal integration

Previous literature has shown that visual, tactile and auditory stimuli can be processes both in unimodal than in multimodal cortical areas of the brain (Benson, 1993; Bushara, Hanakawa, Immisch, Toma, Kansaku, & Hallett, 2003; Downar, Crawley, Mikulis, Davis, 2000; Jacobs, Schall, Prather, Kapler, Driscoll, Baca, et al. 2001; Mesulam, 1998). Nevertheless, the neural mechanisms underlying crossmodal integration remains to date still not entirely clarified. This partial lack of clarity is probably due to the extreme complexity of the brain structure and of the mechanisms involved. The extant research shows that basic characteristics of stimuli (colour, form, pitch) are encoded in upstream sectors of unimodal areas. By contrast, more complex sensory experiences (e.g., the perception of faces, sound sequences, word-forms) are encoded in downstream sectors of unimodal areas. Transmodal areas, the highest synaptic levels of sensory-fugal processing are represented by heteromodal, paralimbic and limbic cortices. These areas play an important role in binding the activity of multiple unimodal and other transmodal areas in order to generate multimodal neural representations (see Mesulam, 1998 for a detailed review). Benson (1993), from clinical and anatomical correlations schematized the major functional subtypes of brain cortex as hierarchically organized and corresponding to a growing complex level of neural processing. The four divisions in which Benson classified the cerebral cortex could be useful in helping to investigate the neural basis of multisensory integration: primary cortex, involved in the initial stages of sensory processing and the final output stage for motor functions; unimodal regions that discriminate, categorize and integrate information within a single modality to form a percept; heteromodal cortex that compares a particular percept with previously experienced percepts from other modalities to form complex multimodal percepts; supramodal association regions, involved in executive control of cognitive networks (see Fig. 3).

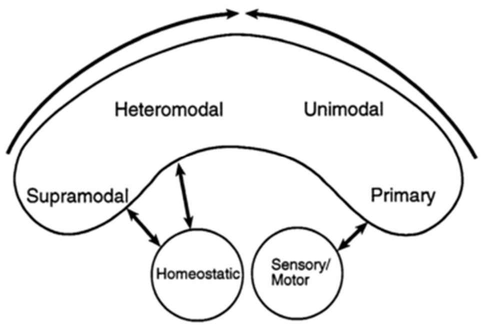


Figure 3 – Represent the Benson's hierarchical schema in classifying the cerebral cortex (from Benson, 1993)

A large number of studies has been devoted to identify where sensory integration occurs in the brain. Early research found evidences that sensory information converges only in higher association areas and specialized subcortical structures, such as the superior temporal sulcus, the intra-parietal sulcus and regions of the frontal lobe (Stein & Meredith, 1993) (see Fig. 4). Subsequently, other studies have investigated the anatomical and functional basis of crossmodal integration in these areas (Avillac, Ben Hamed, Duhamel, 2007; Calvert, Campbell, Brammer, 2000; Graziano, Yap, Gross, 1994; Rizzolatti, Scandolara, Gentilucci, Camarda, 1981; van Atteveldt, Formisano, Goebel, Blomert, 2004; for a detailed review see Van der Stoep, Nijboer, Van der Stigchel, Spence, 2015).

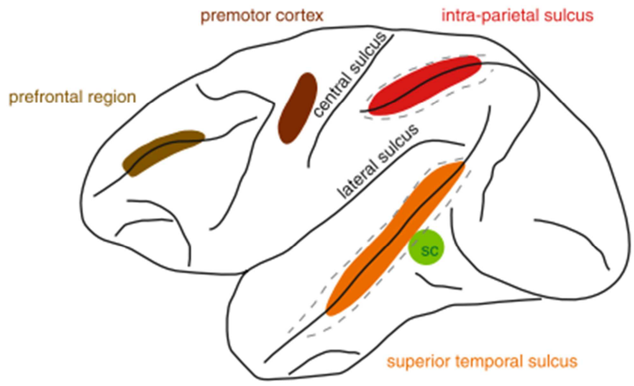


Figure 4 – Represent the cortical areas involved in sensory integration (from Kaiser, & Logothetis 2007)

A number of early studies have also investigated the specific neuronal responses to multisensory information in subcortical structures, such as the superior colliculus. In a series of experiment was shown that the neurons of this area respond to both auditory, visual and somatosensory cues (Stein & Meredith, 1993). Specifically, sensory convergence occurs when the response of a given neuron is elicited by stimuli from different sensory modalities presented alone, or, when its activity is modulated (enhanced or depressed) by a stimulus from another modality. This kind of response was defined also ‘crossmodal interaction’, since different stimuli presented together generate the neuron response to the combined stimulus. The neurons that respond to different sensory stimulations have been therefore defined ‘crossmodal neurons’ (or bimodal, trimodal). As a result of such studies, a number of principles for sensory integration were defined: The principle of ‘spatial coincidence’ (Stein, 1988), according to which the receptive fields of the different neurons which respond to different sensory modalities overlap in the superior colliculus. Only the stimuli that fall within this overlap tend to produce an enhanced response. Whereas, other neurons usually respond to stimulation within a limited spatial region. The principle of ‘temporal coincidence’ (Stein and Wallace 1996) states that an enhanced response of the crossmodal neurons is caused only by stimuli that are presented within a given temporal window. Stimuli that occur outside of this window result into a unisensory response. The interaction between the principle of spatial coincidence and the principle of temporal coincidence, would seem to suggest that, generally only stimuli from the same source can elicit crossmodal interactions (even if research shows that this is not always true). The third principle, namely the ‘inverse effectiveness’ postulates that stimuli eliciting more robust responses, generally provoke little crossmodal interaction, on the contrary, when stimuli that cause weak responses are presented simultaneously, they can elicit multisensory interactions (Perrault, Vaughan, Stein, Wallace, 2003; Stanford and Stein 2007).

More recently, a series of reviews of the literature on neuroimaging and electrophysiological data postulated that the spatial aspects of the hierarchical model of multisensory integration in the human brain need a revision (Driver & Spence, 2000; Kayser & Logothetis, 2007; Macaluso & Driver, 2005; Senkowski, Schneider, Foxe & Engel, 2008). Specifically, a number of authors noticed that multisensory spatial integration can affect also the functioning of 'unimodal' brain areas. This was, for example, demonstrated in some experiments in which during the processing of visual stimuli, the presence of a simultaneous tactile stimulus resulted into a modulation of activation of the occipital cortex (Macaluso, Frith, Driver, 2002).

Actually, the data from the most recent research on visual, tactile and auditory signals interaction would seem to indicate that almost all the neural processes (low and high level) can be defined as 'multisensory' in some ways. In particular, an increasing number of models (Bayes optimal integration, stochastic resonance, phase coherence, subtreshold modulation), the improvement of neuroimaging and electrophysiological techniques (magnetic resonance, functional magnetic resonance, event, related potential, magnetoencephalography) and of the correspondent data analysis (independent component analysis, multivoxel pattern analysis) as well as, the use of new tools of investigation (diffusion tensor imaging, multimodal transcranial magnetic stimulation) would seem to provide the basis for a more specific and sophisticated conceptual framework of crossmodal integration (see Klemen & Chambers, 2012 for a detailed review) (see Fig. 5).

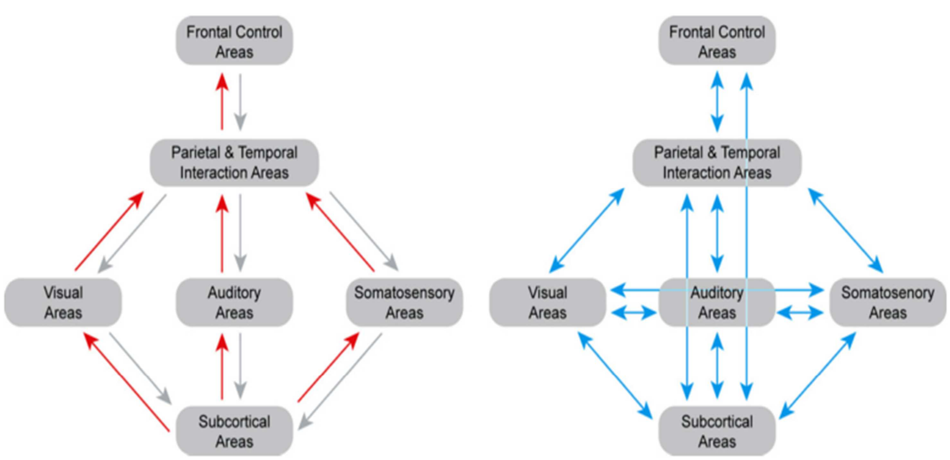


Figure 5 – The comparison between the parallel streams models (left) and the interconnected models (right) of multisensory processing. In the formers sensory information follows a linear processing from subcortical, via sensory areas to higher-order temporal, parietal and frontal multisensory integration sites. In the latters and more recent, all multisensory processing are virtually mutually interconnected and can interact and modulate each other's activity with a different timing from early to late processing stages (from Klemen & Chambers, 2012).

2. Crossmodal correspondence in taste and smell perception.

Surprisingly, until relatively more recent times the study of the integration of the different sensory signals that contribute to form the human gustatory and olfactory experience (the so-called chemical senses) has received very little attention from researchers. This occurred despite of the fact that nutrition-related behaviors are crucial for the survival of all species and probably have strongly contributed to shape human evolution. For this very reason, the lack of knowledge on the integration of gustatory and olfactory information have probably made less solid every early attempt to build an effective and reliable model of human brain multisensory processes. Currently, an increasing number of research are filling this gap by addressing taste and smell crossmodal interaction, as well as the interaction between these senses and other sensory modalities.

It is important highlight here that with the exception of the primary tastes (sweet, salt, sour, bitter, umami), odours are responsible for the largest part of our taste perception. This observation was already made by Titchener (1909), who noticed that people lose their ability to taste even well-known foods when olfactory receptors are blocked by cold (see also Murphy, Cain, & Bartoshuk, 1977). The dependence of the sense of taste on the sense of smell is well described by Rozin (1982) who stated that people attribute some olfactory characteristics of the ingested food to flavour perception (taste-smell confusion). In some pioneering experiments Burdach, Kroeze, & Koster (1984) demonstrated that people report taste quality (sweetness) of non-gustatory solution containing only an odorant (taste-smell illusion).

2.1 Taste vs. flavor

According to Rozin (1982), the term flavour would be more appropriate to describe the mouth and olfactory sensations elicited by foods ingestion in common language; this term is often imprecise with respect to such sensory experience. More specifically, the author argued that 'taste' should be used to refer to the pure gustatory properties (e.g., sweet, salt, sour, bitter) in absence of olfactory or non-gustatory oral sensations. A few decades ago, Garner (1974) postulated that the different components associated to flavour perception (including touch, temperature, chemical irritation, taste, and odour) are perceived as an 'integral' concept. More recently, in a detailed review Spence, Smith and Auvray (2014) regarding the confusion in the use of the two terms, stated that 'tastes' should be classified as a sub-components of 'flavour'. Consequently, basic tastes as 'sweetness' and 'sourness' should be treated as flavours like 'fruity' or 'meaty'. Furthermore, they suggested that the perception of taste is the result of the multisensory interaction among gustatory and non-gustatory sensations that individuals generally classify as tastes (see Fig. 6). Additional topics considered relevant to flavour perception model in Spence's opinion are 'attention' and 'expertise'. In particular, the authors argued that attention is crucial, especially in distinguish the odours that form flavours in their 'retronasal' recognition, (since for humans this seems to be a very difficult task). They postulated that the problem arise from the fact that people are not aware of the fact that they can exert a voluntary control of what is sniffed (Stevenson, 2009). According to this reasoning, the authors also highlight the relationship between attention and expertise; In fact the latter can help to recognize some flavour components when they are familiar, for example, in the case of wine tasters (Ballester, Patris, Symoneaux, & Valentin, 2008; Stevenson, 2009). Spence and colleagues (2014) conclude that the flavour system might be considered a whole separate perceptual sense, conceptually linked to the Gibsonian concept of 'affordances' (Gibson, 1966).

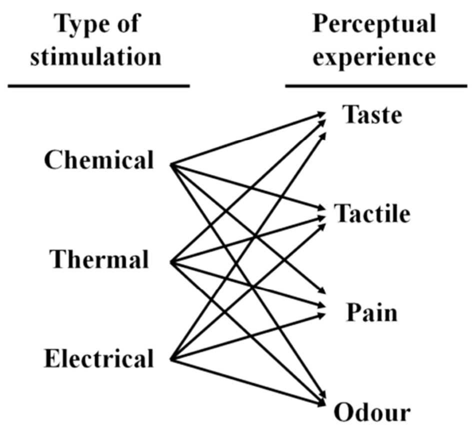


Figure 6 – The complex interactions among the different sensory signals that compose flavour perception (from Spence et al., 2014)

2.2 Gustatory and olfactory crossmodal interaction

Beyond the intricate mutual relationships among the different multisensory perceptions that concur to form the flavour-olfactory experience and make difficult to isolate each other, it is worth mentioning that taste and olfaction are also modulated by the presence of other sensory signals in the environment.

2.2.1 The shape and the appropriateness of the container in food/beverage perception

Research has investigated how certain aspects of the container (rather than of the content itself) can modulate some characteristics of the liquid contained inside it, For example, both in within-cultural than cross-cultural studies it was demonstrated that the shape or, the appropriateness of the container can influence the flavour of a beverage served in it. (Spence & Wan, 2014; Wan, Woods, Seoul, H., Butcher, & Spence, 2015; Wan, Zhou, Woods, Spence, 2015; Wan, Woods, Jacquot, Knoeferle, Kikutani & Spence, 2016; Wan Velasco, Michel, Mu, Woods, & Spence, 2014). The preference of people to drink specific beverages in container of particular shapes would seem to be determined by previous drinking experiences (Standage, 2007). In particular, Spence & Wan (2014) argued that these effects can be formed by a process of associative learning (Pearce & Bouton, 2001). Alternatively, people preferences for the association of determined liquids to specific container shapes, might be driven by people's expectations based on their memory of previous experiences, namely an 'exposure effect' (Gallace & Spence, 2008; 2009) where repeated associations (beverage-container) become more familiar, hence more liked (see Gallace & Spence, 2014, for a review).

2.2.2 The colour of the container in food and beverage perception

In a pioneering work, it was demonstrated that the addition of food colorants (red, brown and yellow) to sparkling mineral water, do not compromise the identification of the liquid both in blindfolded than not blindfolded individuals (Hyman, 1983). Conversely, it was demonstrated that certain colours are univocally associated with particular basic tastes: for example, red and orange with sweet, green and yellow with sour, white with salt (Koch & Koch, 2003; O'Mahony, 1983; Tomasik-Krótki & Strojni, 2008, Wan et al., 2014). Woods and Spence (2016) confirmed the presence of robust cross-modal correspondences between single colours or colour words, and basic tastes or taste words.

Research has also investigated whether people systematically associate specific colours with particular tastes in an acquired, innate, universal, bidirectional or unidirectional fashion. Spence et al. (2015) revised in depth the previous works on the main assumptions of crossmodal association between colour and taste on the basis of the statistical account, the semantic (or linguistic) correspondences, the availability heuristic and the affective correspondences. The statistical account corresponds to the internalization of the statistical regularities of the environment. One example of statistical account is that higher pitches are usually localized spatially higher in space, following on from the fact that as small objects often tend to be more distant from ground than big ones (Woods, Poliakoff, Dijksterhuis, Lloyd, Thomas, 2010). Semantic (or linguistic) correspondence rely on the fact that often, qualitatively different sensory impressions are depicted with the same descriptor (Walker, 2012). Instead, available heuristic (Kahneman, & Tversky, 1973) is linked to the most easily way to exemplifying a given taste. For example, when a person is requested to associate a colour to a sour taste, her/he might create a mental image of a lemon and then name the colour 'yellow'. Lastly, affective correspondence postulates that people tend to match stimuli that raise the same emotion or feeling or are associated with the same affective state (Collier, 1996; see Simmons, 2011 for the demonstration that different colours are linked to different emotions). Actually, none of these hypothesis prevail on the others.

Regarding the influence of the container colour on gustatory perception, much less data have been collected to date. Piqueras-Fiszman & Spence, (2012) showed that participants perceived the flavour of a hot chocolate as enhanced when served in an orange plastic cup, as compared to conditions in which the same beverage was served in red or white cups. Instead, Risso, Maggioni, Olivero and Gallace (2015) demonstrated that people's perceptions, expectations, and choices regarding some characteristics of mineral water (perception of carbonation intensity, freshness, preference for different container's colours to drink sparkling or still water) are differently modulated by the colour of the container where the liquid is served. Guéguen (2003) has demonstrated that beverages contained in blue and green (cold colours) plastic cups were considered most thirst-quenching, as compared to the same beverages contained in red and yellow (warm colours) cups. Whereas, Ngo, Piqueras-Fiszman, and Spence (2012) assessed the presence of crossmodal correspondences between still and carbonated water and colours (blue, red, green). Favre & November, (1979) demonstrated that participants judged as stronger coffee served from a brown jar, as compared to the same liquid served in red, blue or yellow jar. By contrast, in a recent experiment Van Doorn, Wuillemin, and Spence (2014) demonstrated that a white mug enhanced the flavour intensity and reduced the perceived sweetness of the coffee served in it, as compared to coffee served in a transparent or a blue mug.

With respect to the associations between the colour of the container and food, Shankar, Levitan, Prescott and Spence (2009) reported that people judged as more *chocolatey* the M&Ms with a brown label, as compared the green labelled M&Ms. Stewart and Goss (2013) showed that their participants perceived a piece of cheesecake to be sweeter, higher in flavor intensity, superior in quality and more pleasant when eaten on plates with certain association between their shape and colour (i.e., white round or square plates and black round or square plates). Similarly, Piqueras-Fiszman, Alcaide, Roura and Spence (2012) showed that the colour of a plate (black or white) can affect people's perception of a mousse only when served within a certain dish or container.

People expectations on a specific product, have been highlighted among the possible explanations, for accounting the container-colour modulatory effects. In fact, Levitan, Zampini, Li, & Spence (2008) showed that participants asked to judge whether a pair of differently coloured candies (Smarties©) had the same flavour or not ,were affected by the participants' previous beliefs (i.e., regarding whether or not such orange candies taste differently from other coloured candies). The fact that some sensory proprieties (colour, texture, weight, etc.) of the container can modulate individuals' perception or feeling concerning the beverages served in it, was defined 'sensation transfer' (Spence & Piqueras-Fiszman, 2012). Sensation transference would occur beyond people's expectations regarding the liquid tasted. In order to explain some of these effects, researchers have also defined the concept of 'affective ventriloquism'. This concept refers to the fact that the hedonic/emotional attributes of a product/stimulus perceived via one modality can 'pull' (or bias) a person's estimate of the quality and pleasantness of the product/stimulus derived from other sensory modalities into alignment, and by so-doing, modulate a person's overall product/stimulus experience.

It is important to note here that the presence of crossmodale correspondences between colour and taste seems to be well justified by evolutionary pressure. Prehistoric humans were likely looking for food with a high calories content, and for that reason they probably have learned to associate certain colours with high energy foods (just as in the case of the red colour associated with ripe fruits or with animal blood (Maga, 1974; Spence et al., 2010).

2.2.3 The tactile and textural attributes of food/beverage and of the container in taste perception

The gustatory crossmodal integration processes related to the somatosensory features of the container in which food and beverages are served, actually are those that have received less attention from researchers. With reference to the food-texture effects Tournier, Sulmont-Rossé, Sémon, Vignon, Issanchou, and Guichard (2009) showed that a variation of the texture of food can affect people's perception of some of its characteristics. In particular, they found that an increase in the viscosity of a custard dessert enhanced people's perception of its taste intensity. As far as food containers are concerned, Piqueras-Fiszman and Spence (2012b) demonstrated that the texture of a container can modulate people's gustative perception of the biscuits that are consumed in it. Specifically, the biscuits taken from a rough pot were perceived as crunchier and harder than those taken from a smoother pot. Similar results were reported by Biggs, Juravle and Spence (2016) in a series of 'citizen science' tests in which people rated the mouthfeel and food sensations of biscuits and jellies served in plates having rough or smooth finishes. The results showed that participants rated the food as crunchier and rougher when tasted from rougher plates than when tasted from smoother plates. Similarly, participants evaluated the biscuits as saltier and gingerier when picked from the rough plate and sweeter when tasted from the smooth plate.

Among the few studies that addressed the interaction between taste and texture perception of beverages Szczesniak, (2002), investigated through questionnaires and interviews which attributes of liquids and food textures make them unacceptable or inappropriate for participants. Unsurprisingly, it was reported that lumps or hard particles in beverages are considered inappropriate (due to the fact that they provoke fear of choking). Regarding the effect of the textures of the container on liquids, Schifferstein (2009) used cups made of different materials (translucent plastic, opaque plastic, melamine, glass, ceramic) to evaluate the drinking experience relative to two different beverages (soda or hot tea). The participants rated also the empty cups with respect to a set of characteristics related to affective dimensions (i.e., pleasant-unpleasant, good-bad) and sensory perception (i.e., heavy-light, thick-thin). The author found that, with just a few exceptions, the drinking experience followed the experience of the cups (e.g., the more pleasant was perceived the cup, the more pleasant was perceived the drink). On a similar line of research, Krishna and Morrin (2008) investigated the effect of the firmness of a plastic cup on the taste perception of a mixed drink (one can of Sprite diluted into 6 litres of water). The results showed that the firmer a cup was, the higher the participants evaluated the quality of the drink inside.

More recently, Tu, Yang, and Ma (2015) investigated the effect of different packaging materials on taste perception of traditional Chinese cold tea beverage. People were asked to evaluate three dimensions, bitterness, sourness and sweetness of the same tea drink (although they were led to believe that three different brands of the beverage were tasted) served in cups made of different materials (glass, paper, organic plastic). The results showed that the haptic perception of the cup affected people taste perception of the beverage contained in them. In particular, people rated the sense of ice (a sub-dimensions of the scale measuring sweetness) of the beverage as significantly higher when tasted by means of the glass cup with respect to paper or organic plastic cups. The effect of containers textures on the evaluation of mineral water taste, was recently investigated by Risso, Maggioni, Etzi and Gallace (submitted). During the experiment, the water was served in three identical commercial cups: one covered with a layer of sandpaper, the other with a layer of satin, and the third covered by the same material of the cup (plastic). The participants were blindfolded during the task, and were asked to evaluate mineral water (freshness, pleasantness, level of carbonation, lightness) using visual analogue scales. The results showed that mineral water was perceived as fresher and more pleasant when contained in the plastic cups, than when it was contained in the cups covered with sandpaper or satin.

Among the different somatosensory characteristics taken into account, a few studies have investigated the effect of the weight of the container in food and beverages taste perception. In a study by Piqueras-Fiszman and Spence (2012c), it was demonstrated that a heavier container enhances a participant’s perception of the density of yogurt (i.e., a semi-solid food) as well as the expected satiety and feeling of fullness even before the food is tasted. Similarly, Piqueras-Fiszman and Spence (2011) reported that yogurt eaten in the heaviest of three identical bowls was rated as the most dense, pleasant, and expensive. The same research group (Piqueras-Fiszman, Harrar, Alcaide, and Spence, 2011) also showed that participants judged yogurt as more pleasant and higher in quality when eaten with a stainless steel spoon rather than a plastic spoon. It is, however, important to note here that the food used in these experiments was limited to yogurt, a gel-like substance that cannot be fully classified as a solid food or beverage. With respect beverages, only two studies investigated the effect of the weight of the container on beverage taste perception. The first was mainly focused on the effects of increasing the weight of a bottle on people's expectations regarding certain characteristics of wine (Piqueras-Fiszman and Spence, 2012d). The authors of this study found that potential customers expected the wine to be more expensive and of better quality when contained in heavier bottles instead of lighter bottles. Note, however, that the participants in that study did not taste any wine or even interact with its container but instead only evaluated the product using an online questionnaire. Therefore, it remains unclear if beverage perception can be affected by the tactile/haptic aspects of the container and whether various liquids are similarly affected by the same tactile manipulation of the container in which they are served. In another second study the multisensory interactions between some characteristics of two kind of mineral water and the weight of the plastic cup in which the liquid is served was investigated (Maggioni, Risso, Olivero & Gallace, 2015). The participants evaluated the freshness, pleasantness, level The participants evaluated the freshness, pleasantness, level of carbonation, and lightness of two types of mineral water (still and carbonated) using visual analogue scales. The water was served in three identical plastic cups, varying only in terms of their weight (light, medium, and heavy). The results showed that when a heavier cup was used, the participants perceived the mineral water as less pleasant. By contrast, they rated the water served in heavier cups as more carbonated than water served in lighter cups. These data demonstrate that crossmodal associations in taste perception depend on the category of the product being evaluated and the specific quality that is rated.

2.2.4 The hearing contribution to food and beverages cross-modal taste perception

A few studies have addressed the interaction between taste and sound in food and beverage perception. The crossmodal correspondences between audition and taste perception includes the associations with simple auditory stimuli, for example, pure tone and basic tastes (Bronner, Frieler, Bruhn, Hirt, Piper, 2012; Crisinel & Spence, 2009; Crisinel & Spence, 2010a; Holt-Hansen, 1968), as well as, associations with more complex stimuli, for example, flavors and music (Crisinel, & Spence, C. 2010b; Crisinel, & Spence, 2011; Crisinel, & Spence, C. 2012; Knoeferle, Woods, Käppler, Spence, 2015; Mesz, Sigman, & Trevisan, 2012; Mesz, Trevisan, & Sigman, 2011; Reinoso Carvalho, Van Ee, Rychtarikova, Touhafi, Steenhaut, Persoone & Spence, 2015; Spence, 2011b; Spence, & Wang, 2015a; Spence, & Wang, 2015b; Spence, & Wang, 2015c; Spence, Michel, & Smith, 2014). With reference to the low level gustatory-auditory associations, Holt-Hansen (1968) demonstrated that participants matched the taste of two different beers with different pure tones. That is Carlsberg Elephant was matched to an average frequency of 640–670 Hz, and regular Carlsberg was matched to an average frequency of 510–520 Hz. More recently, Bronner et. al. (2012) performed an experiment where participants had to imagine the flavour of a fruit (orange, lemon and grapefruit) associated to a sample sounds having different intensity and sharpness. The results showed that the more intense and sharp the sound samples were, the higher sourness was perceived (orange least sour, lemon most sour, grapefruit between orange and lemon). Similarly, Crisinel and Spence (2010a) used an implicit association test to investigate the strength of the link between high-pitched sounds and the names of sweet-tasting foods, and between low-pitched sounds and the names of salty-tasting foods. The authors demonstrated that sour and sweet-tasting names of foods were associated with high-pitched sounds.

Regarding the association between flavour and music, Mesz et al. (2011) investigated whether taste words (sweet, sour, salty, bitter) elicited consistent musical representations during improvised performances of trained musician. The results showed that 'bitter' musical improvisation are low-pitched and legato (without interruption between notes), 'salty' improvisations are staccato (notes sharply detached from each other), 'sour' improvisations are high-pitched and dissonant, and sweet are consonant, slow, and soft. Instead, Crisinel and Spence (2012) explored the association between the flavour of three different type of chocolate (dark, milk, and marzipan-filled) and a musical note played by a specific instrument with a particular pitch.

In a recent review of the literature, Knöferle & Spence (2012) hypothesize a series of possible mechanisms at the basis of crossmodal correspondences between tastes/flavors and auditory stimuli. The authors postulate four possible explanations with respect the causes of the interactions and associations found. The first is 'intensity matching' (Stevens, 1957), based on the concept that unimodal stimuli can be described in categories of 'less' and 'more'. That is, the loudness of a sound could be mapped onto the intensity of a gustatory stimulus with the effect that an enhancement in a property results into an increase in the other property or dimension (Smith & Sera, 1992). Another hypothesis is related to 'hedonic matching', through which some crossmodal correspondences may depend on the affective value of different stimuli. For example, tastes judged as unpleasant could be matched to sounds rated as unpleasant and vice versa. Nevertheless, Knöferle & Spence (2012) specify that only a few studies have confirmed this hypothesis (Crisinel & Spence, 2010b, 2012), concluding that undoubtedly the origin of the match between taste and pitch is attributable to different mechanisms. Alternatively, crossmodal correspondences between taste and sounds may be explained in terms of 'statistical co-occurrences'. As demonstrated by Simner, Cuskley, & Kirby (2010), participants map some phonetic speech acoustic qualities to particular kind of tastes. For example, sweet tastes are mapped into a lower spectral balance, as compared to sour tastes. Simner and colleagues argued that taste-sound correspondences may have contributed to the naming of objects in language evolution. According to Simner et al. (2010) and Spence (2012) the association between bitter and sweet tastes with low-high pitched vowels respectively could be attributed to the natural orofacial gesture made by every infant in response to different gustatory stimuli. In particular, human babies, just as several other mammalian species, protrude their tongue outward and upward in response to pleasant tastes and outward and downward in response to aversive tastes (Steiner, Glaser, Hawilo, & Berridge, 2001). Statistical co-occurrence would be generated by the babies' experience to generate specific auditory cues in response to specific gustatory input early in life (Spence, 2012).

The last hypothesis, namely 'semantic matching', would originate when a single term is used to define sensations caused by the stimulation of different sensory modalities. An example with respect to taste-sound associations, is the use of the word 'sweet' to define a taste or a music brain: "sweet music". Support for this suggestion is offered by the semantic coding hypothesis by Martino and Marks (1999) according to which, the metaphorical associations between different senses occur at the higher level of information processes. Hence, the information that originate from several senses is codified by means of abstract representations, likely verbal/semantic.

Taking into account the wide range of studies on the crossmodal correspondence between aspects of foods, beverages and sounds, a special mention deserves the association between music and wine. In fact, it has been shown that people have a strong tendency to match specific wines to particular pieces of music. Spence and Wang (2015a, 2015b, 2015c) in a comprehensive review have described in detail such associations often collected during wine tasting event. For example, in one of these events, naive consumers were asked to taste two red and two white wines while listening simultaneously to one of eight pre-recorded classical music selections. They were also requested to rate how well each wine matched with each piece. The results demonstrated that a 2004 Château Margaux (a red wine) was matched by participants with the second and third movements of Tchaikovsky's String Quartet No 1. While, a 2010 Pouilly-Fumé Silex, Domaine Didier Dagueneau (a white wine) was matched with Mozart's Flute Quartet in D Movement 1 Allegro. The authors, in their articulate reviews analyse the possible origins of the match between specific music and different types of wine, with particular emphasis on the fact they are not attributable to synaesthesia. Spence and Wang (2015a, 2015b, 2015c) have observed that synesthetes that experienced specific flavours hearing particular sounds are exceptionally few, while the effects described in their reviews are shared by a great number of people. The authors argued instead that at the basis of the phenomenon, there are the emotions generated by the music which once associated with the wine would seem to increase and hence enhance (through selective attention), the salience of some characteristics of the beverage. In the present doctoral project, it was not addressed the specific crossmodal correspondence between music and wine. On a different line of research Woods et al. (2011) in a series of experiments demonstrated that the intensity of the background noise can modulate the perception of food properties (sugar level, salt level, crunchiness, liking, food crunchiness, overall flavour, food liking). Participants during the experiment ate different foods while listening simultaneously to no sound, quiet or loud background white noise. The results showed that the sweetness and saltiness of food was evaluated as significantly lower in the loud compared to the quiet sound conditions. By contrast, crunchiness was reported to be more intense under the former condition of stimulus presentation.

Zampini and Spence (2005) showed that participants' perception of carbonation intensity of sparkling mineral water is affected by an alteration of the frequency of the auditory feedback emitted by the liquid just before consumption. During the experiment the sound emitted by sparkling water was manipulated in order to amplify its higher frequencies. The researchers found that the participants judged as more carbonated the water presented under this condition of stimulus presentation, as compared to a condition where no sound manipulation was performed. As far as the sound emitted by the machinery used to manipulate food and beverages is concerned, Knöferle (2012) in several experiments demonstrated that participants judged as tasting better the coffee prepared with a machine manipulated to emitted a higher quality sound during its use, as compared to a machine that produced a low quality sound during coffee preparation.

Finally, an intriguing method that can be effectively used to investigate crossmodal correspondances between the elements of the whole context (including music and sounds) where food is consumed is the immersive approach by Sester et al. (2013). The authors suggest that several variables may interact in order to influence food and beverages related behaviors: the food (e.g. package or label), the person (e.g. social factor) and the eating situation (e.g. physical surrounding) (Meiselman, Johnson, Reeve, & Crouch, 2000; Weber, King, & Meiselman, 2004). In order to test their claims the authors created two bar-like environments based on the idea of ‘‘having a drink in a bar’’. The first set, mainly made with wood furniture was defined ‘warm’ and the second, mainly made with blue furniture, was defined ‘cold’. Clips with visual and music stimuli were also projected on a wall to modulate the mood of the ambient (see Fig. 7).

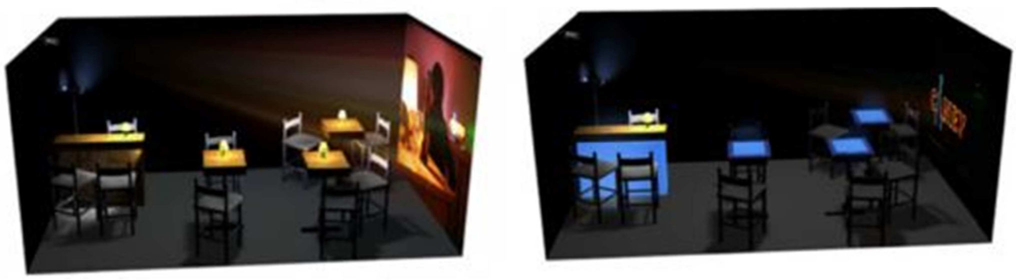


Figure 7 – Left, the laboratory reconstruction of the warm immersive bar. Right, the laboratory reconstruction of the cold immersive bar. (from Sester et al., 2013)

The results of this study demonstrated that the different ambient of consumption are sufficient to affect the drink choices of the participants. However, as also pointed out by the authors, it remains unclear how the different variables of the experimental setting modulate the drink preference: a) separately or only in combination; b) implicitly or explicitly; and c) through perceptual, cognitive or semantic associations? A similar experiment with a more ecological approach was administered in The Chocolate Line Shop Antwerp in which participants tasted different type of chocolate prepared in the working kitchen. In this case the soundscape conditions of the environment were changed so that, people was divided in four groups and tasted the chocolate wearing a pair of headphone in which different audio files were alternately played: the ambient soundscape of the production kitchen; a song; the same song but to participants were also told that it was the chocolatier's source of inspiration when he/she created the chocolate sample; the same song and the participants were told that the song was chosen by a team of scientists because it was found to be effective in enhancing the taste of the chocolate. The results revealed that the participants report a significantly better tasting and highest willingness to pay for the experience in which the sounds were presented as part of the food's identity. That is, in the condition in which they were told that the song was used as the source of inspiration by the chef (Carvalho et al., 2015).

2.2.5 The sound/shape symbolism in food and beverages cross-modal taste perception

The concept of sound symbolism derives from those studies that have investigated the presence of a robust association between abstract rounded or angular shapes and the pseudo-words "Bouba" and "Kiki" or "Maluma" and "Takete" (Köhler, 1929; Köhler, 1947; Jespersen, 1922; Ramachandran, & Hubbard, 2001; Sapir, 1929). Specifically, almost a century ago Köhler, (1929) showed that people significantly associate the non-words 'Baluba' and 'Takete' respectively to rounded and sharped abstract shapes (see Fig. 8). In subsequent years, many experiments have replicated these results using several non-words, although, to date, it has been not yet clarified the underlying mechanisms. Indeed, some researchers have attributed the non-arbitrary association between pseudo-words and shapes to the differences in the dimension and configuration of the vocal articulatory tract in pronouncing vowels /a/, /o/ and /u (in this case open and expanse associated to large and rounded shapes). That is, a small and contract vocal tract in pronouncing vowels /e/ and /i/ might be linked to small and harsh shapes (Maurer, Pathman & Mondloch, 2006; Newman, 1933; Ramachandran, & Hubbard, 2001). It has been suggested that sound symbolism might be the bootstrap of the evolution and of the development of language based on the human inherited capability to map and integrate multimodal inputs (Asano, Imai, Kita, Kitajo, Okada, Thierry, 2015; Imai, Kita, 2014; Maurer et al., 2006; Ozturk, Krehm, Vouloumanos, 2013). Intriguingly, the presence of synaesthetic correspondences between verbal properties of stimuli and gustatory stimuli were studied by changing the visual and auditory features of the non-words, using only specific phonemic sounds, as well as, through the use of correspondent shapes. Gallace et al. (2011) highlighted the presence of crossmodal associations between the visually presented pseudo-words 'takete/maluma' and 'bouba/kiki' and the taste of different kind of food. They found that potato chips and cranberry sauce were rated as being more 'takete' than brie cheese while mint chocolate was rated as more 'kiki' than regular chocolate.

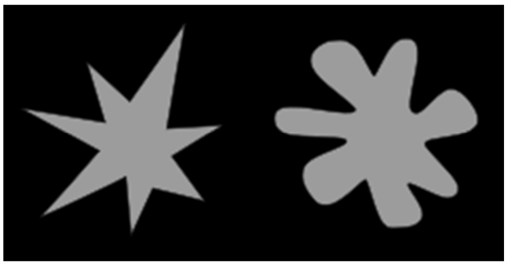


Figure 8 – Left the shape associate to the non-words 'kiki' and 'takete'. Right the shape associate to the non-words 'bouba' and 'maluma' (from Gallace & Spence, 2006)

In a different study Spence and Gallace (2010) asked their participants to taste different foods and beverages and match them to visually-presented shapes and nonsense words. The results revealed that among several foodstuffs people associated sparkling water, cranberry juice, and Maltesers – chocolate-covered malt honeycomb to angular shapes and high-pitched meaningless words, such as 'kiki' and 'takete'. Conversely, still water, Brie, and Caramel Nibbles (chocolate-covered caramel) were associated to lower-pitched pseudo-words, such as 'bouba' and 'maluma'. Instead, Ngo, Misra and Spence (2011) demonstrated that visually presented shapes and non-words are differentially associated to chocolate samples varying in cocoa content. That is, Lindt extra creamy milk chocolate (30% cocoa) and Cadbury's Koko milk chocolate truffles were associated with rounded shapes and softer sounds, lower-pitched pseudo-words, such as 'maluma'. While, Lindt 70% and 90% cocoa chocolates were more strongly associated with sharper (angular) shapes and sounds, such as 'takete'.

A research on the crossmodal associations between commercial exotic fruit juices and sound and shape symbolism showed that juices that were judged sweet and low in sourness, were matched with rounder shapes and speech sounds, and were generally liked more. Conversely, those juices that were judged as tasting sour, were consistently matched with angular shapes, sharper speech sounds, sounds with a higher pitch, and were liked less (Ngo, Velasco, Salgado, Boehm, O'Neill, Spence, 2013). At a more perceptual level, Simner et al. (2010) created four sounds that are thought to represent the phonetic qualities of speech to map some acoustic characteristics of the basic tastes. They found that participants tend to associate sweet tastes to a lower spectral balance (as compared to sour tastes). Moreover, the authors showed that people map several sound qualities to various taste concentrations.

In the last few years, the research of the neuroscientists on the crossmodal associations between particular sounds/shapes and specific objects has attracted the attention of companies interested, at an applicative level, in optimizing the marketing design of their products. Several experimental designs have then focused on certain commercially relevant aspects of food (Salgado-Montejo, Velasco, Olier, Alvarado, Spence, 2014; Velasco, Woods, Deroy, Spence, 2014; Velasco, Woods, Hyndman & Spence, 2015). For example, Velasco et al. (2014) assessed the role of liking in the association of both ‘basic’ taste names and actual tastants to visual morphed shapes along the roundness/angularity dimension. The results demonstrated a significant match only between sweetness and roundness and only in the experimental condition with actual tastants. Moreover, it was showed that people’s liking for a taste influence their shape matching responses. Intriguingly, no results was found in the experimental paradigm where the words that represent basic tastes were presented. By contrast, Salgado-Montejo et al. (2014) demonstrated that simple line segments and shapes that are used as graphic components of some brand images (typeface and logo symbol) evaluated trough visual analogue scale anchored to sound/shape symbolic stimuli, can contribute to convey particular emotional meanings. While, Velasco et al. (2015) by means of an on-line study investigated how basic taste words (sweet, sour, salty, and bitter) match to typefaces, printed on a container and varying in their roundness versus angularity. The authors demonstrated that participants matched rounder typefaces with the word ‘‘sweet,’’ whereas more angular typefaces were matched with the taste words ‘‘bitter,’’ ‘‘salty,’’ and ‘‘sour.

2.2.6 The role of odours in gustatory perception

As already mentioned, the close relationship between odour and taste has led to postulate that the olfactory, gustatory, trigeminal components of food perception, as well as tactile and auditory visual cues perceived when tasting foods, are inextricably joined to form flavor perception (Auvrey & Spence, 2007; Spence et. al., 2014). This view abolishes the idea of basic tastes (such as ‘sweetness’), as a separate category and suggest that they should rather be considered sub-components of flavor, likewise ‘fruity’ or ‘floral’.

Olfaction is not only one of the key elements of gustatory perception in helping to determine a particular flavor, but taken as a separate system, it generates powerful crossmodal associations with tastes/flavors. For example, it was reported that an odour can elicit also a taste response in a tasteless solution, besides the expected olfactory response (Burdach et al., 1984). In a series of pioneering experiments it was observed that strawberry odour enhances the sweetness of a sucrose whipped cream, while peanut butter odour did not enhance sweetness. Moreover, strawberry odour did not enhance the saltiness of sodium chloride, and by pinching the participant’s nostrils the 85% of the effect of strawberry odour on sweetness enhancement was eliminated. Furthermore, it was also shown that the colour red, contrary to strawberry odour, did not modulate sweetness (Frank & Biram, 1988; Frank, Ducheny & Mize, 1989). Subsequently, it has been assessed that the increase-decrease in sweetness taste perception is a function of the specific strategy adopted by participants for the evaluation and of the odours familiarity. In other words, these effects depend on the kind of questions asked to participants (e.g., whether they are asked to rate only the intensity of the sweetness of a flavour or, to rate the different components of a flavour), as well as to the initial familiarity of the odour through repeated exposures (Prescott, 1999). Stevenson, Prescott and Boakes (1999) showed that the degree of odours sweetness rated by participant determines the degree of enhancement or suppression of the sweetness of sucrose. That is, caramel, maracuja, strawberry and lychee odours enhance sweetness taste. While, damascone and angelica oil odours suppress sweetness. Moreover, caramel odour was found to suppress the sourness of citric acid. More recently, it was demonstrated that ‘cut grass smell’ defined as ‘green odour’ (a note characteristic of olive oil), enhances bitterness perception (Caporale, Policastro, Monteleone, 2004). Similarly, it was shown that the sardine aroma enhance salt intensity in tasteless solutions or in low-salt content solutions. (see also Nasri, Septiel, Beno, Salles, Thomas-Danguin, 2012).

Regarding the interaction of odours with more complex stimuli Gallace, Risso, Covarrubias and Bordegoni (in submission), by means of a small size olfactory device investigated the crossmodal correspondence between three different olfactory stimuli (air, chocolate, citrus) and two different types of food (sugar candies and crackers). In particular they found that participants perceived candies and crackers as more pleasant when presented together with the odor of citrus, than when presented with the odor of chocolate or in a no odor condition. Moreover, participants' perception of sweetness of both foods (candy and crackers) increased when presented with the odor of chocolate, as compared to when presented with the odor of citrus or air. Interestingly, the same experiment conducted with three different beverages (sparkling water, tonic water and Sprite®) did not showed significant crossmodal effects of the odours.

Researchers are trying to understand and define the mechanisms and the neural correlates that join odours to flavour perception. Recently, it has been proposed that flavour perception arise by both perceptual experiences and attention (Prescott, 2015). According to Prescott (2015), the hedonic characteristics of tastes are transferred to odours. Hence, odour paired with sweetness become liked and sweet, the opposite occurs for the odours paired with bitterness. What is more, Prescott argued that the binding between odours and tastes is likely mediated by the tactile receptors of the mouth that can provide spatial information and enhance localization (see Fig. 9). As far as this aspects is concerned, in a fMRI study it was demonstrated that odours that contribute to flavour perception and that are perceived via retronasal route (a condition where food molecules reach the back of the nose through eating or drinking), activate the mouth area of primary somatosensory cortex. It is worth noting that odours presented orthonasally (when inhaled or sniffed directly from the nose) did not activate the same area of the somatosensory cortex (Small, Gerber, Mak, Hummel, 2005). Regarding the role of attention, its effect would likely concern the kind of hedonic evaluation requested to participants (synthetic versus analytic). In fact, Prescott, Lee and Kim (2011) demonstrated that the flavour pleasantness of a tea drink is enhanced when the stimulation is evaluated as a whole (synthetic approach), rather than when the participants are requested to rate independently the different components of the beverage flavour, for example, sourness, sweetness, bitterness, lemon flavour, astringency (analytic approach). In other words, the analytic approach of liking diminish the use of hedonic information.

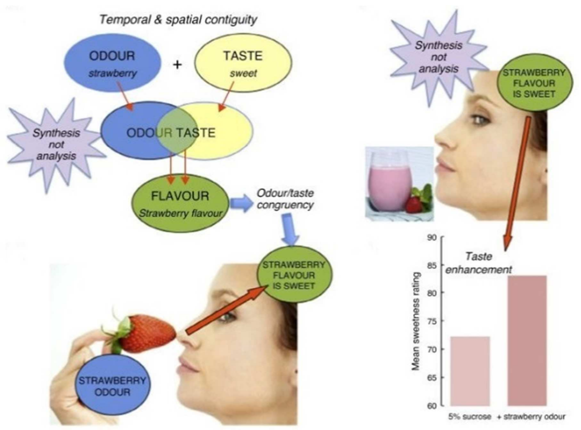


Figure 9 – Prescott's model of olfactory capture (from Prescott, 2015)

In a recent review of the literature, Spence (2016) has underlined the crucial role of the distinction between orthonasal and retronasal olfaction, arguing that the former is relevant to modulate the hedonic aspects and the expectations on food and beverages. While, the latter is more relevant to flavour experience (see Fig. 10). The author also postulated that the best approach to investigate the interaction between taste and odours is the Bayesian causal inference model **(**Bernardo & Smith, 1997; Ernst, 2006; Shams & Beierholm, 2010).

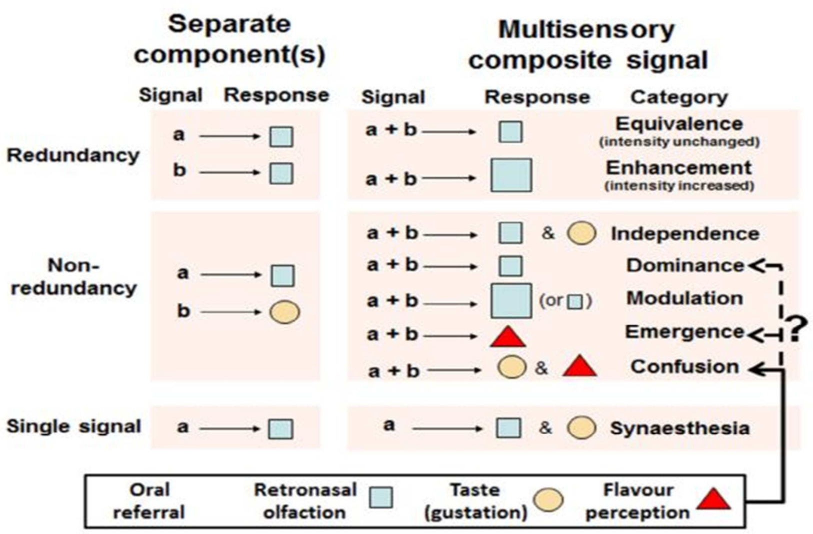


Figure 10 – Spence's modified model of the different types of multisensory interactions. Red triangle represent author's new hypothesis on oral referral (from Spence. 2016)

2.2.7 Olfaction, and the other sensory modalities

Given the uniqueness of the effects highlighted in taste/olfaction crossmodal interactions one may wonder if something similar occurs also with sight, hearing, tactile (out of mouth) and hedonic associations. In previous researches, the presence of crossmodal correspondence between odours and specific colours were observed (Engen, 1972; Demattè, Sanabria & Spence, 2006; Demattè, Sanabria & Spence, 2009; Gilbert, Martin, Kemp, 1996; Morrot, Brochet, Dubourdieu, 2001; Stevenson & Oaten, 2008; Zellner, Bartoli, Eckard, 1991). For example, caramel lactone odour was found to be paired with brown colour (Gilbert et al., 1996). Demattè et al. (2009) investigated both perceptual than semantic level of processing using a speeded odour discrimination task (lemon vs. strawberry). The participants during the experiment were required to ignore the concurrent presentation of three kind of distractors (black and white, red or yellow patches; black and white, red or yellow drawing of a lemon; black and white, red or yellow drawing of a strawberry while smelling the odors. With respect the odour presented the distractor could be neutral, congruent or incongruent (e.g., a yellow strawberry associated to the strawberry odour). The results showed an effect of the congruent colour on the discrimination of the odour. Herz and von Clef , showed that the verbal label assigned to an odour reverse its perceptual judgment by participants of (e.g., a combination of isovaleric and butyric acids, I-B acid, is perceived as ‘vomit’ or ‘parmesan cheese’ and unpleasant/pleasant respectively, as function of the verbal context of presentation). Researchers working on the crossmodal integration between odours and tactile information have demonstrated some interesting effects in evaluating the associations between odours and the texture of fabric swatches (Demattè, Sanabria, Sugarman & Spence, Fiore, 2006; Laird, 1932; Spector & Maurer, 2012) or, odours and the texture of abstract clay sculptures (Jezler, Gilardi, Gatti, Obrist, 2016). Olfactory information has also shown to interact with sounds, in particular pitches, musical notes and specific musical instruments (Belkin, Martin, Kemp, Gilbert, 1997; Crisinel & Spence, 2012a; Crisinel, Jacquier, Deroy, & Spence, 2013). Regarding musical instruments, significant associations were observed between musk odour and brass musical instrument. Similar associations were found between candied orange, dried plums, iris flower odours and piano (Crisinel et al., 2013). Finally, Belkin et al. (1997) using a method of limits showed as a specific series of odours were matched to n series of auditory tones.

Researchers also demonstrated that shape symbolism affects olfactory perception (Crisinel et al., 2013; Hanson-Vaux, Crisinel & Spence, 2013; Seo et al., 2010). In particular, it was found that lemon and pepper were associated with an angular shape; on the contrary, raspberry and vanilla were associated with a rounded shape (Hanson-Vaux et al., 2013). In Seo et al. (2010) experimental paradigm in which event-related potentials (ERPs) were also measured, some abstract symbols (see Fig. 11) were demonstrated to match certain odours (phenylethanol PEA, similar to violet odour, or 1-butanol, similar to parmesan cheese). In a second experiment participants were requested to rate the pleasantness and the intensity of the two odours (PEA and 1-butanol presented associated to the shapes in three different conditions (no symbol, congruent and incongruent symbol). The behavioral results did not revealed any significant differences in the intensity and pleasantness of the PEA odour (rated as pleasant by participants), or 1-butanol (rated as an unpleasant odour by participants). However, ERPs data demonstrated that the congruency between olfactory and visual stimuli gave rise to faster neural responses to odours. Moreover the congruence effect resulted in changes on peak amplitude and latencies of N1component generated by the stimuli.

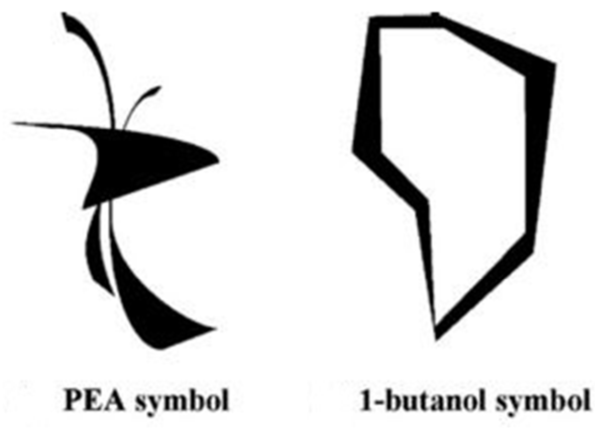


Figure 11 – Seo's symbols significantly associated to odours. On the left PEA Odour, on the right 1-butanol odour (from Seo et al., 2010)

As far as the interpretation of these associations are concerned, it was observed by Deroy, Crisinel and Spence (2013) that associative learning can well explain crossmodal interaction between odours and tastes. Nevertheless, associative learning does not seem to be the best explanation for other kind of sensory integration (e.g., odours and sound pitches or geometrical shapes). Following on from this line of reasoning, the authors in their review suggested that associative learning might be originated by repeated and statistically relevant exposures between particular stimuli (e.g., odours and colour) also defined as ‘metaphorical mapping’. The other types of associations (e.g. between odours and shapes) according to Crisinel and Spence might be better explained by means of the amodal, indirect, and transitive mappings hypothesis based on structural perceptual or neurological determinants.

2.2.8 Neural correlates of crossmodal integration in taste and smell perception

The main issues about taste and olfactory crossmodal correspondence, regards the fact of, whether their neural correlates are similar to those responsible for the integration among the other sensory modalities. As far as auditory-olfactory interactions are concerned, *in vivo* extracellular recordings from the olfactory tubercle in mice showed that single units of this structure selectively respond to odours, and 19% of these units respond also to auditory tone. Moreover, 29% of the single units tested showed superadditive or suppressive responses to the contemporaneous presentation of odours and tones, suggesting, according to the authors, the presence of crossmodal modulations (Wesson & Wilson, 2010). Visuo-olfactory crossmodal correspondence in the human brain were investigated using event-related fMRI by Gottfried and Dolan (2003). The study consisted of an olfactory detection task in which odours alone, pictures alone and odours plus pictures pairs were administered in semantically congruent or incongruent trials (e.g., orange odour/orange picture, orange odour/bus picture). In the congruent condition of odour-picture pairs a perceptual olfactory facilitation for the semantically congruent associations was found. This experimental condition was associated with an increased activity in the anterior hippocampus and rostromedial orbitofrontal cortex (Gottfried & Dolan, 2003; see Fig. 12).

Flavour, conceptualised as an overall unitary perception, was investigated by Small and Prescott (2005). The authors following a comprehensive review of psychophysical, neuroimaging and neurophysiological studies, proposed a neurocognitive model of flavour processing based on prior experience, the particular combination of sensory inputs, temporal and spatial concurrence, and attentional allocation. Following on from the authors’ claims the “flavour network” involves the chemosensory regions of the brain: including the anterior insula, frontal operculum, orbitofrontal cortex and anterior cingulate cortex, as well as other heteromodal regions, including the posterior parietal cortex and the ventral lateral prefrontal cortex. With respect to the role of olfaction in flavour perception, Cerf-Ducastel and Murphy (2001), in a fMRI study demonstrated that the retronasal olfactory stimulation with odorants delivered in aqueous solution, effectively activate the piriform and orbitofrontal cortex, hippocampal region, amygdala, the insular lobe, the cingulate gyrus and the cerebellum. Instead, no brain areas related to taste perception was found to be activated. Verhangen and Engel (2006) proposed a model of taste/olfactory interaction based on a meta-analysis of previous literature. In particular, they argued that some common odour/taste interactions may involve the same neural mechanisms involved in synaesthesia.

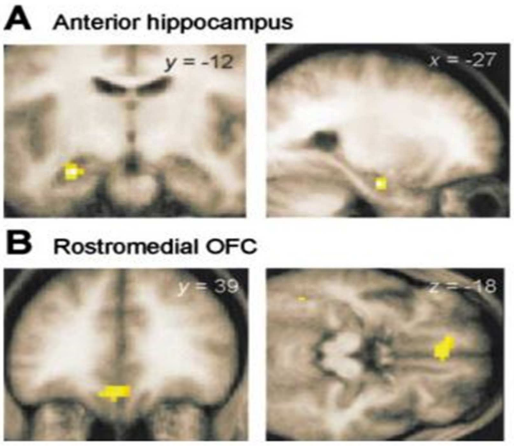


Figure 12 – A) fMRI coronal and sagittal sections show activation for visuo-olfactory integration in anterior hippocampus. B) fMRI coronal and sagittal sections show activation for visuo-olfactory integration in rostromedial orbitofrontal cortex (from Gottfried & Dolan, 2003)

3. Crossmodal correspondances in olfactory memory

3.1 Olfactory short and long-term memory

The study of the olfactory system and of memory for odours in particular, has represented and somehow still represents a challenge to researchers, especially due to the particular characteristics of the stimuli to be used (invisible, highly volatile, often persistent). The main issue concerning olfactory memory regards its architecture and in particular, whether or not a clear distinction between long and short-term memory for odours (similar to that reported in other sensory systems) exists. Within this debate, a second relevant question regards the possibility that olfactory short term memory (OSTM) is comparable to the multi-component model of visual-verbal memory proposed by Baddely and colleagues (Baddeley & Hitch, 1974; Baddeley, 2010) (see Fig. 13).

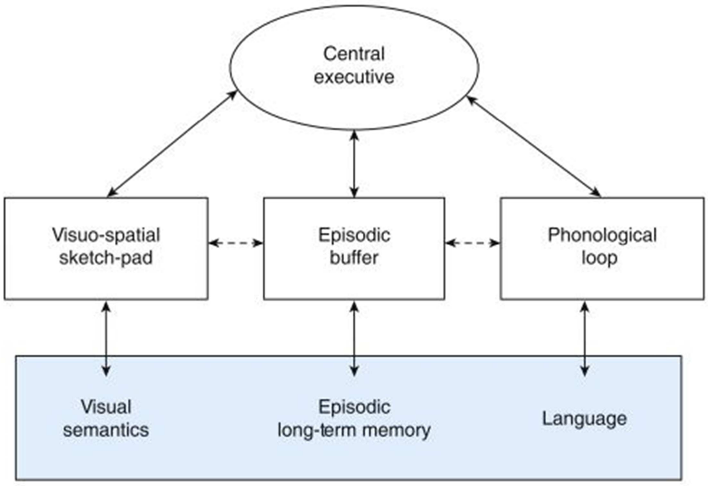


Figure 13 – Baddeley’s multicomponent model of visual-verbal memory (from Baddeley, 2010)

Indeed, some authors have described olfactory memory (OM) as only consisting of long-term components (Engen, 1982, 1991; Gabassi and Zanuttini, 1983; Wilson & Stevenson, 2006; Zucco, 2003). In particular, Wilson and Stevenson hypothesized the existence of an olfactory-centered unitary model in which the difference in memory for odours (e.g., in terms of duration of the trace) should be due to different patterns of receptor activity that occasionally overlap, rather than to different systems activated by different retention intervals (see Fig. 14). Recently, it has been hypothesized that the distinction between short and long-term memory for odours is plausible, although to be conceptualized within an unitary architectural system (see White, 1998, 2009 for detailed reviews on this topic). In early research that has attempted to study the most suitable model of memory for olfactory stimuli four classic experimental paradigms were used: capacity differences, differential coding, differential memory losses in neuropsychological patients, serial position effects.

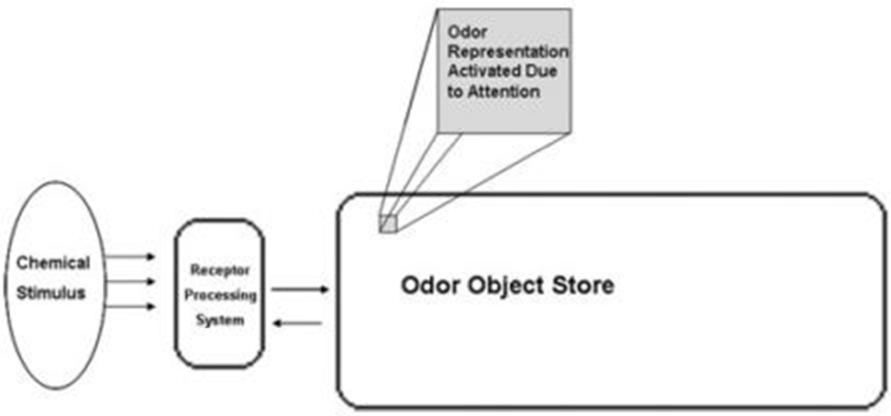


Figure 14 – The olfactory-centered unitary memory model with attentional activation (from White, 2009)

The studies on olfactory STM (theorized as a temporary storage system with limited capacity), have shown that a smaller number of odours are remember better than larger quantities of odours (Engen, Kuisma, & Emas, 1973; Jones, Roberts, & Holman, 1978). Conversely, studies on long-term memory for olfactory stimuli have shown that a large number of odours cab be remembered for a long period of time (Engen and Ross, 1973; Lawless, 1978; Lawless and Cain, 1975). The research on the way in which olfactory stimuli are encoded in short and long-term memory would seem to suggest the existence of differences between the two systems, similar to those responsible for the storage of information from other sensory modalities.

One important question in the study of olfactory memory regards the code used to represent the stored information: perceptual or semantic. One might indeed suggest that OSTM is based on a perceptual code while OLTM on a semantic code. If OSTM is more based on a perceptual coding system, the similarity between to-be-remembered odours should generate confusion in the recognition of the stimuli (Jones et al., 1978; Jehl, Royet, & Holley, 1994; White, Hornung, Kurtz, Treisman, & Sheehe, 1998). Performance in OLTM tasks instead should not be affected by perceptual similarity, but only by semantic similarity. Moreover the fact that certain odours can be easily named or labelled should improve OLTM but not OSTM. (Jehl et al., 1997; Schab, DeWijk, & Cain, 1991). However, White et al. (1998) observed the presence of semantic representations in OSTM too, and Annett and Leslie (1996) demonstrated that verbal and visual interferences do not produce performance differences in olfactory memory tasks in which participants were tested after 5 minutes or 7 days.

Familiarity, is also a factor that plays an important role in olfactory memory tasks, especially with shorter temporal delays (2, 20, 40 and 100 s between coding and testing). In fact, it has been demonstrated that familiar odours are better remembered than unfamiliar ones, especially with relatively longer temporal delays (Schab et al., 1991). The ability to identify odours is another characteristic suggested to be relevant in OLTM. Specifically, identifiable and familiar olfactory stimuli are found to be better remembered, as compared to unfamiliar and unidentifiable odours (Lyman and McDaniel, 1990).

The principal characteristic of the above mentioned studies is the heterogeneity of the procedures and timing of the experimental paradigms adopted. Generally, for STM is intended a very brief time period in which the recognition phase is requested immediately after the presentation of the stimuli, that is, within a few seconds. However, the correct timing of odours administration it is a very difficult-to-tackle question, since olfactory perception is rather slow compared to the other sensory modalities (vision, hearing). This fact by itself might be taken to suggest that OSTM could be qualitatively different from other types of short term memory. Another important difference between memory for olfaction and other memory system is the fact that odours can be referred to the object that releases the odorant molecule, rather than to the chemical compound that is directly responsible of the odour itself. Consequently, the representation of odours is likely associated to the image of the object from which it exhales. Therefore, it is likely that certain odours, especially those that are easily nameable and familiar activate multiple representations in the human brain: linguistic, iconic and perceptual (related to chemosensory perception). This observation raises the question of what is actually tested during olfactory experiments: purely olfactory features or the visual and linguistic characteristics linked to the odours?

Another important question that affect the study of olfactory memory is the difficulty in controlling all of the strategies of stimuli elaboration (verbal, visual, perceptual) adopted by the participants during the task. A number of techniques can be used to tackle this problem. For example, in order to avoid the use of verbal coding strategies one might use a series of difficult to be named odours. Yeshurun, Dudai, and Sobel (2008) performed a series of experiments in which nameable and hard-to name stimuli were administered with monorinhal presentation, or to both nostrils. The results demonstrated that nameable odours are better remembered than hard to name odours and the nameability effect was enhanced in both nostrils presentation. An experimental design on olfactory short and long-term memory with odours previously rated as nameable and hard to name is presented in this thesis (see Chapter VI)

As far as the neuropsychological evidences of the distinction between brief and long temporal delay in olfactory memory are concerned, it should be noted that a double dissociation between short and long term memory task has been reported in brain damaged patients (e.g., patients H.M and K.F; Milner, 1966; Shallice & Warrington, 1970), and in patients affected by the Korsakoff syndrome (Mair, Capra, McEntee, & Engen, 1980). Though, the largest part of neurological patients showed an overall impairment of both olfactory detection (more related to OSTM) and odor quality discrimination (more related to OLTM), just as it also occurs in Alzheimer patients (Doty, Reys, & Gregor, 1987).

Lastly, serial position in odours memory is the phenomenon through which a series of smells are better remembered when presented at the beginning (primacy effect, associated to STM processes) or at the end (recency effect, associated to LTM processes) of the to-be-remembered sequence. It is perhaps from the attempt to study serial position effects in odors memory that the greater difficulties associated with the study of olfactory memory emerges (leading often to contradictory results). Reed (2000) in five experiments where a two-alternative forced choice (2AFC) task was used, found both recency and primacy effects for the short (3 seconds) retention of olfactory stimuli. During the experiments the participants were presented with a list of items and in the test phase they had to identify which of two test odours belonged to the previous series. The retention interval used during experiments were 3s, 30s or 60s and, odour lists length could be composed of 1 – 4 – 5 – 6 - 7 items. Note however that Miles and Hodder (2005) in seven experiments investigated recognition memory for sequentially presented odour by means the same (2AFC) task used by Reed. In none of their experiments they were able to demonstrate a primacy or a recency effect. Miles and Hodder used nameable and hard to name odours, articulatory suppression, as well as, different temporal delays between items. The authors did not report olfactory fatigue: recognition accuracy simply improved across trials. These two experimental paradigms are thus representative of the global trend of contrasting results affecting the extant literature on olfactory memory (Annett & Lorimer, 1995; Miles & Jenkins, 2000; Yeshurun, Dudai, & Sobel, 2008; White & Treisman, 1997; see also Gabassi & Zanuttini, 1983; Lawless & Cain, 1975). The possible different results among the studies reported is likely related to the role played by the verbal mediation in the coding and representation of olfactory information. This aspect has been also faced by using nonhuman animal participants, although the results reported can not be directly compared with those collected with human partecipants (Miles & Hodder, 2005).

Another aspect to be considered here is that the results of the extant literature on olfaction would seems to suggest a lack of clear and robust evidence for the existence in OSTM of a fundamental aspect of memory in other sensory modalities, namely the ability to retain the serial order of the stimuli (Baddeley, Gathercole, Papagno, 1998; Burgess & Hitch, 1999). That is, is that possible to retain within an olfactory memory system a certain amount of the items presented with respect to their exact position in the series, just as it occurs for verbal or numerical material (i.e. a memory span) and what is the capacity of this system? Recently, a neuroscientific study made use of an odour span task, previously adopted in animal studies (on rats), in order to study olfactory memory in five amnesic patients with a damage limited to the hippocampal region and sixteen healthy volunteers (Levy, Manns, Hopkins, Gold, Squire, 2003). The experiment started with the presentation of the first of a series of fourteen odours, smelled by the participant and successively inserted on a cardboard bottle holder, together with another odour of the series in a random order. Subsequently, the task for the participants was to identify which of the two olfactory stimuli presented on the cardboard was the new one. The experimenter continued to add another odour to the list (again randomly selected) and the task for the participant was always to identify which of the three odours was the new. Following each correct answer a new smell was added and the task was repeated. Olfactory span length was measured as the number of consecutive trials on which participants correctly identified the new odor on their first attempt. Neurologically normal reached a span length of 7.9 ± 0.8 and patients of 5.3 ± 1.3; nevertheless, the comparison between the performances of the two groups did not reach significance.

3.2 Neural correlates of olfactory short and long-term memory

The study of the olfactory system and of memory for odours, has taken advantage from the latest neuroscience research techniques, (e.g., fMRI, ERP, PET). By using these techniques researchers have tried to identify the population of neurons that are activated during the different phases of odour perception, retention and recollection. In a positron emission tomography (PET) study was demonstrated that odour sensory stimulation engaged bilateral piriform and orbitofrontal regions, while discrimination between odours involved the hippocampus. The correct identification of previously presented odours involved instead the left inferior frontal lobe (Kareken, Mosnik, Doty, Dzemidzic, Hutchins, 2003). Savic and Berglund (2000), in a PET study showed that unfamiliar odours discrimination performance was superior when the stimuli were presented to the right nostril compared to the left nostril presentation. This condition also resulted in a higher activation of the right cerebral hemisphere. Interestingly, discrimination performance for familiar odours was correlated to activation of both hemispheres, probable due to an involvement of the language areas in the brain.

Dade, Zatorre and Jones-Gotman (2001) investigated the involvement of temporal lobe structures in odour learning and memory by means a PET study in patients who underwent the surgical resection of one temporal lobe as a result of an intractable epilepsy. The results showed that patients performed worse than control participants. However, no difference regarding the side of resection were found. In the same study, different level of activity in piriform cortex (primary olfactory cortex) were found depending on the ongoing process. That is, no increased activity was found during odour encoding, a small bilateral increase was found during short-term recognition and a larger increase of bilateral activity was found in long-term recognition. Such evidences would seem suggest that olfactory memory requires information from both left and right structures to be fully effective.

Howard, Plailly, Grueschow, Haynes, Gottfried (2009) demonstrated that odour quality coding and categorization specifically activate spatially distributed neurons in the human posterior piriform cortex but not in anterior piriform cortex, amygdala or orbitofrontal cortex. The temporal sequences of activation of olfactory processing were investigated recording event-related potentials (ERPs) by Lascano, Hummel, Lacroix, Landis, Michel (2010). They identified four distinct processing steps ranging between 200 and 1000 ms from odour presentation. Ipsilateral activation in the mesial and lateral temporal cortex (amygdala, parahippocampal gyrus, superior temporal gyrus, insula) immediately followed the stimulation of the nostril by odours. Subsequently, the corresponding structures on the contralateral side became involved, followed by frontal structures at the end of the activation period.

An important relationship exists between olfaction and emotions, since odours can elicit particular emotional state (Seubert, Rea, Loughead, & Habe, 2008; Weber & Heuberger, 2008). In particular, odours can induce positive (appetitive) or negative (aversive) valence, to certain features of the environment. These effects might be also related to the partial overlap between brain structures responsible for odour processing and storage and structures responsible for the generation of emotional responses (such as, amygdala, hippocampus, insula, anterior cingulate cortex and orbitofrontal cortex; see Soudry, Lemogne, Malinvaud, Consoli, Bonfil, 2011 for a review). In an fMRI experimental paradigm Herz, Eliassen, Beland and Souza (2004) showed a greater activation in the amygdala and hippocampal regions during the presentation of self vs. other odours. Instead, during a PET study Royet, Plailly, Delon-Martin, Kareken and Segebarth (2003) participant’s evaluated hedonic valence of a series of hundred twenty-six olfactory stimuli previously rated as pleasant or unpleasant. The results showed different responses of several brain areas to the qualities of the olfactory stimuli. In particular, unpleasant odours activated the piriform-amygdala area and the ventral insula more than pleasant odours. Moreover, unpleasant odours activated the left ventral insula in right-handers and the right ventral insula in left-handers, hence, suggesting that emotional smells processing is lateralized on the basis of handedness (see Yeshurun and Sobel, 2010 and Gottfried, 2010 for detailed reviews on these topics).

The issue regarding whether odours are coded by means of verbal, sensorial or both kinds of representations, was investigated through a functional magnetic resonance imaging (fMRI) paradigm by Zelano, Montag, Khan and Sobel (2009) using nameable or unnameable olfactory stimuli to be remembered. The results revealed a double dissociation between the memory of nameable odorants which activated prefrontal language areas, and unnameable odorants which activated primary olfactory cortex. According to the authors, the main task of the frontal piriform cortex is to maintain representations of the hard to name odour during working memory tasks.

In the following chapters of this doctoral thesis a number of questions related to crossmodal correspondence in food and beverage perception and memory for odours will be addressed. In particular:

Chapter II

The association between a container's weight and the perception of the mineral water presented inside

Chapter III

The association between a container's weight and the perception of the mineral water presented inside

Chapter IV

The association between the tactile attributes of a container and the perception of the mineral water presented inside

Chapter V

The effects of a small size olfactory device on people’s taste of food

Chapter VI

The effects of different experimental paradigms on olfactory memory for brief and long time periods

VII

The differences in olfactory and visuo-verbal memory in probable Alzheimer's disease patients

VIII

General discussion

CHAPTER II
THE ASSOCIATION BETWEEN THE COLOUR OF A CONTAINER AND THE TASTE OF A LIQUID PRESENTED INSIDE

This research was published in:

Risso, P., Maggioni, E., Olivero, N., and Gallace, A. (2015). The effect of coloured cup on people's perception, expectation and choice of mineral water. *Food Quality and Preference,* **44,** 17–25.

1. Introduction

The behaviours associated with thirst are guided by a complex set of factors that include physiological states, genetic inheritance and activation of high and low level neural processes (comprising perceptual and semantic elaboration) (Egan et al., 2003; McKinley & Johnson, 2004; Szinnai, Schachinger, Arnaud, Linder, & Keller, 2005). The interaction between these factors certainly contributes to determine people's judgments of food and beverages (see Gallace & Spence, 2014; Spence, Hobkinson, Gallace, & Piqueras-Fiszman, 2013; Wan, Woods, Seoul, Butcher, & Spence, 2015, for recent reviews). Pioneering work on the effects of modulating a visual quality of food, namely the colour, on people's perception of carbonated water demonstrated that the addition of food colorants (red, brown and yellow) to sparkling mineral water, did not compromise the identification of the liquid in blindfolded and not blindfolded individuals (Hyman, 1983). More recent studies have also investigated whether or not certain aspects of the container, rather than of the content itself, can affect the participants' judgments regarding the beverage that is contained inside it (see Wan et al., 2015). For example, it has been shown that an orange plastic cup can enhance the flavour of hot chocolate, as compared to conditions where the same liquid is served in a red or in a white cup (Piqueras-Fiszman & Spence, 2012). Similarly, Guéguen (2003) has demonstrated that beverages contained in blue and green (cold colours) plastic cups were considered most thirst-quenching, as compared to the same beverages contained in red and yellow (warm colours) cups. Importantly, by using questionnaire procedures, it has been shown that certain colours are associated with particular basic tastes (see also Spence & Wan, 2015d, for a recent internet-based study regarding the effect of the 'appropriateness of the container on the overall perception of the beverage that is usually served in it). For example, the colours red and orange were shown to be positively associated with sweet, green and the colour yellow with sour and white with salt. In contrast, green, brown, black and grey were found to be negatively associated with sweet and red, blue, brown, purple, black, grey and white negatively linked to sour (Koch & Koch, 2003; O'Mahony, 1983; see also Tomasik-Krótki & Strojni, 2008, for the effect of cross-cultural factors on the associations between basic tastes and colours; see Wan, Woods, et al., 2014, for a review on this topic). Recently, Ngo, Piqueras-Fiszman, and Spence (2012) employed an on-line questionnaire to assess the presence of crossmodal correspondences between still and carbonated water, colours (blue, red, green) and shapes (rounded or angular). This research showed that participants associated still water with rounded shapes and carbonated water with angular shapes (see also Spence & Gallace, 2011, for similar results; see Wan, Velasco, et al. (2014) for a cross-cultural study on the associations between colour/shape of a container and food). Moreover, both water samples (still and carbonated) were preferably associated with the colour blue rather than red or green.

Despite of the increasing number of studies on the topic of multisensory interactions in food/beverage perception, at the moment it remains unclear whether the associations and the perceptual effects found in the existent literature between colour and flavour are general or specific for certain kinds of products. For example, does a certain colour always enhance the flavour of different food/liquids (perhaps also on the basis of the intrinsic arousing/calming effect of such colour on people's perception; (see Labrecque & Milne, 2012; Wilson, 1966). As far as this point is concerned, it is important to consider the broad range of flavours and the diversity in terms of intensity of taste among different liquids and food. On the basis of these peculiarities, one might expect different multisensory interactions for every kind of beverages or food. In support of this view, it should be considered that the enhancement of taste perception of a certain liquid served in a particular coloured container often depends on some sort of associative and memory based elaborations made by the participants. For example, it was demonstrated that a coffee (a typically dark brown beverage) served from a brown jar (a clay container with a wide opening at the top, that is usually used for storing food) was judged as stronger than the same coffee served in red, blue or yellow jar (Favre & November, 1979; pp. 82–85). By contrast, in a recent experiment Van Doorn, Wuillemin, and Spence (2014) demonstrated that a white mug enhanced the flavour intensity and reduced the perceived sweetness of the coffee served in it, as compared to coffee served in a transparent or a blue mug.

As far as the main causes of these effects are concerned, it is worth noting that a number of studies have suggested that people's expectations regarding a specific product can exert an important influence on its overall evaluation (e.g., Levitan, Zampini, Li, & Spence, 2008). In particular, Levitan and her colleagues (2008) asked their participants to judge whether a pairs of differently coloured candies (Smarties?) had the same flavour or not. The authors demonstrated that the judgments were affected by the participants' previous beliefs (i.e., regarding whether or not such orange candies taste differently from other coloured candies).

Miller and Kahn (2005) proposed an interesting explanation for the influence of colours on people's flavour perception based on Grice's (1975) theory of ''conversational implicature''. Specifically, these authors postulated that an ambiguous use of colours or flavour names (i.e. blue haze, Alpine snow) might lead the consumer to search for the reason of the deviation from their expectations. Such search might in turn results in more cognitive efforts to characterize the product, and even to more favourable responses. Therefore, on the basis of these considerations, and on the fact that water is colourless as compared to other beverages, one might expect completely different (or even none) interactions between the colour of the container where the liquid is served and its taste, as compared to studies performed on other kinds of beverage. Importantly, previous studies on the topic of multisensory interactions in food evaluation investigated separately perception, expectations, opinions and choice regarding a given product. It is however important to notice, that all of these three aspects might be differently modulated by the same experimental manipulation. This difference is certainly relevant to the applied field (see Spence & Gallace, 2011b). In fact, from a marketing perspective one might reasonably claim that in order to maintain old customers it is more profitable to invest more resources into the perceptual characteristics of a product (in order to maintain it constant or even to improve it). The possible associations between the perception of the product and the colour of the container might be also relevant here. In fact, if it becomes apparent that a certain visual quality of a food product (i.e., a colour) is associated with its taste in the mind of the consumers, it might be profitable for the company that produces it to try to brand such visual aspect (e.g., see the Coke red or T-Mobile pink). By contrast, if a company's aim is to extend the sales of their products to new customers, it is essential to focalize the efforts on the expectations of their potential clients.

The aim of the present study is to investigate the effects of manipulating the colour of a container on the perception, expectations and choices regarding a naturally not coloured liquid, namely water that is served inside such a container. The participants' evaluation of the water was measured by means of four different scales (along the dimensions of freshness, pleasantness, level of carbonation and lightness). The choice of these scales was justified by the fact that people do not recognise other aspects regarding the basic taste of water (sweet, sour, salty and bitter) if not professionally trained. Therefore the scales that were used here are those that people generally associate to thirst and evaluation of water intake, or to those emerging from marketing strategies studies (Dietrich, 2006; Lucchiari & Pravettoni, 2012).

2. Experiment 1

2.1 Participants

Twenty-seven participants, with a mean age of 25.40 years (SD = 5.31, 19 female), took part in Experiment 1; they were graduate and undergraduate students and received course credits for their participation in the study. All the participants gave written consent prior to their participation. The Experiments described here were all performed in accordance with the ethical standards laid down in the 2008 Declaration of Helsinki and approved from the local ethical committee. Experiment 1 lasted for approximately 50–60 min. This duration comprises an initial overview of the experimental setup, the explanation of the instructions, the explanation and signature of the ethical forms and a final 10–15 min of debriefing regarding the main aims of the experiment. The actual experiment lasted about 30–35 min. People who claimed to be affected by any olfactory or taste dysfunctions, as well as people suffering from cold or flu were excluded from taking part in the experiment.

2.2 Stimuli

Three different types of mineral water were used: slightly sparkling (Ferrarelle®, 0.5 l bottle) sparkling and still mineral water (S. Benedetto? sparkling and still mineral water, 0.5 l bottle) the chemical and physical properties of each type of water are represented in Table 1. Each plastic cup used was filled with 20 g of water and the bottles used were always kept at constant room temperature (19–22 °C). Common plastic cup, produced by the same commercial brand (®DOpla S.p.A) and varying only in terms of their colour (blue, red, and white, see Fig. 15) were used to serve the water.

Table 1
Chemical and physical properties of the three kinds of mineral water used in Experiment 1, 2 and 3.

	S. Benedetto still mineral	S. Benedetto sparkling	Ferrarelle slightly sparkling
Bicarbonate	313.0*	313.0*	1433.0*
Calcium	50.3*	50.3*	392.0*
Sodium	6.0*	6.0*	50.0*
Chlorine	2.2*	2.2*	20.0*
Silica	12.0*	12.0*	86.0*
Magnesium	30.8*	30.8*	22.0*
Nitres	9.0*	9.0*	4.0*
Sulphites	3.7*	3.7*	4.0*
Chlorides	2.2*	2.2*	20.0*
Potassium	0.9*	0.9*	50.0*
Fluorides	<0.1*	<0.1*	1.1*
Carbon Dioxide	8.0*	8.0*(with post addition of CO_2)	2360.0*
Oxygen	6.4*	6.4*	–

Note: *mg/l.

Figure 15 – The coloured plastic cup used in Experiment 1, 2, and 3

2.3 Procedure

The procedure followed a within-participant design. The study was conducted in an experimental booth fitted with a laptop (screen resolution: 1024x768 pixels, refresh rate: 60 Hz) positioned on a desk directly in front of the participants. The participants sat comfortably on a chair, approximately 70 cm away from the laptop screen. In each trial, a plastic cup filled with water was placed on the desk by the experimenter. The participants were instructed to grasp the cup at a signal of the experimenter and to drink as much water as they wished. They were also asked to rate the water, immediately after drinking it, along four dimensions (freshness1[1], pleasantness, carbonation and lightness), by means of 150mm long visual analogue scales (VAS), anchored with the terms 'not at all' and 'very much' and presented on the PC screen. The participants used the mouse to select the point on the scale that best represented their evaluation. Each type of water was presented 3 times in each coloured plastic cup for a total of 27 (3 waters x 3 colours x 3 repetitions) samples of water to be evaluated. Three different random combinations of colours and water types were counterbalanced every 9 participants. The plastic cups were presented one at a time and a black paperboard box was used to hide all of the cups before they were presented.

[1] In Italian the word 'freschezza', (freshness) has different meanings; in this case we used the term with the meaning of thirst-quenching/refreshing capacity rather than of the water temperature itself.

2.4 Results

The participants' judgments regarding the water (see Table 2) were submitted to a repeated measures ANOVA with the colour of plastic cup (white, red, blue), type of water (still, slightly carbonated, carbonated) and scale (freshness, pleasantness, level of carbonation and lightness) as factors. The analysis revealed a significant effect of water [$F(2,52) = 6.25$, $p = 0.004$], a significant interaction between scale and colour [$F(6,52) = 2.52$, $p = 0.024$] and a significant interaction between scale and water [$F(6,156) = 62.00$, $p < 0.0001$]. A Newman–Keuls post hoc test on the significant main effect of water showed that participants on average provided quantitatively lower evaluations (i.e., evaluations closer to the 'not at all' endpoint of the scale) for still mineral water than for carbonated water ($p = 0.003$) and quantitatively lower evaluations for slightly carbonated water than for carbonated water ($p = 0.036$). A Newman–Keuls post hoc test on the interaction between scale and colour, showed that on the scale measuring carbonation perception, mineral water was judged to be more carbonated when tasted in a red ($p = 0.002$) or blue ($p = 0.001$) plastic cup, as compared to the same liquid tasted in a white cup (see Fig. 16A). No differences were found on the other scales. A Newman–Keuls post hoc test on the interaction between the factors of scale and water revealed significant differences between still water and carbonated water and between carbonated water and slightly carbonated water on the scale of carbonation intensity. As expected, still water was perceived as less carbonated than slightly carbonated ($p < 0.0001$) and carbonated water ($p < 0.0001$). Moreover the post hoc test also revealed significant differences between still water, slightly carbonated water and carbonated water on the scale of lightness, with still water perceived as lighter, as compared to slightly carbonated ($p = 0.001$) and carbonated ($p < 0.001$) water (see Fig. 16B). No significant differences were found on the remaining scales. The main effect of colour [$F(2,52) = 0.70$, $p = 0.50$], scale [$F(3,78) = 1.06$, $p = 0.37$], and the interaction between scale, colour and water [$F(12,312) = 0.95$, $p = 0.50$] did not result to be significant. The results of Experiment 1 show an effect of the colour of the plastic cup on the participants' evaluations of certain characteristics of mineral water. In order to understand weather or not such effects are solely determined by the participants' expectations (determined by the colour of the plastic cup), rather than to any multisensory interactions occurring at a more perceptual or cognitive level, in Experiment 2 we asked the participants to evaluate the same qualities of the water without tasting the liquid.

Table 2

The participants' mean judgments (and standard errors of the means) on each of the four scales (freshness, pleasantness, carbonation intensity, and lightness), as a function of the kind of water presented and of the colour of the plastic cup where the liquid was served in Experiment 1

Colour of plastic cup:	Still water			Slightly carbonated water			Carbonated water		
	White	Red	Blue	White	Red	Blue	White	Red	Blue
Scales:									
Carbonation	112.69 ± 0.46	79.82 ± 0.54	17.64 ± 0.50	13.84 ± 0.59	72.57 ± 0.51	101.76 ± 0.56	17.85 ± 0.48	84.07 ± 0.42	107.83 ± 0.45
Lightness	88.59 ± 0.51	85.62 ± 0.69	85.82 ± 0.68	65.41 ± 0.52	67.05 ± 0.45	65.81 ± 0.57	60.03 ± 0.49	59.90 ± 0.55	67.11 ± 0.52
Freshness	82.32 ± 0.52	82.68 ± 0.64	80.51 ± 0.58	70.02 ± 0.68	70.14 ± 0.50	73.87 ± 0.57	76.15 ± 0.59	73.30 ± 0.56	76.23 ± 0.46
Pleasantness	80.68 ± 0.55	80.30 ± 0.71	75.67 ± 0.68	68.93 ± 0.69	64.91 ± 0.59	68.90 ± 0.68	71.88 ± 0.65	69.64 ± 0.66	69.15 ± 0.61

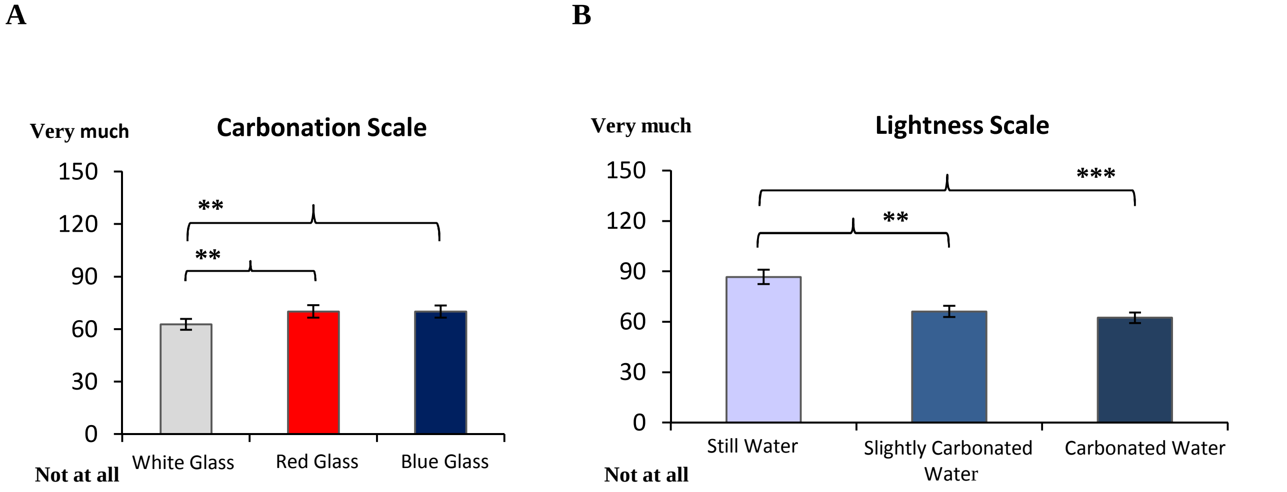


Figure 16 – [A] The mean participants' judgments of carbonation intensity as a function of the colour of the plastic cup in which the liquid was served. [B] The mean participants' judgments of lightness perception for still, slightly carbonated, and carbonated water. Asterisks represent Newman–Keuls significant differences at: *p* * < .05; ** < .001; *** < .0001

3. Experiment 2

3.1 Participants

Twenty-two undergraduate and graduate students, with a mean age of 24.68 years (SD = 4.45, 11 female), took part in Experiment 2. Just as in Experiment 1, all the participants received course credits for their participation in the study. The experiment lasted for approximately 40 min.

3.2 Stimuli

The materials used in Experiment 2 were identical to those used in Experiment 1.

3.3 Procedure

The procedure followed a within-participant experimental design. Experiment 2, investigated how the colour of the plastic cup modulated the participants' expectations, regarding a number of features of the water (freshness, pleasantness, level of carbonation and lightness). Exactly the same procedures as those used in Experiment 1 were adopted in Experiment 2, with the following exception: the participants were asked to evaluate the water only by watching the plastic cup and without tasting the liquid. The four water characteristics were rated using the same scales used in Experiment 1, on the basis of the participants' expectations regarding the water rather than on its actual taste.

Table 3

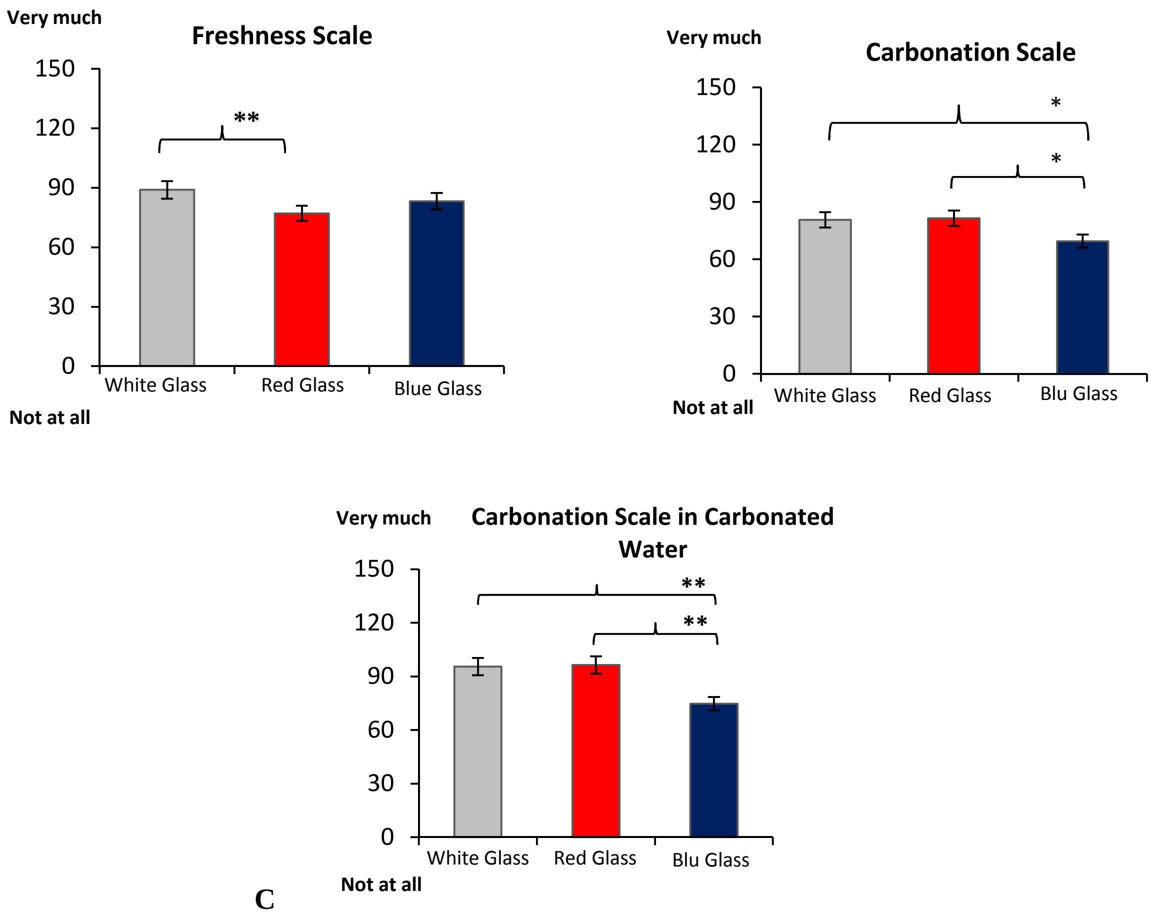
The participants' mean judgments (and standard errors of the means) each of the four scales (freshness, pleasantness, carbonation intensity, and lightness) as a function of the kind of water presented and of the colour of the plastic cup where the liquid was served in Experiment 2.

Colour of plastic cup:	Still water			Slightly carbonated water			Carbonated water		
	White	Red	Blue	White	Red	Blue	White	Red	Blue
Scales:									
Carbonation	50.96 ± 6.19	54.80 ± 6.45	57.80 ± 5.18	95.14 ± 3.99	93.20 ± 6.29	75.58 ± 5.64	95.52 ± 5.31	96.34 ± 4.98	74.80 ± 5.74
Lightness	83.05 ± 7.40	75.08 ± 6.57	73.66 ± 6.62	82.42 ± 6.50	70.75 ± 5.97	74.72 ± 6.33	77.14 ± 6.06	66.58 ± 4.89	66.83 ± 6.21
Freshness	81.22 ± 6.57	72.13 ± 5.93	78.68 ± 6.92	90.79 ± 6.00	78.96 ± 5.47	83.67 ± 5.32	94.80 ± 6.52	80.24 ± 5.38	87.17 ± 6.36
Pleasantness	73.54 ± 5.92	73.85 ± 6.15	70.61 ± 6.56	80.21 ± 5.34	78.91 ± 5.16	77.75 ± 5.58	85.03 ± 5.25	75.65 ± 4.26	78.92 ± 6.30

3.4 Results

The participants' mean ratings (see Table 3) were submitted to a repeated measures ANOVA with the factors of colour of the plastic cup (white, red, blue), type of water (still, slightly carbonated, carbonated) and scale (freshness, pleasantness, level of carbonate and lightness). The results of the analysis revealed a significant main effect of water [$F(2,42) = 13.56$, $p < 0.0001$], but not of the scale [$F(3,63) = 1.34$, $p = 0.269$]. The effect of colour approached the significant level [$F(2,42) = 2.91$, $p = 0.065$]. The interaction between scale and colour [$F(6,126) = 3.32$, $p = 0.004$], scale and water [$F(6,126) = 14.21$, $p < 0.0001$] and scale, colour and water [$F(12,252) = 2.44$, $p = 0.005$] also resulted to be significant. The interaction between colour and water [$F(4,84) = 2.02$, $p = 0.10$] did not result to be significant. The interaction between scale, colour and water was analysed by means of four separate ANOVAs, one for each scale adopted. This analysis performed on the scale of freshness revealed a significant main effect of colour [$F(2,42) = 5.14$, $p = 0.010$] and of water [$F(2,42) = 7.61$, $p < 0.001$]. A Newman–Keuls post hoc test on the effect of colour revealed that people expected the mineral water to be fresher when presented in a white plastic cup ($p = 0.007$), as compared to the same liquid served in a red cup (see Fig. 17A). A Newman–Keuls corrected post hoc test on the significant main effect of water showed that people expected still mineral water to be less fresh, than slightly carbonated ($p = 0.010$) and carbonated ($p = 0.001$) mineral water. The interaction between colour and water [$F(8,84) = 0.56$, $p = 0.69$] did not result to be significant. The ANOVA on the scale measuring pleasantness did not revealed any significant main effect of colour [$F(2,42) = 0.42$, $p = 0.66$], water [$F(2,42) = 3.14$, $p = 0.05$] and of their interaction [$F(4,84) = 1.05$, $p = 0.38$]. The ANOVA performed on the scale measuring carbonation intensity revealed a significant main effect of colour [$F(2,42) = 4.81$, $p = 0.013$], water [$F(2,42) = 26.27$, $p < 0.0001$] and of their interaction [$F(4,84) = 4.21$, $p = 0.004$]. A Newman–Keuls corrected post hoc test on the significant main effect of colour revealed that mineral water was expected to be more carbonated when contained in a white ($p = 0.01$) or red ($p = 0.02$) plastic cup, as compared to the same mineral water contained in a blue cup (see Fig. 17B). A Newman–Keuls corrected post hoc test on the main effect of the water revealed that still mineral water was expected to be less carbonated than slightly carbonated ($p < 0.0001$) and carbonated ($p < 0.0001$) water. A post hoc test (Newman–Keuls) on the interaction between colour and water revealed that participants expected slightly carbonated water to be less carbonated when contained in a blue plastic cup, as compared to the same liquid contained in a white cup ($p = 0.0006$). The analysis also revealed that the participants expected carbonated water to be less carbonated when contained in a blue plastic cup, as compared to the same liquid contained in a white ($p = 0.005$) or red ($p = 0.005$) cup (see Fig. 17C). The ANOVA on the scale measuring lightness failed to reveal any significant effect of colour [$F(2,42) = 2.88$, $p = 0.07$], water [$F(2,42) = 1.66$, $p = 0.20$] and of their interaction [$F(4,84) = 0.29$, $p = 0.88$]. The results suggest that the colour of the plastic cup affected the participants' expectations regarding a number of characteristics of mineral water. Importantly, the effect of the colour on the participants' evaluations were not the same as those reported in Experiment 1. In Experiment 3, we investigated whether the participants' preferentially choose a certain drink plastic cup colour to taste different kinds of mineral water. The main aim of this study was to understand if the participants' choices were consistent with more perceptual (as tested in Experiment 1) or more expectancy-driven (as tested in Experiment 2) factors (or with none of the two).

A B



C

Figure 17 – [A] The mean participants' judgments of mineral water on the freshness scale as a function of the colour of the plastic cup in which the liquid was served. [B] The mean participants' judgments of mineral water on the scale of carbonation intensity, as a function of the colour of the plastic cup in which the liquid was served. [C] The mean participants' judgments of carbonated water on the scale of carbonation intensity, as a function of the colour of the plastic cup in which the liquid was served. Asterisks represent Newman–Keuls significant differences at: * $p < .05$; ** < .001

4. Experiment 3

4.1 Participants

Thirty-six undergraduate and graduate students, with a mean age of 22.97 years (SD = 2.96, 25 female) took part in Experiment 3. All the participants received course credits for taking part in the study.

The participants were recruited using the same restriction parameters as in Experiments 1 and 2. The experiment lasted for approximately 20 min.

4.2 Stimuli

The stimuli used in Experiment 3 were identical to those adopted in Experiments 1 and 2.

4.3 Procedure

The experimental procedures consisted in a within-participant experimental design. In order to test the participant's choice regarding the plastic cup where each type of water was contained, the participants were instructed to select one of three cups presented horizontally aligned in front of them. The plastic cups were presented on a desk at a distance of 70 cm from the participant's body. The task was phrased as follow: ''Please image to choose a cup to drink mineral water; which one of the present cups would you like to use?''. The participants were also informed about the type of water that was supposedly contained in the plastic cup (still, slightly carbonated and carbonated). The same task was per- formed for the three types of water (still, slightly carbonated and carbonated). The linear sequence of the coloured cups and the order of the water type were randomized for each participant: A total of 9 cups (3 colours ? 3 water types) were presented to each participant. A black paperboard box was used to hide all of the plastic cups before they were presented to the participants, just as in Experiment 1 and 2.

4.4 Results

The percentage of participants who chose to drink mineral water in a certain coloured plastic cups were calculated over the total. The results showed that 69.44% of the participants chose a white cup to drink natural water, 25.00% chose a blue cup and 5.56% a red cup (see Fig. 18A). A chi-square test on the preference expressed by the participants indicated the presence of significant differences between those values ($v2 = 64.99$, $p < 0.001$). A comparison between the proportion of preferences for a certain plastic cup colour demonstrated that the largest part of participants chose a white cup to drink still water, as compared to a red ($p < 0.001$) or blue cup ($p < 0.001$). Moreover, 44.44% of the participants chose a blue cup to drink slightly carbonated water, 41.67% a red cup and 13.89% a white cup (see Fig. 18B). A chi-square test on the preference expressed showed that these values were significantly different (v2 = 17.13, p = 0.001). The comparison between the proportion of preferences for a plastic cup colour to drink slightly carbonated water showed that the largest part of participants selected a blue or red cup (p = 0.005; p = 0.003, respectively), rather than a white cup. Finally, 55.55% of the participants chose a blue cup to drink carbonated water, 27.78% a red cup and 16.67% a white cup (see Fig. 18C). A chi-square test on the preference expressed revealed that these values were significantly different (v2 = 24.04, p < 0.001). The contrast between the proportion of preferences for a certain cup colour demonstrated that the participants preferred to drink carbonated water in a blue cup, as compared to a white (p < 0.001) or red cup (p = 0.009).

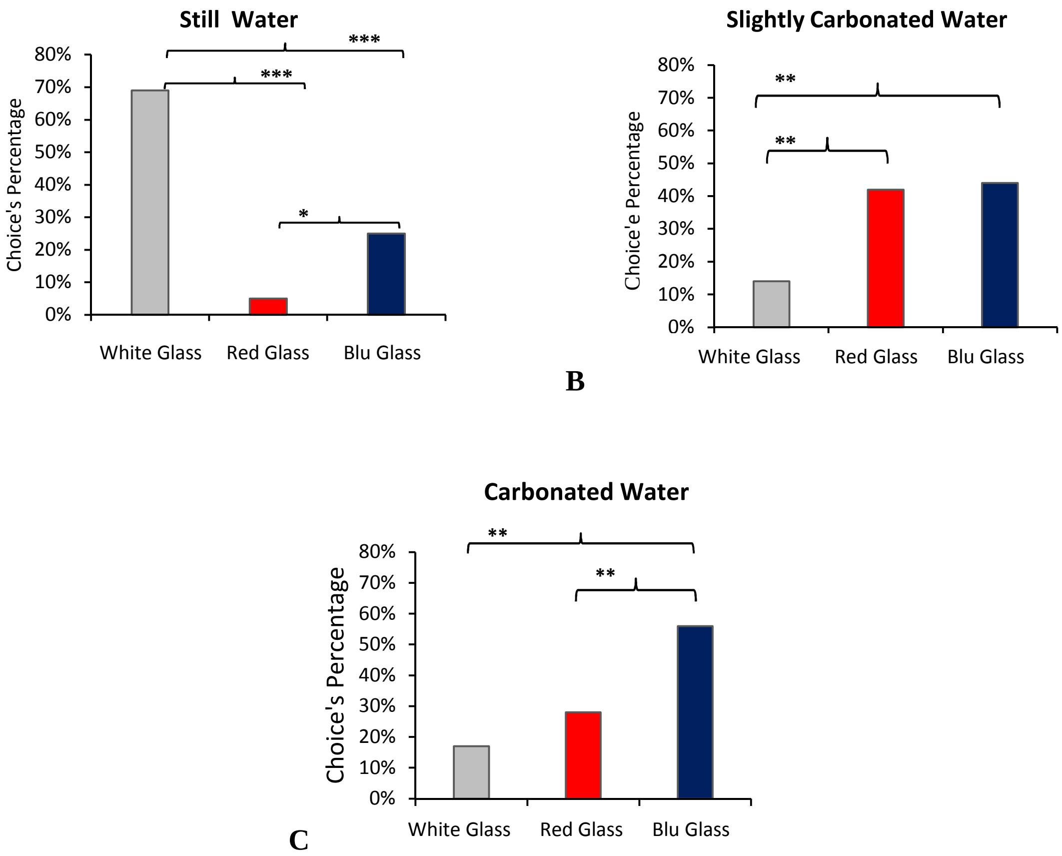


Figure 18 – Results of Experiment 3. [A] Percentage of participants who chose to drink still mineral water from a certain coloured plastic cup. [B] Percentage of participants who chose to drink slightly carbonated mineral water from a certain coloured plastic cup. [C] Percentage of participants who chose to drink carbonated mineral water from a certain coloured plastic cup. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article)

5. General discussion and conclusions

The results of the three experiments reported here showed that people's perception, expectations and choice regarding mineral water are differentially affected by the colour of the plastic cup where the liquid is contained. In particular, the results of Experiment 1 demonstrated that the participants perceived all kinds of mineral water (still, slightly carbonated, carbonated) to be more carbonated when the liquid was tasted using a red or blue cup, as compared to when it was served in a white cup. These results are partially compatible with those obtained by Ngo et al. (2012). In fact, these researchers demonstrated that still and sparkling water were associated to the blue colour, but were not associated to red or green colour. It is important to note here that in our Experiment 1 participants actually tasted the water, whereas in the study by Ngo and colleagues the test was performed by using internet-based questionnaires. On the basis of this difference, one can reasonably conclude that the effects related to the actual perception of the water can be different by those related to memory and expectations regarding a given liquid (see also the results of Experiment 2, for further support of this claim). Another important difference between our study and the one reported by Ngo and colleagues is that in the latter the experimental items were selected on the basis of the colour of the plastic bottles that are generally used to sell mineral water. For this very reason, different colours were selected in their experiment as compared to ours (e.g., green instead of white). Finally, one might expect that colours have different meanings and/or lead to different perceptual effects when attributed to different plastic packaging, (e.g., a bottle of mineral water, or a plastic cup). The results of Experiment 1 support those obtained by previous research showing the presence of multisensory interactions in beverage and food perception, (see Stewart & Goss, 2013; Wan et al., 2015) but they also show the presence of interesting differences with the extant literature. In particular, Hyman (1983) demonstrated that the addition of food colorants to sparkling mineral water does not compromise people's perception of the liquid. By contrast, the results of the present study showed that the colour of the container can affect the participants' evaluation of the characteristics of the mineral water served in it. However, it is important to notice that Hyman did not ask his participants to rate a certain quality of the water (e.g., its carbonation intensity), but only whether or not they could identify correctly the nature of the liquid tasted among a number of alternatives (comprising soda, diet coke and tonic water). Therefore, it remains possible that a modulation of colour is not sufficient to alter the participants' recognition of water, but it might alter its perception across a number of dimensions (such as that relative to the perception of carbonation). That is, the colour red cannot shift people's perception from water to soda, but can make them perceive the water as slightly more carbonated.

A possible explanation of the effect of the colour of the plastic cup on taste perception of mineral water might be related to a change in participant's level of arousal determined by the colour. In fact, it has been reported that colour can affect people's arousal. More specifically, research has shown that red would seem to have a greater capability of increasing arousal as compared to blue (Ali, 1972; Gerard, 1958; Piatti, Savage, & Torgler, 2012). Importantly, our results showed that both blue and red equally increased the perception of carbonation intensity (as compared to white), thus suggesting that an increase of arousal elicited by the colour cannot be the sole explanation of the effects found. Moreover, it remains unclear why an increase of arousal should lead to an alteration of carbonation perception. One might also hypothesize that the effects found in our experiment are not related to the hue of the colour per se, but to other parameters involved in colour perception such as, saturation and contrast. In particular, Van Doorn and his colleagues showed that a white mug enhances the intensity of the flavour of a coffee, as compared to a transparent mug; while, a white mug diminishes people's perception of the coffee sweetness, as compared to the blue or transparent mug (Van Doorn et al., 2014). The authors of this study hypothesized that such effects might be attributed to the colour contrast between the coffee and the mug. Importantly, however, a study by Bruno, Martani, Corsini, and Oleari (2013) showed that participants eat and drink significantly less food and liquids when contained in red plastic plates and red labelled plastic cups than when contained in white or blue plastic plates and blue labelled plastic cups Bruno et al. (2013). Crucially, Bruno and his colleagues also considered the possible effects of contrast and luminance of plateware and cups on food intake, but failed to find any effect of these parameters. They suggested that their results could be due to a sort of avoidance behaviours implicitly associated to the colour red, as unconscious reference of danger and prohibitions (Elliot, Maier, Binser, & Pekrun, 2009; Genschow, Reutner, & Wänke, 2012). This interpretation does not seem to be easily extended to the results of our study. The results of Experiment 1 also showed that the participants perceived still water as lighter, than slightly carbonated and carbonated water. The fact that still water was evaluated as lighter than other kinds of water although not related to the effect of the colour, is an interesting and, to our knowledge, novel result. One might argue that the different evaluations of the liquid on the scale of weight might be related to the perception of water weight in the participant's mouth. That is, the burst of CO_2 bubbles might elicit an activation of mechanoreceptors and nociceptors on the tongue that are interpreted by the participant's brain as a variation of weight. Interestingly, the mouthfeel sensations elicited by CO_2 (defined by participants as tingling, prickling, painful, burning and irritant; Carstens et al., 2002; Dessirier, Simons, Carstens, O'Mahony, & Carstens, 2000; Dessirier, Simons, O'Mahony, & Carstens, 2001; Green, 1992; Hewson, Hollowood, Chandra, Hort, Hyman, 2009; Simons, Dessirier, Carstens, O'Mahony, & Carstens, 1999; Yau & McDaniel, 1991) would seem to be generated by the activation of the trigeminal, facial and glossopharyngeal nerves. It is worth noting here that the trigeminal and glossopharyngeal nerves also innervate the somatic sensory receptors, giving rise to superficial sensations (touch, pressure, and temperature) and allowing people's estimation of the weight of the bolus in mouth (Miyaoka, Ashida, & Miyaoka, 2008). Whether or not the activation of such receptors due to the CO_2 can be also related to water weight perception is certainly a topic that psychophysiological studies will need to address in the future. Another explanation for the different evaluations of water lightness as a function of the CO_2 diluted in it, might be linked to the cross-modal associations between liquids and the perception of some sensory attributes of the stimuli. As far as this point is concerned, research has demonstrated that participants associate carbonated mineral with angular visual shapes and with particular high-pitched non-words, such as 'Takete'. By contrast, still mineral water is generally associated with rounded shapes and low- pitched non-words (such as 'Maluma') (Ngo et al., 2012; Spence & Gallace, 2011a). Such kind of multisensory or synaesthetic associations (see Gallace, Boschin, & Spence, 2011; Gallace & Spence, 2006), might also be present between water and a typically somaesthetic aspect of the stimuli, such as weight. The main results of Experiment 2 showed that the expectations of the participants regarding certain characteristics of mineral water can be modulated by the colour of the plastic cup in which the beverage is served. In particular, the participants expected slightly carbonated mineral water to be less carbonated when contained in a blue plastic cup than in a white plastic cup. Participants also expected carbonated water to be less carbonated when contained in a blue plastic cup than in a white or red plastic cup.

It is important to notice here, that the effects found in Experiment 2 differ, at least in part, from those reported in Experiment 1. In particular, in Experiment 1 the participants tasted the liquid and rated mineral water as more carbonated when contained in a red or blue plastic cup than in a white plastic cup, while in Experiment 2 people evaluated carbonated water as more carbonated when contained in a white or red cup than in a blue cup. This difference is important for two reasons. First, it shows that participants in Experiment 1 did not base their evaluations only on the visual aspects of the water (that were tested in Experiment 2). That is, people's expectations regarding a beverage are not the sole component to drive their perception of it. Secondly, these data clearly show that different evaluations can be obtained by asking people to taste a liquid or to evaluate it only on the basis of their expectations.

The effects found in Experiment 2 might be related to the memory of previous experiences with liquids and container or on some sort of higher order associations in the participants' minds. That is, people might have learned to associate a particular colour to highly carbonated mineral water by their shop experience in supermarkets or through the media. In fact, brands such as 'Rocchetta' advertise their 'Brio Blu' water with blue bottles for slightly carbonated and bright red bottles for highly carbonated mineral water. Similarly, the market leader 'San Pellegrino' sparkling water has used a red star on its label since 1908. Another interesting result of Experiment 2 regards the scale of freshness. As far as this quality is concerned, we found that the participants expected mineral water to be fresher when contained in a white plastic cup, as compared to the same liquid served in a red cup. Here, it is worth mentioning that in Italian the word ''freshness'' in beverage taste perception is more often used to rate the thirst quenching nature of a drink more than its temperature. However, participants were not forced to adopt this interpretation of the term and the possibility of an alternative interpretation cannot be fully excluded.

Interestingly, the effect on freshness was not found in Experiment 1 where the participants tasted the water. This result might be based on people's higher order associations between the colour white or red and the experience of fresh or heat respectively. In fact, in nature white is the colour of snow and ice, while red is the colour of fire, volcanic lava, and hot substances. Similarly, red is also the colour of some spicy and generally defined 'hot' food such as chill-pepper. The results of Experiment 3 showed that people preferentially chose a specific plastic cup colour to drink each different kind of mineral water (still or carbonated). In particular, participants chose preferentially a white cup to drink still water and a blue or a red cup to drink slightly carbonated water. They also preferred to drink carbonated water in a blue cup rather than in a white or red cup. Here one might argue that people have chosen the plastic cup on the base of their personal preference for a colour over the others (Hansen, Olkkonen, Walter, & Gegenfurtner, 2006; Helm & Tucker, 1962; Hurlbert & Ling, 2007; Moscovici, Lage, & Naffrechoux, 1969; Özgen & Davies, 2002). However, if this was the case, the choice would have been the same for every kind of mineral water. Instead, participants chose a specific cup colour as a function of the level of carbonation that was expected for that kind of water (as communicated by the experimenter). This clearly suggests that the choice of the plastic cup is not merely based on perceptual preferences for different colours, but most likely, on the associations (being them perceptual or cognitive) between a certain colour and a certain kind of water.

One important matter to be considered here, is whether the participant's choice regarding the cup colour (Experiment 3) are consistent with people's perception, as tested in Experiment 1, and/or with people's expectations regarding the liquid, as tested in Experiment 2. A greater number of participants in Experiment 3 chose a red or blue plastic cup to taste carbonated mineral water. Interestingly, in Experiment 2 the participants expected the water to be more carbonated when contained in a white or red plastic cup than in a blue plastic cup. By contrast, in Experiment 1 the participants perceived the water as more carbonated when contained in a red or blue cup than in a white cup. On the basis of these results, one might infer that the choice of a blue plastic cup for tasting carbonated water found in Experiment 3 was related more to perceptual, rather than expectation-based factors. That is, participants perceived the water in the blue (and red) cup as more carbonated than in white plastic cup (Experiment 1) and they also chose to drink carbonated water when it was served in a blue rather than in a white cup (Experiment 3). By contrast, even if they expected the carbonated water to be more carbonated when served in a white (or red) plastic cup (Experiment 2), they still chose to drink the water in a blue cup rather than in a white or a red cup (Experiment 3).

The topic related to the main factors responsible for the participant's choice of coloured glassplastic cup is certainly relevant for the development of marketing strategies. That is, if the marketing strategy is related to gaining new consumers the results of Experiment 2 should be considered and a white bottle should be used for selling carbonated water. If the marketing strategy is related to maintaining an old consumer, a blue or red bottle should perhaps be used instead (in order to improve the customer's perception of the water).

However, before drawing any conclusions on the basis of the factors involved in affecting the participants' choice of container colour and on their possible application to the marketing field, It is important to note that in our experiments we did not assess the participants' individual preferences for a certain kind of water over the others. Nevertheless, one might reasonably think that also this variable could have affected the results of Experiment 3 (and to a lesser extent those of Experiment 1 and 2). That is, if a person does not like carbonated water he/she will probably chose the glass where carbonation is perceived, or is expected to be, less intense. The opposite will likely occur for a person who likes carbonated water. The factor related to individual preferences should certainly be considered in future studies on this topic.

A final aspect to be considered here, is that the results of the present experiments were obtained with a relatively small number of participants (a total of 85 in the three experiments), who tasted a small number of water samples (3 repetitions for each condition). Although a larger number of tasting sessions cannot be achieved when water intake is required to human participants (due to their physiological limitations to drink larger amount of water in a relatively short period of time), the possibility to recur to larger and less homogenous (in terms of age and cultural background) groups of participants, should be considered in the future. In fact, one might expect that different results can be obtained in populations that differ from the one tested in the present study.

In conclusion, the results of the present study show that perception and expectations regarding mineral water can be differently affected by the colour of the plastic cup where the liquid is served. Moreover, the results also showed that the participants preferentially chose to drink certain kinds of water when served in plastic cups having a specific colour. Further investigations should be directed on how perceptual and cognitive factors regarding a container interact with the participants' preferences and level of expertise (see the Associazione Italiana Degustatori Acque Minerali – ADAM www.degustatoriacque.com for an example of professionally trained water tasters) in affecting their perception and choice of mineral water.

CHAPTER III
THE ASSOCIATION BETWEEN A CONTAINER'S WEIGHT AND THE PERCEPTION OF THE MINERAL WATER PRESENTED INSIDE

This research was published in:

Maggioni, E., Risso, P., Olivero, N., & Gallace, A. (2015). The effect of a container's weight on the perception of mineral water. *Journal of Sensory Studies*, **30,** 395-403.

1. Introduction

The need for nourishment and fluids is basic to every living organism's survival. Importantly, however, eating and drinking behaviors are determined by a complex combination of physiological, perceptual, cultural, and social variables. As far as sensory and perceptual aspects are concerned, it has been shown that the evaluation of external stimuli, whether they are related to food and drink, is determined by multisensory interactions occurring within a person's neurocognitive system. Different sensorial aspects have been shown to determine the final perception of a given food or drink (Søresen et al. 2003). Importantly, not only do sensorial aspects of a given food or drink contribute to its perception, but it has been suggested that all stimuli that are involved in the eating and drinking experience affect our final evaluation and behavior (Edwards et al.2003; King et al. 2007; Sester et al. 2013). In particular, an increasing number of studies in the last few years have shown that people's taste perception can be affected by certain features of the container in which food or beverage is served and/or experienced. For example, it was demonstrated that the color and the shape of a plate can modify the sweetness, flavor intensity, quality, and enjoyment perception of a dessert (Stewart and Goss 2013). In particular, Stewart and Goss (2013) showed that their participants perceived a piece of cheesecake to be sweeter, higher in flavor intensity, superior in quality and more pleasant when eaten on plates with certain association between their shape and color (i.e., white round or square plates and black round or square plates). Similarly, Piqueras-Fiszman et al. (2012) showed that the color of a plate (black or white) can affect people's perception of mousse when served in a certain dish or container. Note, however, that these studies failed to find a direct effect of the plate's shape on their participants' perception. In beverage perception, it has also been shown that the taste of a liquid can be altered by modifying the characteristics of its container (e.g., Piqueras-Fiszman and Spence 2012a,c; see also Standage 2007). For example, it has been shown that the same batch of hot chocolate was perceived as more flavorful when served in an orange plastic cup compared to a white or a red cup (Piqueras-Fiszman and Spence 2012a). Other experiments have instead investigated the presence of multisensory mental associations between colors, shapes, and beverages. These studies have shown that people tend to associate still and carbonated water with the color blue rather than red or green (Ngo et al. 2012). Interestingly, participants associate still water with round shapes and carbonated water with angular shapes (Spence and

Gallace 2011; Ngo et al. 2012). In a recent study, Risso et al.(2015) demonstrated that changing the color of a plastic cup is sufficient to change the perception of the mineral water in which it is served. More specifically, the authors reported that their participants rated mineral water as more carbonated when contained in a red or blue cup instead of a white cup. Risso and her colleagues also reported that the effect of the container's color not only affected the participants' perception of the liquid but also their expectations and final choice. Many other studies have documented the effects of crossmodal interactions between the characteristics of a liquid and certain features of the container on people's perception and expectations (see Spence and Wan 2015 for a recent review; Wan et al. 2015). See also Gatti et al. (2014) for a study on the effect of the color and weight of a soap bottle on the fragrance of its contents).

A large majority of studies on the interaction between the perception of a beverage and the beverage container focused on the visual aspects of the container (e.g., Cliff 2001; Raudenbush et al. 2002). So far, very little attention has been dedicated to other relevant characteristics of the container such as its tactile qualities (e.g., Krishna and Morrin 2008). However, it is important to note here that touch has been suggested to be a very powerful sensory modality that can affect people's behavior, emotions and perception (see Gallace and Spence 2014). Recent studies have begun to address the role of tactile sensory signals in food evaluation. In a study by Piqueras-Fiszman and Spence (2012c), it was demonstrated that a heavier container enhances a participant's perception of the density of yogurt (i.e., a semi-solid food) as well as the expected satiety and feeling of fullness even before the food is tasted. Similarly, Piqueras-Fiszman and Spence (2011) reported that yogurt eaten in the heaviest of three identical bowls was rated as the most dense, pleasant, and expensive. The same research group (Piqueras-Fiszman et al. 2011) also showed that participants judged yogurt as more pleasant and higher in quality when eaten with a stain-less steel spoon rather than a plastic spoon. It is, however, important to note here that the food used in these experiments was limited to yogurt, a gel-like substance that cannot be fully classified as a solid food or beverage.

The only study that discussed beverage perception was conducted by Piqueras-Fiszman and Spence (2012d) who investigated the effects of increasing the weight of a bottle on people's expectations regarding certain characteristics of wine. These authors found that potential customers expected the wine to be more expensive and better quality when contained in heavier bottles instead of lighter bottles. Note, however, that the participants in that study did not taste any wine or even interact with its container but instead only evaluated the product using an online questionnaire. That is, Piqueras-Fiszman and her colleagues asked their internet-recruited participants to rate their agreement with a series of statements about the correlation between the weight of a bottle and the quality and price of the wine using a 9-point Likert scale. They correlated the participants' responses with the weight of the bottles in which the wines are commonly sold. Therefore, it remains unclear if beverage perception can be affected by the tactile/haptic aspects of the container and whether various liquids are similarly affected by the same tactile manipulation of the container in which they are served.

Understanding the way in which different aspects of a container may affect people's perception of beverage is very relevant, not only from a theoretical point of view but also from the perspective of practical application. In particular, marketing strategies would certainly benefit from understanding the perception of package or container attributes that can drive people's perception and choice of certain beverages. Furthermore, understanding one or more aspects of a container that facilitates the perception of water as more appealing may help improve the drinking experience for people who are at risk of dehydration, with possible positive consequences for their water intake. If one considers that dehydration has been shown to affect people's performance in a number of cognitive and psychomotor tasks (see Suhr et al. 2004; Edmond and Burford 2009), the usefulness of modulating water perception becomes even clearer. For example, the elderly, who suffer from an insensibility to thirst (hypodipsia: Silver 1990; McKinley et al. 2007); children who live in countries with frequent high temperatures (Bar-David et al. 2005), and children and adolescents who participate in sports (D'Anci et al. 2009) may all benefit from a container design that optimizes the perception of water's beneficial attributes.

The present study aims to investigate the consequences of the manipulation of a container's weight on the perception of certain characteristics of the liquid being contained. Based on the fact that touch and proprioception appear to have a profound effect on people's perceptions and behavior (see, for example, Jostmann et al. 2009, for a study that showed how the physical weight of a curriculum vitae can affect the evaluation of the job applicant) and that our perception of the external world is often, if not always, multisensory in nature (Spence and Driver 2004), one might expect that the characteristics of a beverage can be affected by a change in weight.

2. Participants

Thirty-three participants, with a mean age of 23.79 years (SD53.19, 21 female), took part in this study. The participants pants were graduate and undergraduate students. They received course credit for their participation in the study, and all gave written consent prior to their participation. The experiment described here was performed in accordance with the ethical standards described in the 2008 Declaration of Helsinki and was approved by the local ethics committee. The experiment lasted approximately 30–40 minutes. People who claimed to be affected by any olfactory or taste dysfunction as well as those affected by temporary conditions known to alter the sense of taste and olfaction (i.e., cold or flu) were excluded from taking part in the experiment.

3. Stimuli

Two types of mineral water were used: carbonated and still mineral water (S. Benedetto®, 0.5-L bottle, see Fig. 19A). The chemical and physical properties of each type of water are reported in Chapter II (Table 1). Each cup used was filled with 20 mL of water and the bottles used were kept at a stable room temperature (19–22C). Standard white plastic cups, produced by a commercial brand (®DOpla S.p.A) and varying only in terms of their weight (see Fig. 19B), were used to serve the water. The cups' weight was manipulated by creating a false bottom to the cups. Three experimental conditions were adopted: light (2 g, no weight was added to the cup), medium (11 g), and heavy (30 g). The quantity of the water used was the same (20 g) in all three experimental conditions. The different weights of the cups were chosen according to pretests performed in our laboratory and based on the extant literature on human weight perception (Ross and Murray 1996; Kawai 2002). All cups used in the three experimental conditions were visually identical, varying only in terms of their weight.

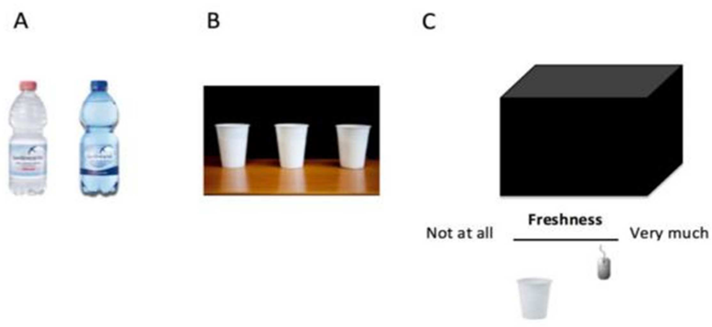


Figure 19 – (A) Two types of water bottles used in experiment. (B) the three identical plastic cups, varying only in terms of their weight, used in the present experiment. (C) experimental set-up: a cup of water to be evaluated; the participants used the mouse to select the desired point on the scale the vas presented on the pc screen; and in the background, the black paperboard box used to hide the cups before they were presented

4. Procedure

The procedure followed a within-participant experimental design. The study was conducted in an experimental booth equipped with a laptop (with a resolution of 1024 x 768 pixels and a refresh rate of 60 Hz) positioned on a desk directly in front of the participants. The participants sat comfortably on a chair approximately 70 cm away from the laptop screen. To test the effect of the container's weight on water perception, a cup filled with water was presented by the experimenter on the desk. The participants were instructed to grasp the cup at the experimenter's signal and drink as much water as they wished. They were also informed that, after tasting the water, they were to rate the liquid according to four attributes (freshness[1], pleasantness, level of carbonation and lightness) using a 150 mm long visual analogue scale (VAS), anchored with the terms "not at all" and "very much." The evaluation scales adopted in the present experiment have been used in previous studies (see Risso et al. 2015) and were chosen on based on the fact that people are not typically able to identify the basic taste of water (i.e., sweet, sour, salty, and bitter; see Wells 2005) if not professionally trained (Hyman 1983; de Araujo et al. 2003; Simon et al. 2006; Galindo-Cuspinera et al.2006). As far as the lightness scale is considered, we did not provide a specific interpretation to be used for the term. However, in the Italian mineral water market, this term is commonly associated with the digestive properties of the liquid and its low mineral and impurity content. The VAS was displayed at the center of the PC screen, and the participants used the mouse to select the desired point on the scale. Each type of water was presented 3 times in each manipulated cup for a total of 18 (2 types of water x 3 different cup weights x 3 samples) samples of water to be evaluated by each participant. Three different random combinations of weight and water types were counterbalanced for every 11 participants. The cups were presented one at a time and a black paperboard box was used to hide the cups before they were presented (see Fig. 19C).

5. Results

The mean participant VAS-based evaluations were subjected to repeated-measures ANOVA in terms of the weight of the plastic cup (light, medium, and heavy), type of water (still and carbonated) and scale (freshness, pleasantness, level of carbonation, and lightness). The analysis revealed a significant main effect of scale [F(3, 96) = 10.45, $p < 0.0001$] and a significant main effect of water [F(1, 32) = 31.62, $p < 0.0001$]. The analysis also revealed a significant interaction between scale and weight [F(6, 192) = 3.07, $p = 0.007$], scale and water [F(3, 96) = 71.43, $p < 0.001$] and a trend toward significance in the interaction between weight and water [F(2, 64) = 2.54, $p = 0.08$]. The main effect of weight [F(2, 64) = 1.38, $p = 0.26$] and the interaction between scale, weight and water [F(6, 192) = 1.46, $p = 0.19$] did not show any significance.

A Newman–Keuls post hoc test on the interaction between weight and water on the pleasantness scale showed that people perceived mineral water in the heavier cup as less pleasant ($p < 0.05$) compared to mineral water in the lighter cup (see Fig. 20B). On the contrary, the same post hoc analysis on the carbonation intensity scale revealed that participants perceived mineral water served in the heavier cup as more carbonated ($p = 0.05$) compared to mineral water served in the lighter cup (see Fig. 20A). That is, the use of heavier cups resulted in the participants reporting a decrease in water pleasantness and an increase in carbonation perception.

A Newman–Keuls post hoc test on the significant main effect of scale showed that participants on average gave quantitatively lower scores (i.e., scores closer to the “not at all” end of the scale) on the carbonation scale than on the freshness ($p = 0.05$), pleasantness ($p = 0.05$) and lightness ($p = 0.05$) scales.

A Newman–Keuls post hoc test on the significant main effect of water revealed that participants on average gave quantitatively lower scores (i.e., scores closer to the “not at all” end of the scale) for still mineral water than for carbonated water (p = 0.05). A post hoc test (Newman–Keuls) on the interaction between scale and water showed on the carbonation intensity scale that people perceived still water as less carbonated (p = 0.05) than the carbonated water. The results for the carbonation intensity scale, in which carbonated mineral water was rated as more carbonated compared to still water, demonstrated that participants were able to discriminate between the two types of liquid in the experiment. This analysis also revealed that people perceived still water as lighter (p < 0.001) than carbonated water (see Fig. 20C).

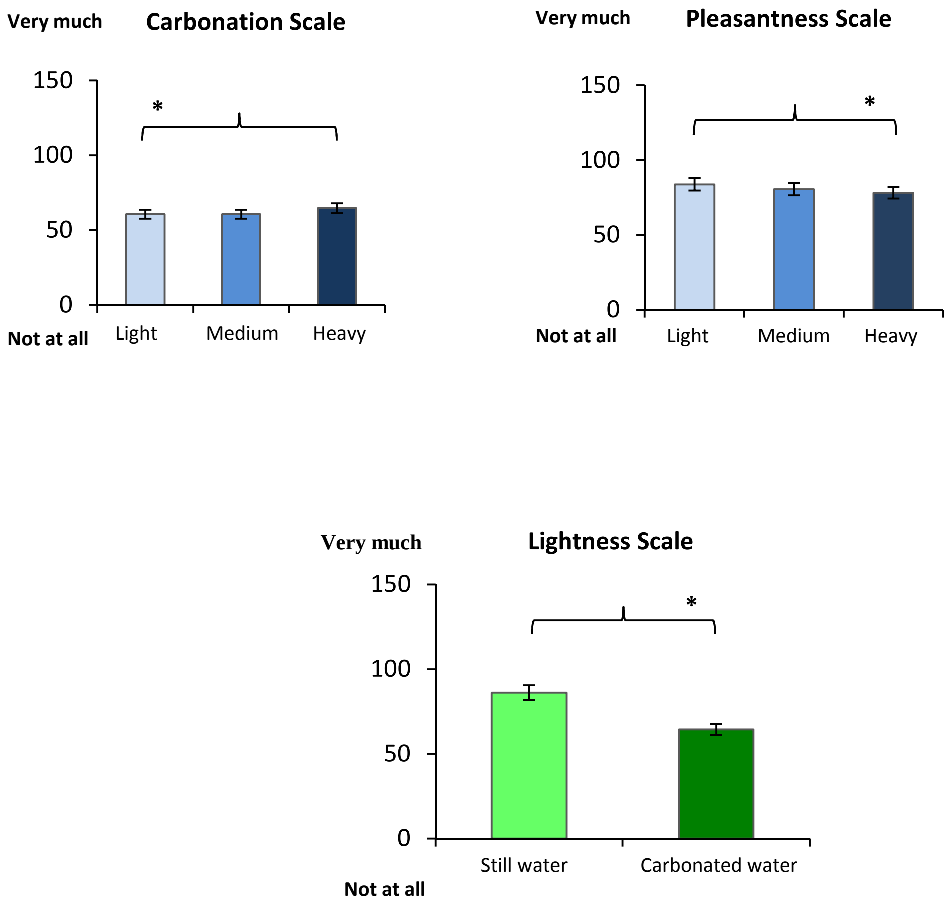


Figure 20 – (A) The mean participants' judgments of carbonation intensity as function of the weight of the plastic cup in which the liquid was served. asterisks represent the newman–keuls significant differences at p<0.05. (B) The mean participants' judgments of pleasantness perception for still and carbonated water as function of the weight of the plastic cup in which the liquid was served. asterisks represent the newman–keuls significant differences at p<0.05. (C) The mean participants' evaluation of lightness perception of still and carbonated water as function of the weight of the plastic cup in which the liquid was served. asterisks represent the newman–keuls significant differences at p < 0.01

6. General discussion and conclusion

The results obtained in the present study clearly demonstrate that the weight of the plastic cup affected the participants' taste perception of mineral water. Importantly, the effect of the weight differed as a function of the characteristics of the liquid to be evaluated. Interestingly, participants perceived mineral water as less pleasant when contained in the heavier cups. However, participants judged mineral water to be more carbonated when contained in the heavier cups. That is, an increase of cup weight resulted into lower levels of pleasantness and higher levels of carbonation. The first result does not appear to be fully consistent with the previous literature on the effects of cup weight on people's taste perception. In fact, Piqueras-Fiszman and Spence (2012d) reported that their participants judged wine in heavier bottles as more expensive and superior in quality to wine in lighter bottles. It is, however, important to note here that participants in that study did not taste the wine, nor were the bottles manipulated; this makes any comparison of their results with those obtained in our study difficult. In a separate study, Piqueras-Fiszman et al. (2011) also reported that participants rated the same yogurt as more pleasant, more expensive, and thicker when served in a heavier dish than when served in a lighter dish. However, the particular type of food used by Piqueras-Fiszman et al. (2011, 2012c), again, presents difficulties when comparing their results with those in the present research. Moreover, it is relevant to mention here that while lightness is a quality sought after in mineral water, the same quality is probably not considered equally important for yogurt or wine. That is, a yogurt or wine that is "too light" may be perceived as somehow "diluted" and thus of lower quality.

Our study improves upon previous research by highlighting that tactile/proprioceptive qualities may play a role in affecting a participant's evaluation of a liquid in addition to the visual characteristics of the container, such as its color (see Risso et al. 2015). It is also important to note that while the visual characteristics of the container have been shown to affect only the participants' evaluation of water carbonation (Risso et al. 2015), the tactile/proprioceptive manipulations used in the present study also affected the perception of the overall pleasantness of the liquid. This result certainly strengthens the claim that somatosensory information plays an important role in hedonic evaluations (Gallace and Spence 2011a, 2014; Etzi, Spence & Gallace, 2014).

The reduced pleasantness perception of water contained in the heavier cup might be linked to the role of higher order cognitive associations affecting perception. For example, it has been shown that the perceived pleasantness of interpersonal tactile contact and the neural activation that results depends on the perception of the person who delivered the touch (Lee and Guerrero 2001; Gazzola et al. 2012; see also Gallace and Spence 2010 for a review). Interestingly, based on a number of studies on the role of touch in product evaluations, it has been suggested that the abstract concept of "importance" (i.e., comprising the expected price and quality of a product/service) is based on the bodily experience of weight (Jostmann et al. 2009). The results of a recent study published in Science appear to support this claim (Ackerman et al. 2010). In fact, Ackerman et al. (2010) reported that a job applicant is evaluated more highly when his/her curriculum vitae is presented in a heavy, rather than a light, cover (even if the CV itself remained unchanged; Ackerman, Nocera, & Bargh, 2010). Not surprisingly, the results of the present experiment clearly show that the role of weight in product evaluation is not always unidirectional (e.g., more weight results in more positive evaluations), but strictly depends on the specific product and qualities to be rated.

It is worth mentioning here that at an associative/semantic level, the idea of the water is often tied to the concept of lightness rather than the idea of weight. That is, who prefers to drink "heavy" water[2]? In fact, water is probably the quickest stimulus that flows to the stomach (as compared to solid food and various other liquids) with its extremely low level of viscosity (see Gupta 2014). Currently, the natural association between water and lightness is likely to be more reinforced by the number of mineral water marketing campaigns. For example, in Italy, the marketers of the top selling mineral water "Levissima" by the San Pellegrino group have focused their marketing campaign on the light- ness of this product. Interestingly, the name of the product "Levissima" is formed by the superlative of the Latin word "levis," or "lightness" in English.

The result obtained for the evaluation of carbonation intensity showing that participants perceived the mineral water served in the heavier cup as more carbonated may be linked to the sensations in the mouth caused by carbonated water at a more sensory level. Specifically, the sensation of bubbles from carbonated water in the mouth likely elicits complex neural circuit activity that involves oral thermal receptors,

[2]Note that in chemistry, "heavy water" refers to a specific form of water that contains a larger than normal amount of the hydrogen isotope deuterium. This water is actually highly toxic for humans and animals.

mechanoceptors, and nociceptors (the trigeminal nerve; Green 1992; Dessirier et al.2000; Hewson et al. 2009). Moreover, it has been demonstrated that carbonation perception involves the afferent nervous fibers linked to weight perception in the mouth (Miyaoka et al. 2008). Therefore, one might speculate that the pressure caused by bubbles bursting in a participant's mouth is interpreted by the brain as increased weight on the tongue. In this case, the information regarding the weight of the cup may directly interact with the processing of weight in the participant's somatosensory cortex. If so, such an explanation may also be useful for clarify the results found in the interaction between scale and water, where we found that the participants judged still water as lighter than carbonated water (see also Risso et al.2015, for a similar finding). These speculations certainly require further and more accurate investigations. One may also wonder whether the perceived carbonation and overall pleasantness of the water are related, in which a change in one variable may determine the change in the other. Unfortunately, however, in the present experiment, we did not collect any data that allow us to determine a causal role of one variable over the other. To answer this question, one would probably need to know the participants' preferences for certain qualities in water. That is, it might be expected that if the participants generally tend to prefer carbonated water to still water, an increase in the perceived level of carbonation may also affect the perceived pleasantness. Therefore, the participants' preferences regarding certain qualities of water type (e.g., perceived carbonation) represents another important factor that should be considered when conducting further research on this topic.

One might argue that the results obtained in the present study resulted from the focus of the participant's attention only on the weight differences of the containers rather than on the characteristics of the liquid that they were evaluating. However, in the debriefing session that followed our experiment, the results showed that the large majority of the participants (approximately 90%) declared that they were not aware of the weight manipulation. Therefore, it is unlikely that their evaluations were explicitly affected by the effect of weight on people's attention.

In one of the few studies which have investigated the tactile/haptic aspects of a container on beverage perception, Krishna and Morrin (2008) showed that the firmness of a plastic cup can affect people's perception of the quality of the mineral water served in the cup. That is, these authors reported that the firmer the cup is, the higher the participants' evaluations of water quality will be. Interestingly, this result was found when participants with a low autotelic need for touch (a non-focused pleasure to touch; Peck and Childers 2003) were tested. Although, weight and firmness are different haptic characteristics, researchers have shown an important relationship between the two, leading to a “material-weight illusion” (Wolfe 1898; Flanagan and Wing 1997; Ellis and Lederman 1999). In other words, objects with identical mass that are made with different surface materials are judged as having different weights. For this very reason, one could argue that the effects found in our experiment are related to the perceived firmness of the container rather than the manipulation of weight, per se. Nevertheless, it is important to highlight that in the present study, unlike Krishna and Morrin’s study, the manipulation of the weight did not result in a change of the firmness of the cup, given that all containers that were used shared the same texture. Moreover, the large majority of participants failed to notice any change in the water containers.

In conclusion, the results of the present experiment clearly demonstrate that mineral water perception can be affected by the weight of the cup in which the liquid is served. A detailed understanding of the different sensory interactions between water and the weight of its container may be employed in multiple contexts. Recently, restaurateurs have begun to draw more attention to pairing mineral water with the specific characteristics of the food to be eaten, just as has been done with wine for many decades (Wilk 2006). Seen within this context, the results of the present study would seem to suggest that the characteristics of the water and the cups in which the water is served should be considered for these food-water associations to be more successful (which has been reported for different types of wine/liquors and their containers; Delwiche and Pelchat 2002; Wan, Velasco, Michel, Mu, Woods, Spence, 2014; see also Standage 2007, for a discussion on the importance of the container in liquid evaluation). Finally, further investigation regarding the specific multisensory associations between the tactile/proprioceptive aspects of a container and those of the liquid within will likely improve our understanding of the neural mechanisms and constraints underlying food and beverage sensory evaluations.

CHAPTER IV
THE ASSOCIATION BETWEEN THE TACTILE ATTRIBUTES OF A CONTAINER AND THE PERCEPTION OF THE MINERAL WATER PRESENTED INSIDE

1. Introduction

As any professional chef would know, our experience of food is not solely related to the sensations arising from the activation of a few chemical receptors on our tongue (see Spence & Piqueras-Fiszman, 2014, for a review). For example, Michel, Velasco, Gatti, and Spence (2014) recently examined how some visual factors can influence food taste perception. The authors demonstrated that the participants provided higher tastiness ratings to the culinary elements of a salad dish when arranged in an artistic way (similar to a Kandinsky's paint), as compared to the ratings given to the same dishes presented with no artistic arrangement. As far as food containers are concerned, Stewart and Goss (2013) demonstrated that the association between the colour and the shape of a plate (i.e., white round or square plates and black round or square plates) can significantly modify the sweetness, flavour intensity, quality, and enjoyment perception of the dessert served in them (Bruno, Martani, Corsini, Oleari, 2013).

With reference to beverages, Zampini and Spence (2005) showed that participants' perception of carbonation intensity of sparkling mineral water is affected by an alteration of the frequency of the auditory feedback emitted by the liquid just before consumption. During the experiment, the sound emitted by sparkling water was manipulated in order to amplify its higher frequencies. The researchers found that the participants judged as more carbonated the water presented under this condition of stimulus presentation, as compared to a condition where no sound manipulation was performed (see also Spence and Gallace, 2011a, for the connection between carbonation intensity of mineral water and certain word sounds).

The texture of food is one of the key aspects used in everyday cooking, just as by professional tasters, for their evaluation of food quality and pleasantness. In fact, Tournier et al. (2009) showed that a variation of the texture of food can affect people's perception of some of its characteristics. In particular, they found that an increase in the viscosity of a custard dessert enhanced people's perception of its taste intensity. As far as food containers are concerned, Piqueras-Fiszman and Spence (2012b) demonstrated that the texture of a container can modulate people's gustative perception of the biscuits that are consumed in it. Specifically, the biscuits taken from a rough pot were perceived as crunchier and harder than those taken from a smoother pot. Similar results were reported by Biggs, Juravle and Spence (2016) in a series of 'citizen science' tests in which people rated the mouthfeel and food sensations of biscuits and (jellies babies) served in plates having rough or smooth finish. The results of this study showed that participants rated the food as crunchier and rougher when tasted from rougher plates than when tasted from smoother plates. Similarly, participants evaluated the biscuits as saltier and gingerier when picked from the rough plate and sweeter when tasted from the smooth plate.

Regarding the interaction between taste and texture perception of beverages Szczesniak, (2002) investigated through questionnaires and interviews which attributes of liquids and food textures make them unacceptable or inappropriate for participants. Unsurprisingly, they reported that lumps or hard particles in beverages are considered inappropriate (due to the fact that they provoke fear of choking). While, with respect the effect of the textures of the container on liquids, Schifferstein (2009) used cups made of different materials (translucent plastic, opaque plastic, melamine, glass, ceramic) to evaluate the drinking experience relative to two different beverages (soda or hot tea). The participants rated also the empty cups with respect to a set of characteristics related to affective dimensions (i.e., pleasant-unpleasant, good-bad) and sensory perception (i.e., heavy-light, thick-thin). The author found that, with just a few exceptions, the drinking experience followed the experience of the cups (e.g., the more pleasant was perceived the cup, the more pleasant was perceived the drink). Note, however, that in this study the participants rated the whole experience of drinking (consisting, as suggested by the authors of the perception through the senses, the meanings and values attached to the product, and the feelings and emotions that are elicited) rather than the actual perception of the drink inside the cup. On a similar line of research, Krishna and Morrin (2008) investigated the effect of the firmness of a plastic cup on the taste perception of a mixed drink (one can of Sprite diluted into 6 litres of water). The results showed that the firmer a cup was, the higher the participants' evaluated the quality of the drink inside.

In a more recent study, Tu et al. (2015) investigated the effect of different packaging materials on taste perception of traditional Chinese cold tea beverage. Participants were asked to evaluate three dimensions, bitterness, sourness and sweetness of the same tea drink (although they were led to believe that three different brands of the beverage were tasted) served in cups made of different materials (glass, paper, organic plastic). The results showed that the haptic perception of the cup affected people taste perception of the beverage contained in them. In particular, people rated the sense of ice (a sub-dimensions of the scale measuring sweetness) of the beverage as significantly higher when tasted by means of the glass cup with respect to paper or organic plastic cups.

The aim of the present study is to shed more light on the interaction between touch and taste in beverage perception by investigating whether and how the texture of a container can affect the perception of the water that is served in it. We hypothesized that the tactile properties of the containers might affect people's judgment by means of a phenomenon called '*affective ventriloquism'* (Spence & Gallace, 2011). This concept concern to emotional domain findings and refers to research by means, for example, participants rate how happy or sad is a person of which can see the face and hear the voice. Researchers, through the manipulation of the face emotion and of the voice simultaneously presented, derived the relative contributes of the two different sensory modalities regarding people's affective judgments (de Gelder, & Vroomen, 2000). Spence & Gallace (2011) argued that affective ventriloquism effects might be extended to tactile multisensory stimulation with particular reference to products packaging design. That is, some research suggest that in multisensory stimulation during people's estimation of several qualities of a stimulus, the sensory modality with the lowest variance (i.e., noise) probably will "drive" or "dominate" the perception of inputs arriving from the other sensory modalities. Such effect was defined maximum likelihood estimation (Ernst & Banks, 2002). Alternatively, the container textures effects on beverage perception could be attributed also to 'halo/horn effect' (Beckwith & Lehmann, 1975; Lawless and Heymann, 1997 Thorndike, 1920). The former, refers to the fact that the positive hedonic/emotional attributes of a product/stimulus perceived via one modality can 'pull' (or bias) a person's estimate of the quality and pleasantness of the product/stimulus derived from other sensory modalities into alignment, and by so-doing, modulate a person's overall product/stimulus. Conversely, the definition horn effect is used when the negative attributes within a product/stimulus lead to general more negative evaluation of it with respect the norm or in term of intensity.

It has been shown that touch plays a very important role for our emotional wellbeing (Gallace & Spence, 2011; Gallace & Spence, 2014; Hertenstein, Verkamp, Kerestes, & Holmes, 2006; Walker & McGlone, 2013) and that tactile sensations can convey emotions (Hertenstein et al., 2006), just as visual properties of stimuli (Paradiso, Johnson, Andreasen, O'Leary, Watkins, Boles Ponto, & Hichwa, 2014).

Following on from these considerations, the emotional valence of textures (see Etzi, Spence, & Gallace, 2014, for a study on people's judgments of haptically explored textures) experienced during the manipulation of containers, might be transferred to the perception of the liquid that is contained inside and thus influencing its perceptual evaluation (e.g., more pleasant textures might lead to more pleasant evaluations of the water). Alternatively, an effect of the texture of the container on beverage perception might be driven by people's expectations based on their memory of previous experiences (*exposure effects*) with water containers (Gallace & Spence, 2008; 2009). In this case, the more the container deviates from a number of features that are perceived as 'standard' in water containers, the less pleasant and lower in quality could be perceived the water. In this case, one might expect that an often used container (such as the plastic glass) leads to more positive water evaluations than novel - differently textured - containers. Woods, Poliakoff, Dijksterhuis and Thomas (2010) experimental paradigm, strengthen the hypothesis based on people's memory of previous experiences. The authors demonstrated that two drinks served from two jugs, and differing only in sweetness were rated as more similar when poured from two identical jug, as compared to when presented from different jugs. They argued that these results are in agreement with the assimilation-contrast model (Anderson, 1973; Hovland, Harvey, Sherif, 1957). Such a model postulated that if a food is sufficiently similar in liking and flavour to people's previous experiences, the expectations were respected and it is assimilated to the norm (Woodruff, Cadotte, Jenkins, 1983). Conversely, the model foretell the failure to assimilate a flavour to the norm when individual perceives an incongruity of the present gustatory experience with the memory of analogous experiences. Woods, Poliakoff , Dijksterhuis, Lloyd, Thomas A. (2010) postulated that the consecutive exposures to a flavour improve the memory representations of its natural fluctuation starting from the prototypical one. These last considered as (the peak of the distribution) and (the spread of the distribution) respectively. Huttenlocher, Hedges, Vevea (2000) developed a Bayesian model by means to determine the degree and extent of the shape of the distribution of taste expectation effects, on the basis of the uniformity and the amount of previous experience with a food.

In our experiment, the participants' judgments of the liquid were measured by means of four different scales (along the dimensions of freshness, pleasantness, level of carbonation, and lightness), which were used in previous studies (Maggioni, Risso, Olivero, & Gallace, 2015; Risso, Maggioni, Olivero, & Gallace, 2015). The scales were chosen among the descriptors of the categories used to classify the mouthfeel sensations of liquids (Szczesniak, 1979). The choice of mineral water as experimental item is due to the fact that it is odourless, so that, smells cannot interfere with the evaluation of the features of the liquid (something that cannot be said of the beverages used in previous experiments on this matter; e.g., Tu et al., 2015). By using this particular stimulus, we could directly analyse the effect of tactile qualities of containers on people's taste perception of liquids, without the influence of other sensorial attributes of the stimuli.

Given that water is often defined as tasteless by untrained people (i.e., with the exception of highly trained hydrosommeliers) we asked our participants to assess the characteristics more closely linked to thirst, or to the advertising campaign related to mineral water (Dietrich, 2006; Lucchiari & Pravettoni, 2012), instead of the basic tastes (sweet, sour, salty, bitter).

2. Participants

Forty-eight participants, with a mean age of 23.61 years (*SD* = 4.75, 38 female) took part in the experiment; they were graduate and undergraduate students. The students received course credits for their participation in the study. All the participants gave written consent prior to their participation. The experiment was performed in accordance with the ethical standards laid down in the 2008 Declaration of Helsinki and it was approved from the local ethical committee. The experimental session lasted for approximately 40-50 min. This duration includes an initial overview of the experimental setup, the explanation of the instructions, and a final debrief of 10 minutes, regarding the main aims of the study.

3. Stimuli

Two different types of mineral water were used: sparkling and still mineral water (S. Benedetto® sparkling and still mineral water, 0.5 l bottle). The chemical and physical properties of each type of water are represented in Chapter II (Table 1). Common plastic cups, produced by the same commercial brand (®DOpla S.p.A) and varying only in terms of the material used to cover them (sandpaper, satin, and plastic) were used to serve the water (see Fig. 21). The textured covers (satin and sandpaper) were selected on the basis of a previous study showing that, across a range of ten different materials, people perceive sandpaper and satin as respectively a very rough (and unpleasant) and a very smooth (and pleasant) material (see Etzi et al., 2014). The textures were glued around the container leaving uncovered only the part of the cup where the participant's lips had to be placed in order to drink the content. Each plastic cup used was filled with 20 ml of water and the bottles used were always kept at constant room temperature (19–22 °C).

Figure 21 – The coatings used to cover the plastic cups. Starting from the left plastic, sandpaper and satin

4. Procedure

The procedure followed a within-participant design. The study was conducted in an experimental room fitted with a laptop computer (screen resolution: 1024*768 pixels and had a screen size of 23 cm in height x 30,6 cm in width; refresh rate: 60 Hz). The computer was placed on a desk directly in front of the participants. The participants sat comfortably on a chair, approximately 50 cm from the laptop screen. In each trial, a plastic cup filled with water was placed on the desk in front of the participants by the experimenter at about 25-30 cm from the participants' body. The individuals were blindfolded and instructed to grasp the cup when the experimenter placed it among their fingers and to drink as much water as they wished. Immediately after the tasting session, they were asked to remove the blindfold and rate the water along four dimensions (freshness[1], pleasantness, carbonation and lightness), by means of 150mm long visual analogue scales (VASs), anchored with the terms 'not at all' and 'very much' and presented on the centre of the PC screen. Participants were not informed that during the experiment tasted always the same two kind mineral water (still and sparkling). Responses to the VASs had to be provided by using a computer mouse. At the end of the experimental session people evaluated the pleasantness of the three textured cups using the same VASs of the previous part of the experiment. The participants were also requested to indicate what kind of mineral water they generally prefer to drink. Each type of water was presented 3 times in each different cup for a total of 18 (2 waters x 3 textures x 3 repetitions) samples to be evaluated.

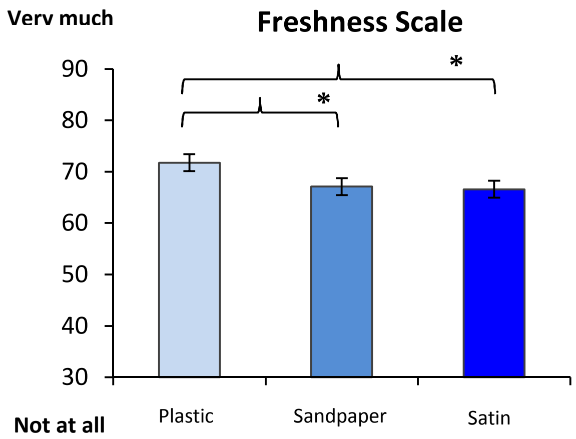


Figure 22 – The participants' mean judgments on the scale measuring freshness perception for both kind of water as a function of the texture of the glass in which the liquid was served. Error bars represent standard errors of the means. Asterisks represent Newman-Keuls significant differences at $p < .05$

5. Results

The data were analysed with STATISTICA 6.0 (StatSoft, Italy). The participants' mean ratings were submitted to a repeated measures ANOVA with the factors of texture of the plastic cup (i.e., sandpaper, satin, plastic), type of water (i.e., still, carbonated) and scales (i.e., freshness, pleasantness, level of carbonate, lightness). The results of the analysis revealed a significant main effect of the scale [F(3,141) = 13.96, $p < 0.001$] and of texture [F(2,94) = 5.42, $p = 0.006$], but not of water [F(1,47) = 3.68, $p = 0.061$]. The interaction between scale and texture [F(6,282) = 2.37, $p = 0.03$], as well as the interaction between scale and water [F(3,141) = 118.43, $p < 0.001$] resulted to be significant. The interaction between texture and water [F(2,94) = 0.06, $p = 0.94$] and between scale, texture and water [F(6,282) = 1.14, $p = 0.34$] were not significant. Newman–Keuls post hoc tests were performed on all the significant effects. The main effect of scale showed that on average participants provided quantitatively lower evaluations (i.e., evaluations closer to the 'not at all' endpoint of the scale) for the intensity of carbonation scale than for freshness ($p < 0.001$), pleasantness ($p < 0.001$) and lightness ($p < 0.001$) scales. A post hoc test on the significant effect of texture demonstrated that people on average provided quantitatively lower evaluations (i.e., evaluations closer to the 'not at all' endpoint of the scale) for sandpaper ($p = 0.01$ and satin ($p = 0.01$), as compared to the plastic texture. A post hoc test on the interaction between scale and texture revealed that participants perceived mineral water as fresher when served in a plastic cup, as compared to a cup covered with sandpaper (p = 0.049) or satin (p = 0.028) cups (see Fig. 22).

The post hoc test also revealed that water was perceived as more pleasant when served in a plastic cup, as compared to the water served in cups covered by sandpaper (p = 0.01) or satin (p = 0.04) (see Fig. 23). Finally, the results showed that the mineral water was perceived as lighter when served in a plastic cup, than when served within a cup covered by sandpaper (p = 0.054) (see Fig. 24). No significant differences were found on the scale of carbonation intensity. A post hoc test on the interaction between the factors of scale and water revealed that participants perceived still water as fresher (p = 0.01), more pleasant ($p <$ 0.001) and lighter ($p <$ 0.001) than carbonated water. Not surprisingly, carbonated mineral water was perceived as more carbonated than still water ($p <$ 0.001).

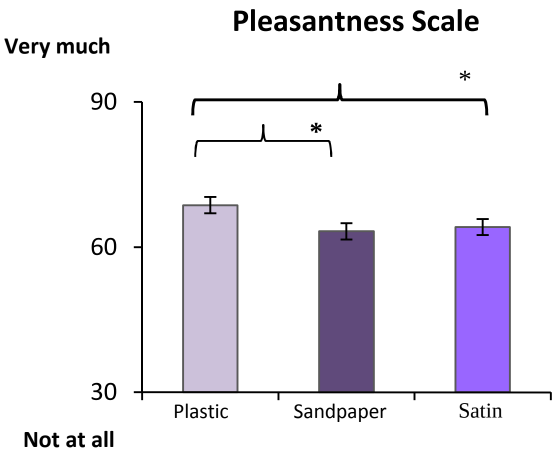


Figure 23 – The participants' mean judgments on the scale measuring pleasantness perception for both kind of water as a function of the texture of the glass in which the liquid was served. Error bars represent standard errors of the means. Asterisks represent Newman-Keuls significant differences at $p < .05$

A univariate ANOVA was performed on the participants' pleasantness evaluations of the three textures. The results of the analysis revealed a significant main effect of texture [$F(2,141) = 13.06$, $p <$ 0.001]. A Newman-Keuls post-hoc test showed that participants rated sandpaper as less pleasant as compared to satin ($p <$ 0.001) and plastic ($p <$ 0.001). Finally, people's responses regarding their ability to recognise the textures and their preference for the mineral water were calculated: 47 individuals recognised the plastic (98%), 41 recognised the sandpaper (82%) and 2 recognised the satin (4%). As far as the evaluations of the water preferences are concerned, 36 participants in general preferred to drink still water (75%), 10 carbonated water (21%), and 2 slightly carbonated water (4%).

A linear regression analysis was carried out in order to evaluate the relationship between the perception of mineral water and the pleasantness of the textures on each of the four scales. The four dimensions investigated freshness [$r = 0.11$, $p = 0.93$], pleasantness [$r = 0.35$, $p = 0.77$], carbonation intensity [$r = 0.93$, $p = 0.23$] and lightness [$r = 0.55$, $p = 0.63$] of the water did not show any correlation with the perceived pleasantness of the textures.

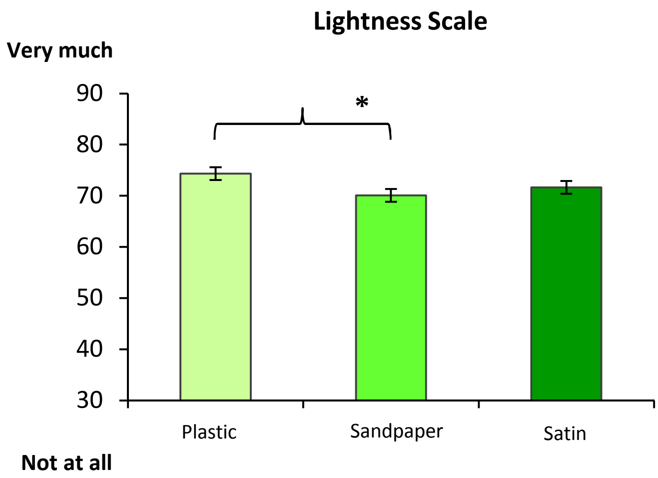


Figure 24 – The participants' mean judgments on the scale measuring lightness perception for both kind of water as a function of the texture of the plastic glass where the liquid was served. Error bars represent standard errors of the means. Asterisks represent Newman-Keuls significant differences at $p < .05$

6. General discussion and conclusions

The results of the present study revealed that the perception of certain attributes/qualities of mineral water was affected by the different textures used to cover the cup where the liquid was served. In particular, the results demonstrated that participants perceived both the still and the carbonated mineral water as fresher and more pleasant when the liquid was tasted in a plastic cup, as compared to conditions where the cups were covered by sandpaper or satin. On the dimensions of lightness was found that people perceived mineral water lighter when the liquid was tasted in a plastic cup, as compared to conditions where the cups were covered by sandpaper. That is, people perceived both kinds of mineral water as more pleasant and fresher when served in plastic cups, than when served inside sandpaper and satin covered cups. Intriguingly, these results show that the texture of a container can modulate people's judgments regarding some characteristics of mineral water.

One might wonder whether this effect is determined by the overall evaluation of the pleasantness of the textures. That is, participants could have transferred their perception of pleasantness from a given material to the liquid contained in such material. However, this interpretation is not supported by the results given that in the present experiment satin and plastic cups were rated by the participants as equally pleasant. As well as, it cannot be attributed to halo/horn effects (Beckwith & Lehmann, 1975; Lawless and Heymann, 1997). Since, there is the lack of a fundamental propriety, that is, the shift of the positive/negative hedonic feelings of some characteristics of the stimuli on their overall evaluation. In fact, the textures differentially modulated mineral water perception. For example, carbonation intensity perception, was not modulated by the textures, and regarding lightness was found a significant difference only between plastic and sandpaper covered cusps. Moreover, regarding halo/horn effects it occur when are rated characteristics that belong to the same cluster (i.e., mouthfeel sensations), as reported by Kappes, Schmidt and Lee (2006) and not when in addition were rated attributes in other different modality. Lastly, to our knowledge in literature were not reported halo/horn effects due to the tactile features of the experimental stimuli.

Several hypotheses may explain the effect reported in the present study. First, a key factor could be the degree of the appropriateness of the container to the whole drinking experience of the participants. In fact, as reported by Spence and Wan (2015d) for alcoholic drinks, people quickly learn to associate the consumption of different liquids to receptacles made of specific materials and having specific shapes. One might then hypothesise that these preferences can also extend to non-alcoholic beverages. In the present study, it is possible that the participants, as a function of their previous experiences, considered the plastic cup (covered by the same material used to make the cup) as the more appropriate container in which to drink mineral water. In fact, it should be noticed that sandpaper and satin represent unusual materials for a cup. Thus, drinking the water from containers covered with those materials, could have violated the participants' expectations regarding their drinking experience (Szczesniak, 2002).

It might also be possible that participants attributed to the water some of the characteristics of the texture (such as the presence of rough particles of sandpaper and of fabrics), thus diminishing the level of acceptance of the water. Note in fact that drink acceptance mainly depends on the presence of certain unexpected hard particles or of no edible materials in beverages (Szczesniak, 2002). In addition, the use of materials, such as sandpaper and satin, that are generally not used to serve water might have also compromised the participants' perception of water drinkability (see a detailed review on the appropriateness of the container on the perception of contents; Spence & Wan, 2015d).

It is important to mention here that the effects found can be also related to emotional responses to the stimuli. That is, the breaking of participant's expectations regarding the matching between the container and the content could have generated negative emotions, which in turn may had affected the evaluation of water characteristics. In this case, therefore, one might suggest that the evaluation of water was determined by the affective ventriloquist effect; (see Spence & Gallace, 2011b) for which the emotional response elicited by a tactile aspect of the container (negative in this case due to the break of expectations), affected the overall evaluation of the drinking experience. Hypothesis that agrees well with Woods et al. (2010) model, since containers covered with sandpaper and satin could be totally novel with respect participant's previous drinking experience. Hence, this fact could have caused a perceptual discrepancy regarding the flavour of the mineral water served in classic plastic container, more similar to the prototypical beverage flavour stored in memory. Intriguingly, the intensity of carbonation of mineral water was not affected by any crossmodal effect with respect the three different textures of the cups. In the future, emotional reactions to the containers should be evaluated also by means of physiological measures (Etzi & Gallace, 2016).

Finally, it needs to be considered here that while sandpaper and satin textures were glued around the plastic container (just as it occurs with product labels or covers), the plastic cup was covered by the very same material of the cup in our experiment. One might then suggest that the more or less explicit perception that the container was manipulated (less relevant in the plastic covered cups), rather than the presence of the specific materials, resulted into a more negative evaluation of the content pleasantness. It would be important in the future to explore also the effect of textures on water perception using cups, which are specifically designed with specific surface properties (e.g., Schifferstein, 2009). Moreover, as already mentioned participants were not informed that they would always tasted the same two types of water. When informed during the debriefing, some of them reported that have guessed it, others reported they supposed have tasted different types of mineral water and somebody reported did not understand well how many types of water were tasting. Hence, the a priori knowledge of the experimental aim should not have interfered with people's evaluations. However, this cannot completely exclude that someone has tried to please the experimenter during the evaluations, if her/he sensed the aim of the experiment. It might also be pointed out, at a methodological level that the number of the experimental stimuli is too small (only two) and there is a lack of a neutral ones. Since, as observed by Woods et al. (2011), an experiment that includes liked, neutral and disliked stimuli prevent the possibility of some hidden effects. Nevertheless, the experimental project, which the present experiment, is part, investigated crossmodal interaction specifically of tasteless and odourless stimuli (for naïve people), and only water possesses these characteristics. In particular, the general aim of the experimental project is to exclude the so called basic tastes (sweet, sour, bitter, salt) and odours perceived both retronasally than orthonasally from participant's taste experience. Relevant issue, taking into account how proposed according to Auvray and Spence (2007) regarding flavour, in which basic tastes, smells, trigeminal, and tactile sensations would be inextricably unit to form a unitary percept. It is also true that it could be added also slightly carbonated mineral water to the experimental stimuli. However, the problem would remain unchanged, since, this last is rated as the most unpleasant and ambiguous stimulus. Essentially, there is no mineral water considered neutral in terms of pleasantness. Probably, these conditions could prevent the possibility to extend these results to a more wide range of stimuli. Nevertheless, Italy is the country with the highest number of mineral water spring and is the first exporter in the world. Circumstances that perhaps, could compensate for the possibility of the scarce generalization of the observed effects.

In conclusion, the results of the present study show that the perception of mineral water can be modulated by the textures of the materials used to cover the cups in which the liquid is served. Further investigations should be directed to assess how different types of liquids interact with the same characteristics of the textures used to cover the containers. For example, one might study the effect of sandpaper coated cups on the taste perception of grainy beverages (i.e., pear juice) to see whether it could lead to different results with respect to mineral water.

The results of the present study might provide important insights to the study of crossmodal correspondences between haptic/tactile and gustative aspects of the stimuli. Moreover, they are also of importance for the development and marketing of water packaging able to enhance the positive characteristics of a beverage or to modulate its consumption (see Gallace, 2015). As well as, to improve the distinctive characteristics of certain beverages by means of the multisensory stimulations elicited also by the container (Gallace, 2015; Spence & Gallace, 2011). Interestingly, these findings, together with those of other recent studies (Maggioni et al., 2015; Risso et al., 2015), shed light on how the extrinsic qualities of the packaging affect the perception and the evaluation of the products contained in it (Gallace, 2012; Gallace & Spence, 2011b). In particular, the results of the present study might be also useful for the development of more appropriate and effective products labels or covers (see Spence and Piqueras-Fiszman, 2012, for the observation that a vodka producer has recently advertised its product by means of a label printed on sandpaper).

CHAPTER V
THE EFFECTS OF A SMALL SIZE OLFACTORY DEVICE ON PEOPLE'S TASTE OF FOOD

1. Introduction

In Human Computer Interaction (HCI), olfaction is very seldom included as interaction modality. This is because knowledge of olfactory perception is less developed as compared to other sensory modality. As consequence, it is hard to use smell effectively, especially under conditions of multisensory stimulus presentation. Moreover, devices to display odours are in their infancy and cannot be practically usable under ecologically valid conditions of stimulus presentation (see Barfield & Danas, 1995; Nakamoto, 2013; Sanders & McCormick, 1993). That is, the majority of current olfactory devices are cumbersome and definitely not wearable. Here we tested a new conception small size olfactory display in order to determine if the sensory experience generated by the device can be successfully used to modulate people's evaluation of a number of food characteristics.

In the last decades, psychological and neuroscientific research has shown that the different features of a product, such as its color, shape, odor, taste, tactile feel, sound and so on, are rarely processed in isolation by our neural system. A number of interactions occurs among them, and our final perception is much more than a mere sum of these characteristics (see Spence, 2011a). This consideration also applies to food evaluation, where it has even been suggested that the perception of taste should be considered more of a multisensory than unisensory experience (e.g., Spence, Hobkinson, Gallace, & Piqueras-Fiszman, 2013). In fact psychological and neuroscientific research has shown that visual, auditory, olfactory and tactile aspects of food (see Spence & Piqueras-Fiszman, 2014, for a recent review) can all modulate our gustatory perception. For example, Michel, Velasco, Gatti, and Spence (2014) recently reported that the participants provided higher tastiness ratings when asked to taste a salad dish visually arranged in an artistic way (similar to a Kandinsky's paint), than when the same dish was presented without any artistic arrangement. As far as beverages are concerned, Zampini and Spence (2005) reported that participants' perception of carbonation intensity of sparkling mineral water is affected by an alteration of the frequency of the auditory feedback emitted by the liquid just before consumption. In particular, amplification of the higher frequencies emitted by the beverage when served results into the participants reporting a higher intensity of carbonation while tasting the water.

Interestingly, a number of studies has also demonstrated that food perception is not only affected by the sensory qualities of food, but also by those of the context where food is presented. For example, the color of a container can affect the taste of food and beverage presented in it (e.g., Biggs et al., 2016; Krishna & Morrin, 2008; Maggioni et al., 2015; Spence & Wan, 2015d; Piqueras-Fiszman & Spence, 2012c; Piqueras-Fiszman et al., 2012; Risso et al., 2015; Zampini, & Spence, 2005). In particular, Risso, Maggioni, Olivero, and Gallace, (2015) recently reported that people perceive mineral water as more carbonated when contained in a red or blue plastic cup, than when contained in a white cup. Similarly, Stewart and Goss (2013) showed that different combinations of colours and shapes in a plate can significantly modify the sweetness, flavour intensity, quality, and enjoyment perception of the dessert served in them (see also Bruno, Martani, Corsini, Oleari, 2013). Even the weight of the container would seem to affect the perception of the beverage tasted in it, where heavier cups make the participant perceive the mineral water less pleasant than when served in lighter cups (Maggioni, Risso, Olivero, and Gallace, 2015). Olfaction is certainly one of the most important stimuli used by humans to evaluate gustatory stimuli. In fact, it has been shown that our taste perception decreases when olfaction is not available (e.g., Murphy & Cain, 1980). Following on from these observations, if one's aim is to improve people's experience of food under ecologically valid conditions, such as in restaurants or in realistic virtual reality simulations, olfactory stimuli need to be presented effectively and in a highly controlled way. In particular, wearable olfactory interfaces would allow us to present in a timely precise context specific odors, which might modulate people's food experiences and choices. Here we tested the effectiveness of a new olfactory device in modulating people perception of four different qualities of food (Experiment 1; pleasantness, sweetness, saltiness and bitterness) and of beverages (Experiment 2; pleasantness, sweetness, saltiness, bitterness and carbonation intensity).

2. The olfactory display

We developed a novel Multi-Fragrance Olfactory Display (MFOD), which is very light and small, and is able to release multiple fragrances. The MFOD consists of a multi-fragrance dispenser of compact powders of fragrances contained into small cases, which allows releasing up to eight fragrances in a manner that is precisely controlled.

The MFOD is based on a novel principle for the generation and release of fragrances, which is the SFR - Solid Fragrance Release method that delivers scents through the modulation of an airflow striking a tablet of solid fragrance. This method differs from those using liquid or vaporous fragrances (8), which are more “invasive” and permeate the environment. In addition, the use of solid particles delivered through airflow allows us to more precisely control the flow.

The same principle can be used for the implementation of a wearable configuration and of a desktop configuration (Covarrubias, Bordegoni, Caruso & Cugini, 2016). In this specific research, a desktop version of the MFOD has been used (see Fig. 25). It consists of an actuated dispenser allowing us to store eight fragrances and to control the timing, intensity and duration of the fragrance release. The MFOD includes a centrifugal fan (see Fig. 25 (1)), which provides and controls the airflow, a servo-assisted cylindrical repository (3), and eight small tubes including compact powder fragrances (4). The servo-assisted cylindrical repository is controlled through an Arduino board (arduino.cc), which is connected to the E-Prime tool (www.pstnet.com/eprime.cfm). E-Prime is an environment for computerized experiment design, data collection, and analysis, which has been here used for the selection and delivery of the fragrances. Finally, a pipe (see Fig. 25 (5)) releases the selected odour to the user’s nose.

The MFOD performs three main functions:

1. Airflow Generation – A Direct Current (DC) powered fan generates and airflow that is directed towards the fragrance repository.

2. Odour Selection – Small PVC tubes contain the fragrance compact powders. Each tube contains a specific fragrance, except one that is left empty and is used as cleaning function. The tubes are fixed to a rotating cylinder, similar to a revolver gun. A servo motor is used to rotate the cylinder to the desired position and select the specific smell to deliver.

3. Odour Delivery – The airflow generated by the fan passes through the selected tube in the fragrance repository, and the odorous airflow, generated by an erosion process, goes through the flexible plastic pipe and is delivered close to the user’s nose.

The fragrance intensity can be adjusted by modifying the airflow generated by the centrifugal fan. The latency from generation to perception of a selected odour is less than 0.5 sec., with a length of the delivery pipe of 600 mm. This configuration has been tested and judged as sufficiently fast to allow users to feel a new selected fragrance synchronous with the user's interaction.

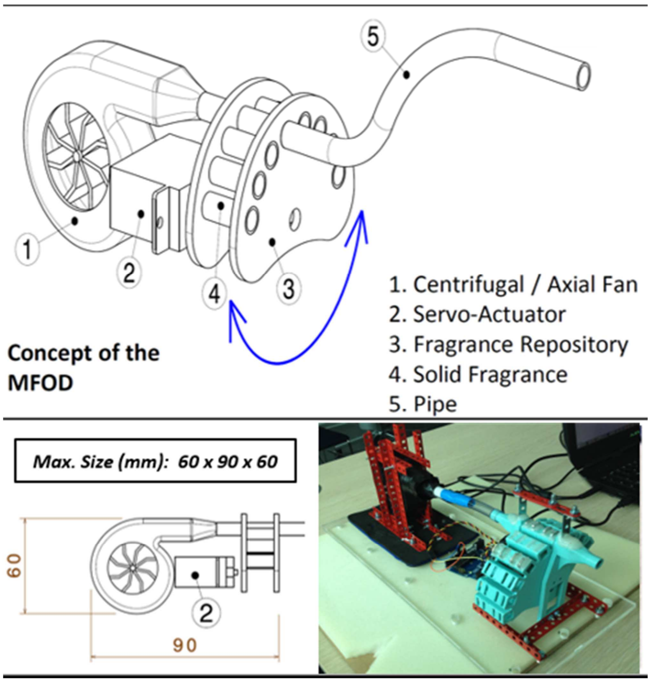


Figure 25 - The Multi-Fragrance Olfactory Display

3. Experiment 1

3.1 Participants

Eight participants with a mean age of 29 years (SD = 9.83, 6 female), took part in Experiment. All the participants gave written consent prior to their participation. The Experiment described here were all performed in accordance with the ethical standards laid down in the 2008 Declaration of Helsinki and approved from the local ethical committee. The Experiment lasted for approximately 20–30 min. People who claimed to be affected by any permanent or temporary olfactory or taste dysfunction, were excluded from taking part in the Experiment.

3.2 Stimuli

Two different types of food were used: salty cracker (Carrefour) and lemon sugar candies (Perugina). Common white plastic dishes (produced by Bibo Italy S.p.A. for Carrefour) were used to serve the food. The two odors administered were chocolate and a mixture of citrus fruit (Oikos Fragrances).

3.3 Procedure

The study was conducted in an experimental booth. The participants sat comfortably on a chair in front of a desk. The participants were instructed to grasp and eat the food presented on the desk at a signal of the experimenter, while at the same time they smelled an odor or clear air administered to both nostrils for about 15s. They were also informed that after tasting the food they had to rate it along four dimensions (pleasant, sweet, salty, and bitter) by means of a 150 mm long visual analogue scale (VAS), anchored with the terms 'not at all' and 'very much'. The VAS was presented at the center of a 17'' PC screen. The participants used the mouse to select the point on the scale that best represented their evaluation. Each food was presented 3 times for each olfactory condition, for a total of 18 (2 foods x 3 odors x 3 repetitions) samples of food to be evaluated by each participant. The presentation of the food and the odors was completely randomized.

3.4 Results

The mean participants' judgments along the VASs were submitted to a repeated measures ANOVA with the within subjects factors of Odor (chocolate vs. citrus), Food (sugar candy vs. cracker), and Scale (pleasantness, sweetness, saltiness, and bitterness). The results of this analysis revealed a significant interaction between all the three factors [$F(6,42)=2.48$; $p=.003$]. Consequently, we decided to perform one ANOVA for each of the four scales adopted, with the factors of Odor and Food.

The ANOVA on the scale of Pleasantness showed a significant main effect of the factor Odor [$F(2,14)=5.09$; $p=.02$] and of the interaction between Odor and Food [$F(2,14)=4,32$; $p=.03$]. A Newman-Keuls post hoc on the factor of Odor showed that participants evaluated the taste of both food as more pleasant when presented with the odour of chocolate (p=.01) or citrus (P=.03) than when no odour was presented (see Fig. 26). A Newman-Keuls post hoc test on the interaction showed that the participants evaluated the taste of candies as more pleasant when presented together with the odour of citrus (p<.001) or with the odour of chocolate (p=.002) as compared to when it was presented without any odour.

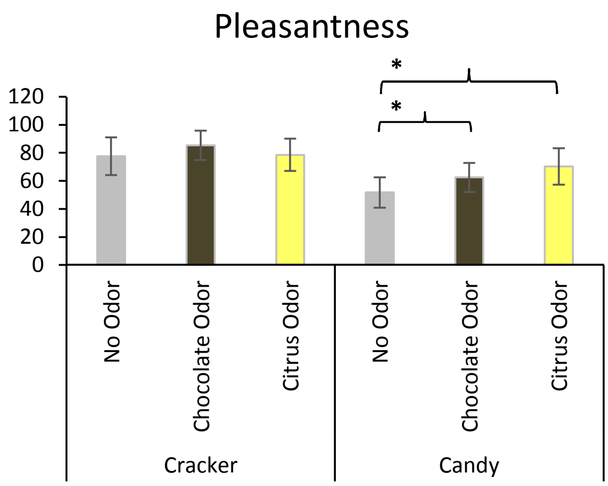


Figure 26 - The participants' mean judgments of pleasantness in mm (0=not at all; 150=very much) for the two foods tasted, as a function of the different odour conditions. Error bars represent the standard errors of the means

The ANOVA on the scale of sweetness resulted in a significant main effect of the factor of Odor [F(2,14)=4.4; p=.03] and of Food [F(1,7)=85.47; p <.0001]. As expected, participants found the candy sweeter than the cracker. A Newman-Keuls post hoc on the factor of Odor showed that participants found the taste of both food as sweeter when presented with the odor of chocolate than when the odor of citrus (p=.03) was presented ; see Fig. 27). The interactions between the two factors did not result to be significant [F(2,14)=2.27; n.s.].

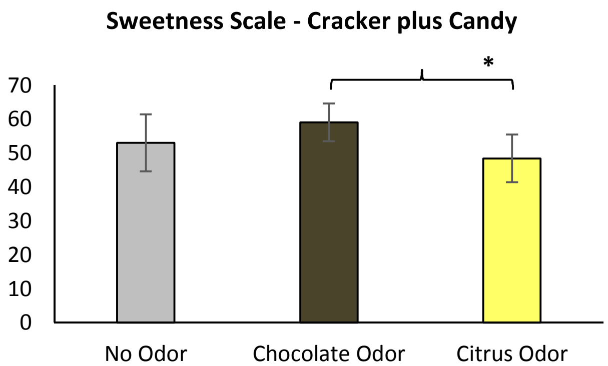


Figure 27 - The participants' mean judgments of sweetness in mm (0=not at all; 150=very much) for the foods tasted, as a function of the different odour conditions. Error bars represent the standard errors of the means

The ANOVA on the scale of saltiness resulted in a significant main effect of the factor of Food [$F(1,7)=94.60$; $p<.0001$]. As expected, the participants found the crackers as saltier than the candies. No significant effects were found for the factor of Odor [$F(2,14)=1,7$; n.s.], nor for the interaction between Odor and Food [$F(2,14)=2,39$; n.s.].

The ANOVA on the scale of bitterness resulted in no significant effects of the main factors and of their interaction (all p.s n.s.). However, a trend towards significance was found for the factor of Food [$F(1,7)=5.07$; $p=.059$].

4. Experiment 2

4.1 Participants

Sixteen participants with a mean age of 24.69 years (SD = 3.89, 10 female), took part in Experiment. All the participants gave written consent prior to their participation. The Experiment described here were all performed in accordance with the ethical standards laid down in the 2008 Declaration of Helsinki and approved from the local ethical committee. The Experiment lasted for approximately 20–30 min. People who claimed to be affected by any permanent or temporary olfactory or taste dysfunction were excluded from taking part in the Experiment.

4.2 Stimuli

Three different types of beverages were used: sparkling mineral water (S. Benedetto®) 0.5 l bottle), tonic water (Schweppes® 0.25 l bottle) and Sprite® (Coca-Cola Company 0.5 l bottle). Common transparent plastic cups (DOpla® S.p.A) were used to serve liquids. The two odors administered were chocolate and a mixture of citrus fruit (Oikos Fragrances).

4.3 Procedure

The study was conducted in an experimental booth. The participants sat comfortably on a chair in front of a desk. The participants were instructed to grasp the plastic cup and taste the beverage served in it at a signal of the experimenter, while at the same time they smelled an odor or clear air administered to both nostrils for about 6s. They were also informed that after tasting the liquid they had to rate it along five dimensions (pleasant, sweet, salty, bitter and carbonation intensity) by means of a 150 mm long visual analogue scale (VAS), anchored with the terms ‘not at all’ and ‘very much’. The VAS was presented at the center of a 17’’ PC screen. The participants used the mouse to select the point on the scale that best represented their evaluation. Each liquid was presented 3 times for each olfactory condition, for a total of 27 (3 beverages x 3 odors x 3 repetitions) samples of liquid to be evaluated by each participant. The presentation of the beverages and the odors was completely randomized.

4.4 Results

The mean participants’ judgments along the VASs were submitted to a repeated measures ANOVA with the within subjects factors of Scale (pleasantness, sweetness, saltiness, bitterness, carbonation intensity, Odor (chocolate vs. citrus) and Beverage (Sparkling Water, Tonica, Sprite). The results of this analysis revealed a significant effect of scale [$F(4,60) = 20.76$, $p < 0.0001$], beverage [$F(2,30) = 22.88$, $p < 0.0001$] and a significant interaction between scale and beverage [$F(8,120) = 15.19$, $p < 0.0001$]. The main effect of odor [$F(2,30) = 0.15$, $p = 0.86$], the interaction between odor and beverage [$F(4,60) = 1.80$, $p = 0.14$] and the interaction between scale, odor and beverage [$F(16,240) = 1.11$, $p = 0.35$] did not result to be significant. That is, the odors presented did not modulate the participants’ perception of the beverages presented in any of the scale analysed.

A Newman–Keuls corrected post hoc test on the main effect of scale revealed that participants on average provided quantitatively lower evaluations (i.e., evaluations closer to the ‘not at all’ endpoint of the scale) for saltiness, as compared to pleasantness ($p = 0.001$), sweetness ($p = 0.001$), bitterness ($p = 0.001$) and carbonation intensity ($p = 0.001$). Moreover, on the significant main effect of scale participants on average provided quantitatively higher evaluations (i.e., evaluations closer to the ‘very much’ endpoint of the scale) for carbonation intensity, as compared to pleasantness ($p = 0.001$), sweetness ($p = 0.001$) and bitterness ($p = 0.001$). A Newman–Keuls post hoc test on the significant main effect of beverage showed that participants on average provided quantitatively lower evaluations (i.e., evaluations closer to the ‘not at all’ endpoint of the scale) for sparkling mineral water than tonic water ($p = 0.001$) and Sprite® ($p = 0.001$). A

Newman–Keuls post hoc test on the interaction between the factors of scale and beverage revealed that participants perceived Sprite® as more pleasant than tonic water (p = 0.001) and sparkling mineral water (p = 0.02), Sprite® as more sweet than tonic water (p = 0.001) and sparkling mineral water (p = 0.001). Tonic water resulted to be perceived as more bitter than sparkling mineral water (p = 0.001) and Sprite® (p = 0.001).

5. General discussion and conclusion

The results of the present study clearly suggest that our olfactory device can be successfully used to alter people's experience of food. In particular, we showed that participants perceived candies as more pleasant when presented together with the odor of citrus or chocolate than when presented with no odor. Moreover, we found that the participants' perception of sweetness of both foods (candy and crackers) increased when the odor of chocolate, as compared to the odor of citrus, was presented. That is, the olfactory stimuli delivered by means of the new olfactory display showed to be effective in modulating people's evaluation of food.

Interestingly, no modulatory effects of the olfactory stimuli were found when beverages where presented. The lack of effect in this case might be related to the perceived congruence between the odors and the presented beverages. That is, chocolate and the citrus fruit might not be the more appropriate odors to be used in order to enhance the quality of the drinks tasted in the present experiment. As a consequence, the more or less explicit perception by the participants that the context of stimulus presentation was artificially manipulated (e.g., that the odour did not arise from the beverage itself) could have made more difficult the integration between the olfactory and gustative qualities of the drinks (cf. Dietrich, 2006). However, it should also be considered the possibility that due to the high variance of the participants' perceptual judgments our study was underpowered to identify significant effects.

The results reported here are in line with previous scientific evidence showing that people's perception of food can be altered by the multisensory context where the stimuli are presented (Maggioni et al., 2015, Piqueras-Fiszman & Spence, 2012c; Piqueras-Fiszman, et al., 2012; Zampini, & Spence, 2005). In fact, despite of the fact that the participants knew that the odor did not originate from the food itself, their evaluation was still significantly affected by it. As far as this point is concerned, our results are the first to show an interaction between taste and odor in people's evaluation of food pleasantness and sweetness by using a small size olfactory interface. Further studies should be addressed at investigating the effects of delivering olfactory stimuli by means of such devices on the perception of different food and beverages, also under ecologically valid condition of stimulus presentation (e.g., in restaurants or within virtual reality simulations).

CHAPTER VI
THE EFFECTS OF DIFFERENT EXPERIMENTAL PARADIGMS ON OLFACTORY MEMORY FOR BRIEF AND LONG TIME PERIODS

1. Introduction

Until a few decades ago, researchers considered the olfactory system a less attractive sensorial domain to be investigated, perhaps also due to the difficulty of handling odours in the experimental setting. Hence, less data on olfaction in general, and on olfactory short-term memory in particular, have been collected so far (as compared to the amount of data regarding visual and auditory processing and memory). To date, one of the more debated issues in the study of the olfactory system is whether olfactory short term memory (OSTM) is structurally and functionally similar to STM in other sensory modalities. In particular, there is no agreement on the conceptualization of long and short-term olfactory memory as two separate systems, as well as, on the verbal coding of the odours (Andrade & Donaldson, 2007; Gabassi & Zanutini, 1983; Herz & Engen, 1996; Engen & Ross, 1973; Zelano, Montag, Khan, & Sobel, 2009; White, 1998; White, 2009; Wilson & Stevenson, 2006; Yeshurun, Dudai, Sobel, 2008; see also Chapter 1 for a discussion on this point).

In order to assess the existence of two separate memory systems for odours, research has investigated the presence of double dissociations in neuropsychological patients who show memory impairments (White, 1998). Moreover, for the very same reason, it was investigated whether memory for odours is sensible to the serial position effects of the stimuli (indicating the presence of two separate memory system: one related to the recency affect and the other to the primacy effect). A wide range of tasks were used in order to evaluate these aspects. A few studies have investigated the presence of differences in storage capacity between short and long term memory in olfaction. Within this domain, it was demonstrated that the immediate recognition of an odour is better when a one to one, rather than a one to three, or one to five comparisons between target odours needs to be performed (Jones, Roberts, Holman, 1978). That is, the more odour are presented the worst is the participants' performance. By contrast, in olfactory long-term memory, participants were shown to be able to recognize accurately the 70% of a large amount of odours (48) up to 30 days after their presentation (Engen & Ross 1973). Importantly, Lawless and Cain (1975) showed that the set size stimuli did not affect long term recognition (while it affects short term recognition). In fact, participants recognized 22 odours with a mean of the 75% of correct responses after 28 days between the presentation and the matching task. Similarly, Lawless (1978) showed that 24 odours were recognized by participants after 4 months from their presentation with an average of 75% of correct responses.

The difference between short and long-term memory in odour coding has been investigated by means of the same procedures used to assess different memory components within the theoretical multi-component model of STM proposed by Baddeley and Hitch (1974). In particular, within this framework, differences between the presence of a perceptual (Conrad & Hull, 1964), rather than a semantic coding (Baddeley, 1966) are considered related to STM and LTM respectively. According to different authors, the similarity between odours within an experimental set should impair participant's performance in an OSTM task (Jehl, Royet, & Holley, 1994; White et al., 1998). According to this claim, Jehl et al., (1994) showed that the similarity of the odour probe with a previously presented target odour in a list of olfactory stimuli diminished its immediate recognition. By contrast, some authors showed that verbal associations with odours did not improve memory for odours (Engen & Ross, 1973; Lawless & Cain, 1975; Herz, 2000). Actually, Lorig (1999) argued that a mutual interference between odour and language based tasks exists.

With respect to LTM for odours, it was demonstrated that not only semantic, but also perceptual characteristics of olfactory stimuli (e.g. familiarity), although to a lesser extent, can modulate people's performance during the memory task (Jehl, Royet, & Holley, 1997; Rabin and Cain, 1984; Schab, DeWijk,. & Cain, 1991). In particular, Schab et al, (1991) showed that within a list of familiar and unfamiliar to be remembered odours with retention intervals of 2, 20, 40 and 100 s., familiar odours were remembered better than unfamiliar odours in all conditions of temporal delay.

As far as the studies on neurological patients are concerned, evidences of patients with a double dissociation between short and long term olfactory memory have been reported (although defined as not particularly robust). For example, patient H.M, affected by an impairment in LTM consolidation in presence of a preserved ability to perform STM tasks (Milner, Corkin, & Teuber, 1968) was also tested in olfactory memory tasks. Eskenazi, Cain, Novelly, and Friend, (1983) showed that H.M. performed correctly in detection and intensity discrimination of odours, while he was not able to discriminate the odour quality.

A number of studies have also investigated odour memory in Korsakoff patients (Mair, Capra, McEntee, & Engen, 1980; Rupp, Fleischhacker, Drexler, Hausmann, Hinterhuber, & Kurz, 2006). In particular, it has been reported that both Korsakoff's patients and neurologically normal control participants performed better in discriminating similar odours than dissimilar odour, a behaviour, suggesting and impairment of OLTM. By contrast, patient K.F. showed an impaired ability in OSTM and a moderately preserved OLTM (Shallice, & Warrington, 1970).

Deficits in OSTM were also observed in patients affected by epilepsy. Hudry, Perrin, Ryvlin, Mauguière and Royet (2003) demonstrated that patients with temporal lobe epilepsy were impaired in odour recognition memory for short temporal dealy. Carroll, Richardson, and Thompson, (1993) also showed that patients with right temporal lobe epilepsy have difficult in the instantaneous recognition of nameable odours.

One important aspects to be considered here is that it remains still unclear whether olfactory and visual or verbal memory share, at least up to a certain extent, the same neural architecture and have similar characteristics. Answering to this question is very relevant from both a theoretical and applied point of view. As far as the latter is concerned, one might hypothesise that if olfactory memory is less compromised than visual or verbal memory in brain damaged patients, olfactory cues might be used as aids to remember relevant information or to perform important actions.

Here in Study 1 we compared olfactory and visual memory for brief time periods using a single probe serial recognition recall task. In Study 2, instead we compared the performances in memory recognition of nameable and hard to name odours for brief and long time periods by means a recognition task. Importantly, in all studies was used the same set of olfactory stimuli previously tested regarding their degree of nameability and familiarity.

2. Study 1

2.1 Experiment 1

2.1.1 Participants

Seventeen participants, with a mean age of 20.53 years (SD = 2.03, 14 female), took part in Experiment 1; they were graduate and undergraduate students and received course credits for their participation in the study. All the participants gave written consent prior to their participation. The Experiment described here were performed in accordance with the ethical standards laid down in the 2008 Declaration of Helsinki and approved from the local ethical committee. People who claimed to be affected by any olfactory or taste dysfunction, as well as people suffering from cold or flu were excluded from taking part in the experiment.

2.1.2 Stimuli

54 olfactory stimuli were used. The stimuli were taken from Le Nez du Vin® wine taster kit (i.e., Jean Lenoir Éditions, Carnoux-en-Provence, FR) and divided into five categories: fruit, floral, vegetal, animal and smoked aromas (see Fig. 32). The odours were rated with respect to their level of familiarity and on how easily they could be named by people in a previous pre test experiment. The nameable odours used in this Experiment 1were: lemon, cinnamon, coffee, licorice, strawberry, vanilla, pear, mushroom, clove, raspberry, pine, peach, leather, caramel, quince, banana, hay. Six stimuli were selected as namable distractors odours: orange, chocolate, saffron, honey, pepper, smoked. The first 18 olfactory stimuli were selected in order to be as much nameable as possible and to ensure that in all the three series of the six odours used in the Experiment all the categories of the kit were represented at least once.. The nine distractors odours were selected to belong to the same category of every odour probe within the three lists of olfactory stimuli presented to participants during the encoding phase of the experiment and also on the basis of their degree of nameability. Every odor was contained in a small glass bottle.

2.1.3 Procedure

The procedure consisted in a single probe serial recognition task. The study was conducted in an experimental booth fitted with a laptop (screen resolution: 1024x768 pixels, refresh rate: 60 Hz) positioned on a desk directly in front of the participants. The participants were blindfolded and sat comfortably on a chair, approximately 60 cm away from the laptop screen. The experimenter sat in front of the participants with the odours bottle hidden from their view. During the test, a sequence of six bottles containing the olfactory stimuli were sequentially placed at about 3 cm under the nostrils of the participant by the experimenter and kept on that position for about 5 seconds with a 5-second interval from each other. At the end of the presentation of the six olfactory stimuli the participants were informed that the next item presented was the odour probe. Participants, after smelling the last odour were allowed to remove the blindfold from their eyes and to assess if that stimulus was previously presented within the lists of olfactory stimuli or not.

They were required only to respond ‘yes’ (stimulus previously presented), or ‘not’ (stimulus not presented before) by pressing a key on a PC keyboard The probe was selected among the stimuli presented only in position 1, 3 or 6 of the odour sequence. The sequence presented in the encoding phase of the experiment were three and were formed by using 18 different nameable odours. The distractor odours were in total 6. Each trial was separated from the next by a rest interval of two minutes. Each target and distractor odour were presented 3 times for each position of the three lists for a total of 18 (2 odours x 3 repetitions x 3 odours lists) olfactory stimuli to be compared. The odours within the three series were partially randomized, such as that items in position 1, 3 and 6 of the three lists were always presented in the same position, while, the corresponding distractors were randomized according to their respective target odour across the three lists. The use of this procedure was forced by the fact that only a relatively small number of nameable odours were available for the experiment. For every participants, the presentation order of the 3 different olfactory lists was counterbalanced according to the 18 presentations. Moreover, the order of presentation of the entire experiment was completely counterbalanced across participants. Experiment 1 lasted for approximately 50–60 min. This duration comprises an initial overview of the experimental setup, the explanation of the instructions, the explanation and signature of the ethical forms and a final 10–15 min of debriefing regarding the main aims of the experiment. The experimental procedure was carry out by means the scientific software E-Prime 2.0.

2.1.4 Results

The mean of participant’s correct responses to the olfactory target in the three different positions of the item lists, were submitted to a univariate ANOVA, with ‘odour position’ in the lists as independent variable. The results of the analysis revealed a significant main effect of the target odour position in the lists [$F(2,99) = 3.84$, $p = 0.03$]. A Newman-Keuls post-hoc test revealed that participants performed better for stimuli presented in position 3, as compared to position 1 ($p = 0.04$) and position 6 ($p = 0.023$) (see Fig. 28).

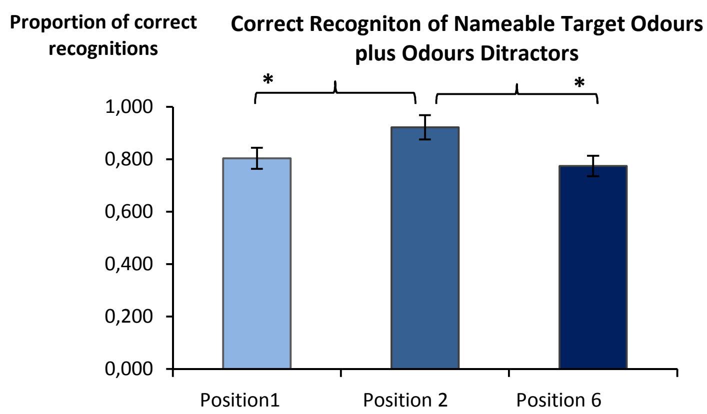


Figure 28 – Participants' means of the correct recognition of nameable target odours plus distractor odours. Asterisks represent Newman-Keuls significant differences at $p < .05$

2.2 Experiment 2

2.2.1 Participants

Seventeen participants, with a mean age of 21 years (*SD* = 2.52) all female, took part in Experiment 1; they were graduate and undergraduate students and received course credits for their participation in the study. All the participants gave written consent prior to their participation. The Experiment described here were performed in accordance with the ethical standards laid down in the 2008 Declaration of Helsinki and approved from the local ethical committee. People who claimed to be affected by any olfactory or taste dysfunctions, as well as, people suffering from cold or flu were excluded from taking part in the experiment.

2.2.2 Stimuli

Eighteen 'hard to name' olfactory targets and nine distractor stimuli were selected from to Le Nez du Vin® wine taster kit (i.e., Jean Lenoir Éditions, Carnoux-en-Provence, FR). Just as in experiment 1, the odours were rated with respect to their level of familiarity and on how hardly they could be named by people in a previous pre-test. The hard to name odours were: cherry, green pepper, blackcurrant bud, linden, thyme, grapefruit, Muscat, walnut, cedar, apricot, acacia, blackcurrant, blueberry, violet, truffle, hawthorn, dry prune. The six hard to name distractors odours were: blackberry, dregs, lychee, butter, toasted almond, musk.

The first 18 olfactory stimuli were selected to be 'as difficult as possible' to be named and to ensure that in all the three series of the six odours used in Experiment 2 all the categories of the kit were presented at least once. The six hard to name distractors odours were selected to belong to the same category of each odour probe within the three lists of olfactory stimuli presented to participants during the encoding phase of the experiment and on the basis of their degree of unameability. Each odor was contained in a small glass bottle just as in Experiment 1.

2.2.3 Procedure

Exactly the same procedures as those used in Experiment 1 were adopted with the only exception that the stimuli used were hard to name odours.

2.2.4 Results

The participant's means of correct responses to the target stimulus (correct recognition of target and rejection of distractor) were submitted to a univariate ANOVA with odours position in the lists as independent variable. The results of the analysis revealed a significant main effect of the odour position in the list [$F(2,99) = 5.67$, $p = 0.005$]. A Newman-Keuls post-hoc test revealed that the participants performed worse in the recognition of odours in position 1, as compared to the odours in position 3 ($p = 0.01$) or in position 6 ($p = 0.01$) (see Fig. 29).

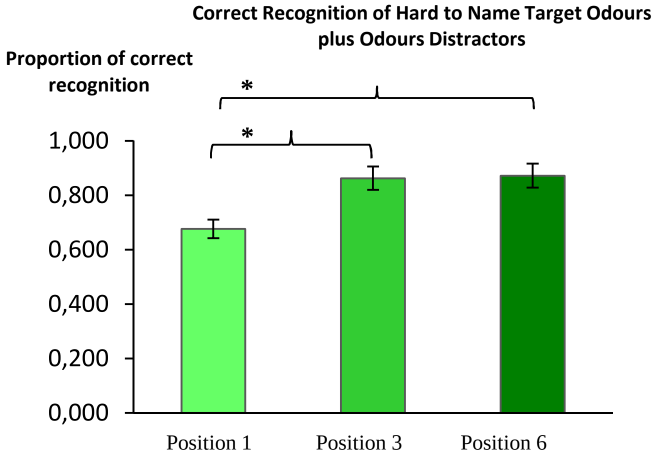


Figure 29 – Participants' means of the correct recognition of hard to name target odours plus distractor odours. Asterisks represent Newman-Keuls significant differences at $p < .05$

The participant's means of the performance in the serial recognition of the odours in Experiment 1 and 2 were compared by means of mixed repeated measures ANOVA with Odour Group and odour Position as factors. The results of the analysis revealed a significant main effect of Odour Position [$F(2,66) = 5.58$, $p = 0.01$] and a significant interaction between Odour Group and Odour Position [$F(2,66) = 4.66$, $p = 0.01$]. The main effect of Odour Group did not revealed any significant effect [$F(1,33) = 0.81$, $p = 0.37$]. A Newman–Keuls post hoc test on the interaction between Odour Group and Odour Position showed a better performance in the recognition of the nameable odours, as compared to the hard to name odours ($p = 0.05$) (see Fig. 30). A Newman–Keuls post hoc test on the effect of Odour Group revealed that, in general, nameable and hard to name odours in position 3 of the item lists are better recognised, as compared to nameable and hard to name odours in position 1 of the item lists ($p = 0.004$).

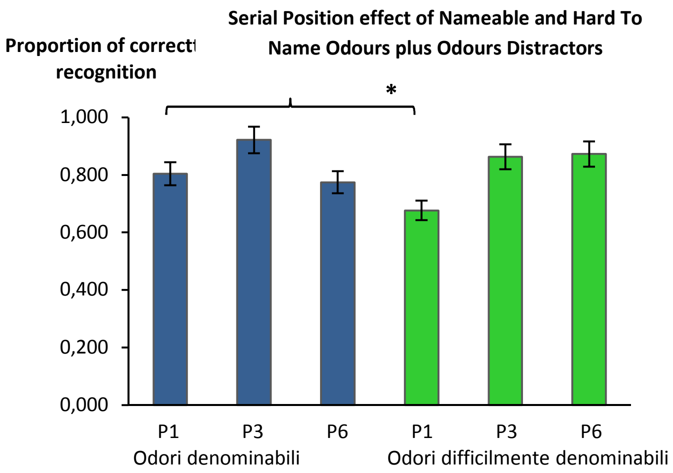


Figure 30 – Participants' means of the correct recognition of nameable and hard to name target odours plus distractor odours in postion 1, 3, 6. Asterisk represent $p < .05$

2.3 General discussion and conclusion

The results of Experiment 1 revealed that in the single probe serial recognition of nameable odours , the target items presented in the middle of the sequence (position 3) were remember better than those at the beginning (position 1) and at the end (position 6) of the list. To our knowledge, none of the previous similar experiment with odours, resulted in such a kind of performance. This is an intriguing result, since generally the literature of visual and verbal memory shows that the items in the middle of a series are those remembered worse. Reed (2000) in a series of five experiments investigate olfactory serial position effects by means of a two alternative forced choice (2AFC) task. The author used different retention intervals between the odours presentation and odours test. The results demonstrated in all experiments an enhanced recognition for the odours presented at the beginning and at the end of the list, as compared to the odours in the middle for the condition with 3s retention interval. Moreover, the presence of articulatory suppression, did not show any effect on serial position recognition. However, very few other studies were able to replicate both primacy and recency effects in olfactory serial position tasks. In fact, Lawless and Cain (1975) and Gabassi e Zanuttini (1983) did not found any serial position effect in their experiment. Nevertheless, it is worth noting that Gabassi e Zanuttini used long retention intervals between the presentation and recognition of the odours (10 min). More recently, Johnson and Miles (2009), by means an olfactory serial position recall task in which participants had to state verbally the position of the probe in the previously presented list of odours, did not observed any serial effect on participant's memory performance. Instead, Annette and Lorimer (1995) used two memory tasks (recall and recognition) with and without verbal elaboration. The authors demonstrated recency olfactory effects in all the experimental conditions and a primacy effect only when the task required a verbal processing of the stimuli. White and Treisman (1997), also found an effect of recency without primacy.

It is possible that the uncommon result obtained in the present experiment were due to the higher nameability of the olfactory stimuli used, or to the specific timing of stimulus presentation. In fact, the processing of nameable odours is in agreement with the use of both a verbal and a perceptual encoding, according to the dual coding theory of Paivio (1986). Alternatively, it is possible that the lack of a primacy effect was caused by the presence of 'bottleneck' that made more difficult the passage of the mnestic traces of the first stimuli presented from short to long term memory. Such hypothesis might be in agreement with the olfactory-centered unitary memory model by White and colleagues (White, 2009; Wilson & Stevenson, 2006) in which odours memory is conceptualized as a unique continuum (i.e., without a clear distinction between STM and LTM). In fact, the model predicts that an increasing number of odours to be remembered affects memory due to an increase in the probability that the essences presented share similar characteristics. This similarity makes more difficult the encoding stage of the stimuli for both short and long term memory tasks. By contrast, the recognition of the odour in position 6 may have been rendered more difficult by the high cognitive load involved in remembering three serial odours positions in a list of 6 stimuli.

The data analysis of Experiment 2 showed that hard to name odours recognition presented in position 1 was worse than for the recognition of odours presented in position 3 and 6. In such a condition a recency effect, just as in Annett and Lorimer (1995) and White and Treisman (1997) studies was found. Intriguingly, again the odours presented in position 3 gave rise to a higher performance, since were better recognised than odours in position 1. These results might be again the consequence of the specific timing used in the experiment, or, as already mentioned for nameable odours, might depend on the specific structure of olfactory memory. Instead, the recency effect found could be related to the fact that the processing of hard to name odours, did not involve the verbal encoding of the stimuli (the attempt to use a verbal strategy with namable odours could have impaired the sensory coding of the stimulus as compared to the condition where hard to name odours were presented).

The comparison between the results of Experiment 1 and Experiment 2 revealed that participants recognised better the nameable odours in position 1, as compared to hard to name odours in the same position. It is likely that these differences depends on the double encoding of nameable odours (verbal and perceptual; this result would seem to suggest that the participants adopted a verbal rather than perceptual coding strategy (see Paivio, 1986).

The study reported here and their comparison with the extant literature clearly demonstrate that olfactory serial recognition data are highly controversial. In particular, different results seem to be collected as a function of the kind of task used (2AFC, single probe serial recognition, delayed-match-to-sample, free recall), of the odours presentation time and of the retention interval timing (Annette and Lorimer, 1995; Johnson and Miles, 2009; Reed, 200; White and Treisman 1997). Another crucial issue in the extant literature concerns the nature of the odorants used, in fact in every experimental design different odours were used, making even more difficult a comparison of the results. Other studies will certainly need to address the most problematic aspects responsible for the contrasting results in olfactory memory studies.

3. Study 2

3.1 Participants

Eighteen in part undergraduate and graduate students of Bicocca University and in part volunteer recruited by means of leaflet and social networks in the city of Milano with a mean age of 31.39 years (*SD* = 14.24, 13 female), took part in the experiment. University students received course credits for their participation in the study. The experiments described here were performed in accordance with the ethical standards laid down in the 2008 Declaration of Helsinki and approved from the local ethical committee.

3.2 Stimuli

Ten target nameable odours and ten target hard to name odours, plus ten nameable and ten hard to name odours distractors belonging to *Le Nez du Vin*® wine taster kit (i.e., Jean Lenoir Éditions, Carnoux-en-Provence, FR) were selected on the basis of a pre-test and used in the experimental design. The ten nameable odours were: lemon, cinnamon, licorice, coffee, orange, banana, strawberry, almond, caramel ,mushroom; the ten nameable distractors were: pear, vanilla, clove, chocolate, peach, ananas, raspberry, quince, toasted hazelnut, pine. The ten hard to name odours were: blackcurrant bud, musk, violet, cherry, cedar, butter, hawthorn, muscat, dregs, blackcurrant; the ten hard to name distractors were: thyme, truffle, acacia, apricot, linden, green pepper, walnut, prune, blackberry, blueberry.

3.3 Procedure

The procedure followed a within-participant design. The experiment consisted in an olfactory recognition task of nameable and hard to name odours plus odours distractors. The participants were blindfolded and sat comfortably on a chair at a desk in front of the experimenter. The experimental paradigm was divided in two different sessions separated by an interval of seven days. In the first session the paradigm consisted of two experimental conditions in which two different kind of olfactory stimuli (nameable odours and hard to name odours parts) were administered. Every condition consisted of two parts: odours presentation/encoding of the ten target odours and odour recognition of the ten target odours plus the distractors. The experiment started in the encoding phase with the presentation of the ten target odours for about 3 sec under the participant's nostrils. After a retention interval of 1 min a random list of ten target odours plus ten distractors were represented to the participant nostrils. People task was establish for each odorants if it was presented among the ten target essences smelled before. The participant's responses consisted in verbally pronouncing the word yes or no. The response was collected by the experimenter then five minutes of rest were left to the participants. After this time of the remaining target odours were presented with the same procedure. The second session of the experiment took place seven days later with the same group of participants. In this part of the experiment participants were only presented with the olfactory target and distractors lists (the same targets presented in the encoding phase of the first session and new distractors). Immediately after the presentation of each target odours or distractors, people have to determine if the stimulus was presented or not in the encoding phase of the first session of the experiment seven days before. The procedure was similar to the recognition phase of the first session both for nameable than hard to name odours. The presentation order of the olfactory stimuli in the encoding and in the recognition phase was completely randomized among participants. The experiments lasted for approximately 30-40 min in the first session and about 20-25 min in the second session. The total duration of the experiment was approximately 55-60 min. People who claimed to be affected by any olfactory dysfunctions, as well as people suffering from cold or flu were excluded from taking part in the experiment.

3.4 Results

The mean participant's correct responses to the nameable and hard to name odours to the two different sessions (1 min after the presentation and after 7 days) (see Fig. 31) were submitted to a multivariate ANOVA with odours nameability (nameable, hard to name olfactory stimuli) and temporal delay (1 min, 7 days) as factors. The analysis revealed a significant main effect of temporal delay [$F(1,17) = 4.29$, $p = 0.05$]. The main effect of odours nameability [$F(1,17) = 2.30$, $p = 0.15$] and the interaction between odours nameability and temporal delay [$F(1,17) = 1.16$, $p = 0.30$] did not showed any significant effect.

A Newman–Keuls post hoc test on the significant main effect of temporal delay showed that, in general, all the odours were better recognised after 1 min of temporal delay, as compared to 7 days of temporal delay ($p = 0.05$) (see Fig. 32).

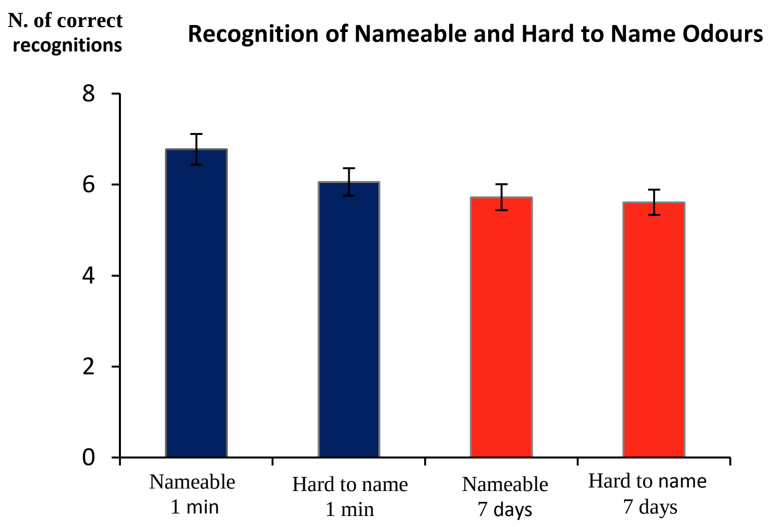


Figure 31 – On the left the averages of the correct target odours recognition in different temporal delay between presentation and recognition: nameable 1 min M = 6.78; hard to name 1 min M = 6.06; nameable 7 days M = 5.72; hard to name 7 days M = 5.61

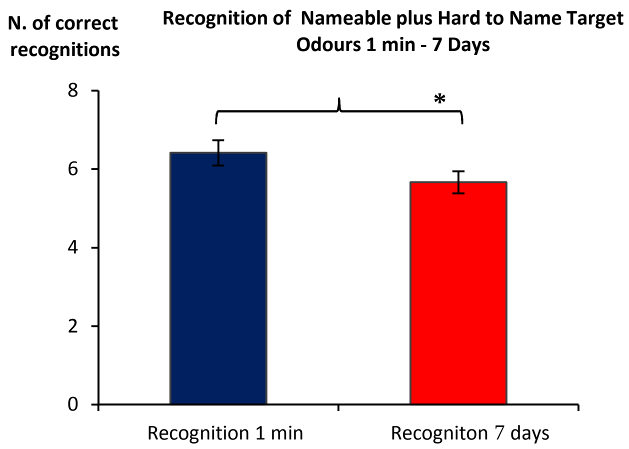


Figure 32 – The comparison of the averages of the target odours recognition of nameable plus hard to name odours with 1 min or 7 days of interval between presentation and recognition. Nameable odours M= 6.42; hard to name odours M= 5.67 Asterisks represent significant differences at $p < .05$

3.5 General discussion and conclusion

The results of the odour recognition task for short and long term time intervals showed that in general, participants performed better after 1 min, as compared to 7 days of delay between target stimuli encoding and the test phase. This result would seem to suggest that there is a decay of the memory trace of olfactory stimuli after 7 days from stimulus presentation, just as it occurs from other forms of memory.

Importantly, however we found a lack of differences between performances obtained with namable odours and with hard to name odours. That is, this result would seem to suggest that linguistic processing of the nameable olfactory stimuli does not contribute to improve their retention. Such a result is in agreement with previous works that demonstrated as the verbal encoding of olfactory stimuli do not improve memory for odours or odours processing (Engen & Ross, 1973; Lawless & Cain, 1975; Herz, 2000; Richardson & Zucco, 1989; Royet and Plailly, 2004; Wilson and Stevenson, 2003). However, others studies showed that the verbal encoding of the olfactory stimuli enhance their long term recognition (Jehl et al., 1997; Lyman & McDaniel, 1986). These incongruences in results are a typical feature of olfactory memory research for both short than long term time intervals and depend mainly by the degree of nameability of the odours used during the studies. Interestingly, the results of our previously described experiment on STM for olfactory stimuli using a serial position task showed that the presentation of nameable and hard to name odours lead to different performances, while those of our latter study showed the lack of such difference. This observation might be taken to suggest that the coding strategy of olfactory stimuli can vary as a function of the task to be performed.

Regarding the results of olfactory long term retention for both nameable and hard to name odours the performances resulted to be worse with respect to those reported in previous experiments. In particular, previous studies demonstrated that a wide numbers of odorants can be remembered for long periods of time. For example, Engen and Ross (1973) found that people (on average) recognise 70% of 48 odours after a time interval of 30 days, while the 75% of 24 odorants was recognised after 4 months (Lawless, 1978), as well as, the 75% of 22 odours was recognised after 28 days (Lawless and Cain, 1975). In the present experiment both nameable than hard to name odours were recognised with a 60% of accuracy by participants, even if the set used was significantly smaller with respect the olfactory stimuli of the above mentioned studies. One of the possible explanations for this finding, is that, differently from other studies in this field, the distractors odours of Experiment 3 (both for nameable than hard to name odours) were matched to the target olfactory stimuli according to their category (fruity, floral, smoked, etc.). Therefore, it is possible, as already shown by Engen and Ross (1973), that the use of similar odours as distractors, significantly impaired target odours recognition.

CHAPTER VII

THE DIFFERENCES IN OLFACTORY AND VISUO-VERBAL MEMORY IN PROBABLE ALZHEIMER'S DISEASE PATIENTS

1. Introduction

Alzheimer's disease (AD) symptoms are characterised by memory deficits, in particular regarding the encoding of new information. Impairments in these patients are caused by the atrophy of the medial temporal lobe structures, specifically the hippocampus (Pearson, Esiri, Hiorns, Wilcock & Powell, 1985; Schroeter, Stein, Maslowski, Neumann, 2009; Sperling, Dickerson, Pihlajamaki, Vannini, LaViolette, Vitolo, Hedden, Becker, Rentz, Selkoe, Johnson, 2010). As far as the visual and verbal modality are concerned, Kawas et al. (2003) investigated whether the long-term deficits found in these cognitive domains can predict the development of AD decades later. The study was conducted by means of the analysis of the Benton Visual Retention Test (BVRT) and the Wechsler Adult Intelligence Scale–vocabulary (WAIS-voc) scores, extracted from the Baltimore Longitudinal Study of Aging (BLSA). The authors demonstrated that a high number of errors in the BVRT (six or more errors) is associated with a doubled risk of AD up to 15 years later. While, WAIS-voc scores did not showed any significant association with AD risk.

Olfactory deficits are a relevant expression of Alzheimer’s disease (i.e., detection sensitivity, discrimination, identification, and memory) (Doty, 2003). Recently, it has been proposed that, similarly to Parkinson’s disease (Baba, Kikuchi, Hirayama, Nishio, Hosokai, Kanno et al., 2012) also AD olfactory symptoms could represent an early marker of the syndrome (Atanasova, Graux, El-Hage, Hommet, Camus, Belzung, 2008; Djordjevic, Jones-Gotman, De Sousa, Chertkow, 2008; Naudin, Mondon, El-Hage, Desmidt, Jaafari, Belzung, Gaillarda, Hommeta, Atanasova, 2014; Serby, Mohan, Aryan, Williams, Mohs, Davis, 1996; Zucco & Negrin, 1994).

A problem concerning the early olfactory impairments in AD is to identify its onset, and to establish if olfactory deficits were present before the beginning of the clinical symptoms. This question is complicated by the fact that the olfactory decline is a common ageing related event (Pinto, Wroblewski, Kern, Schumm, & McClintock, 2015). Djordjevic et al. (2008) investigated these issues by means several tasks (odour detection thresholds, quality discrimination, and identification) administered to three different groups: AD, mild cognitive impairment (MCI) and normal elderly control. The results showed that the olfactory deficits which would appear before the clinical symptoms in AD are: a higher detection threshold and an impaired identification of odours. Moreover, odours perception ability in AD patients continues to decline throughout the entire course of the disease.

It is important to highlight here as the research on early olfactory deficit in AD do not take into account the unresolved debate regarding odours memory architecture and functioning. Consequently, it is difficult to define which specific olfactory functions and structures are first damaged during the pre-symptomatic stage of AD. Furthermore, in the largest part of previous studies only odours identification and detection were considered the prodromal symptoms of the early olfactory decline in AD (Albers, Tabert, Devanand, 2006; Doty, 2008; see Mesholam, Moberg, Mahr, Doty, 1998 for a meta-analysis of 42 studies). However, odour identification is heavily based on the linguistic ability to associate a verbal label to the essence. In particular, Westervelt, Somerville, Ruffolo, and Tremont, (2005) found a stronger correlation between language and odour identification in older adults. Hence, by means the use of an odour identification test (where the odour needs to be named), it might be easier to get poor performances that are only related to the verbal abilities of the patients, rather than to an impairment of the olfactory system itself.

The first two experiments of the present study investigated olfactory and visual memory recognition for different brief period of time (1 min, 3 min, 1 min under articulatory suppression) in three different groups: probable Alzheimer disease patients, elderly neurologically unimpaired, graduate and undergraduate students. The last two experiments assessed the immediate identification of olfactory and visual stimuli. The aim of the first part of the experimental paradigm was to adopt a recognition task that, according to Engen (1987), does not require the verbal naming of the stimuli. A further objective of the first part of the study was to compare the results obtained by the three experimental groups, in order to assess the differences in the decline of both olfactory and visual recognition in AD patients, unpaired elderly and a normal control group. The general aim of the study was contribute to disentangle the question related to an early involvement of olfactory system deficits in AD patients.

2. Experiment 1

2.1. Participants

Sixty-six participants divided into three equal groups took part in Experiment 1; Group 1 was composed by graduate and undergraduate students recruited at the University of Milano Bicocca and young adults recruited through social networks (N= 22; mean age of 31.18 years *SD* = 11.41, 14 female). Graduate and undergraduate students received course credits for their participation in the study. Group 2 was composed by twenty-two elderly participants living in Milan and Bolzano city areas with a mean age of 69.73 years (*SD* = 5.40, 15 female), recruited by means of social networks. Group 3 was composed by twenty-two patients affected by Alzheimer's disease (AD) with a mean age of 85.77 (*SD* = 85.73, 17 female). The patients were recruited at the residence 'Agostoni' in Lissone, Italy, at the Memory Clinic of the Geriatric Ward of Bolzano Central Hospital and by means of social networks in Milan. The Experiment described here was performed in accordance with the ethical standards laid down in the 2008 Declaration of Helsinki and approved from the local ethical committee. The selection criteria for the inclusion of AD patients in the experimental group was a score ≤ 24 to the Mini Mental State Evaluation (MMSE) test with a mean of 18.90 (*SD* = 3.7). The patients' scores to MMSE ranged from 11 to 24. People who claimed to be affected by any olfactory or taste dysfunction, as well as people suffering from cold or flu, were excluded from the experiment.

2.2. Stimuli

54 olfactory stimuli belonging to *Le Nez du Vin*® wine taster kit (i.e., Jean Lenoir Éditions, Carnoux-en-Provence, FR) were used in the experimental design. The stimuli adopted were taken from five categories: fruit, floral, vegetal, animal and smoked aromas.

The olfactory stimuli were randomly assigned to two equals groups consisting of 15 targets and 15 distractors. The targets were: melon, acacia, cut hay, leather, coffee, lychee, linden, pine, cedar, roasted hazelnut, blackcurrant, honey, cinnamon, toasted bread, muscat, pine. The distractors were: pear, hawthorn, truffle, musk, almond, strawberry, violet, clove, licorice, orange, rose, green pepper, smoked, cherry, chocolate, (see Fig. 33). The odours of the kit were rated with respect to their level of familiarity and nameability in a pre-test experiment. A t-test performed to compare the nameability and the familiarity degree of the two groups of stimuli did not showed any significant difference. Every odour was contained in a small glass bottle.

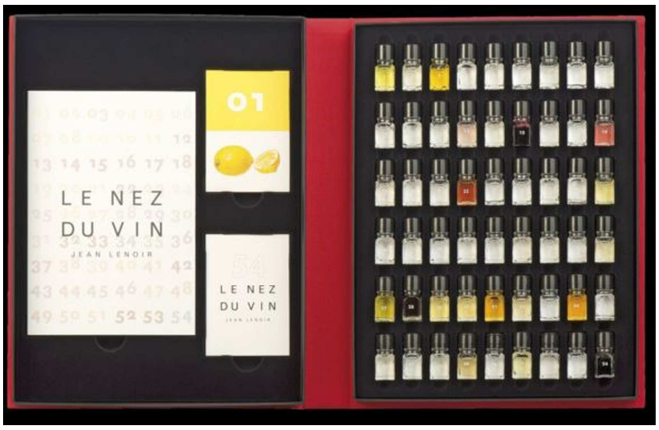


Figure 33 – The olfactory stimuli belonging to Le Nez du Vin® wine taster kit

2.3. Procedure

A pre-test was administered to avoid the recruitment of anosmic or hyposmic individuals, as well as, to avoid medical conditions that reduce olfactory capabilities (e.g., cold or flu). None of the participants showed any problem in odour recognition.

The experimental procedure followed a between-participants design and consisted in an odour recognition task. The study was conducted in an experimental booth with the student control group, at their home in a quiet place with the elderly group, and alternatively in their private room at the Lissone shelter residence, in a study of the Bolzano Hospital or at home with the AD patients.

The participants sat comfortably on a chair at a desk in front to the experimenter and had to assess if the odour presented after a time interval was the same as the previous one. The bottles with the odours were placed at about 3 cm under the nostrils of the participant by the experimenter and kept on that position for about 5 seconds. The test included 30 olfactory stimuli and was divided in three experimental blocks on the basis of the different temporal delay between stimulus presentation (retention phase) and the to-be-evaluated odour (recognition phase). Every block was formed by 10 stimuli (5 target odours and 5 distractors). During the recognition phase, every target odour was presented once with the same stimulus administered in the retention phase and once with the correspondent distractor. In the first block, the temporal delay between the presentation of the target odour and the to-be-evaluated odour was 1 minute; in the second 3 minutes; in the third 1 minute under articulatory suppression (participants repeated aloud the non-word *bla, bla, bla,* during all the temporal delay (Baddeley, 1983). In every experimental block five olfactory target stimuli were presented twice during the retention phase, while, in the recognition phase both the five target odours than the five distractors were presented one time. The inter trial interval of the first experimental blocks was set at 2 min. Each block was separated by an interval of 5 min. Each of the five target odours was administered 2 times in the first presentation of the three experimental blocks and 1 times in the recognition phase of the three experimental blocks, each of the five distractor odours were administered 1 times in the recognition phase of the three experimental blocks for a total of 60 olfactory stimuli to be evaluated. The AD patients were tested in three different sessions, one for each experimental block in order to reduce their olfactory fatigue. The AD patients were tested in different sessions of the same morning, or in different days depending on their level of attention and boredom. The investigator recorded the participants' responses on a sheet of paper. The presentation of the olfactory stimuli was completely randomized both for target and matched odours. That is, the order of the stimuli administered during the retention and the recognition phase was completely different for every participants. Experiment 1 lasted for approximately 65–75 min and was administered in the same session as Experiment 2. The entire experimental session lasted approximately 135-145 min, this duration comprises an initial overview of the experimental setup, the explanation of the instructions, the explanation and signature of the ethical forms and a final 10–15 min of debriefing regarding the main aims of the experiments.

2.4. Results

The participant's means response to the odour recognition task (correct target identification and correct recognition of distractors) were submitted to a mixed repeated measures ANOVA with Temporal Delay as within factor and Group as between factor. The results of the analysis revealed a significant main effect of

Group [F(2,63) = 40.80, $p < 0.0001$] and of Temporal Delay [F(2,126) = 20.45, $p < 0.0001$]. The interactions between these factors also resulted to be significant [F(4,126) = 3.16, $p = 0.02$]

A Bonferroni post hoc test on the main effect of Group revealed that the overall performance of the control students was better than that of the elderly participants ($p = 0.003$) and AD patients ($p < 0.0001$), and the overall performance of the elderly group was better than that of the AD patients ($p < 0.0001$). A Bonferroni post hoc test on the main effect of Temporal Delay demonstrated that in general, all participants performed worse in the 3 min interval condition, as compared to the 1 min interval condition ($p < 0.0001$) and in the 1 min interval condition with articulatory suppression ($p < 0.0001$).

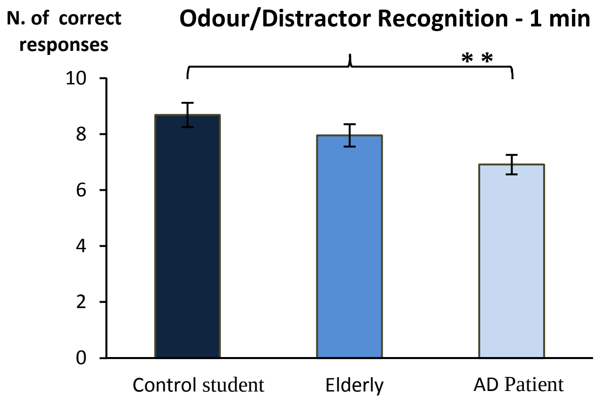


Figure 34 – A The participants' mean of odour target plus distractor with 1 min of delay between stimulus presentation and recognition. Asterisks represent significant differences at $p < .001$

A Bonferroni post hoc test on the interaction between Temporal Delay and Group showed that in the 1 min interval condition between olfactory target stimulus presentation and odour recognition AD patients recognised significantly less odours than control students ($p < 0.0001$) (see Fig. 34A); in the 3 min interval condition AD patients performed worse than control students ($p < 0.0001$) and elderly ($p = 0.01$) (see Fig. 34B); in the 1 min interval conditions with articulatory suppression, AD patients performed worse than control students ($p < 0.0001$)), and elderly ($p = 0.04$ (see Fig.34C).

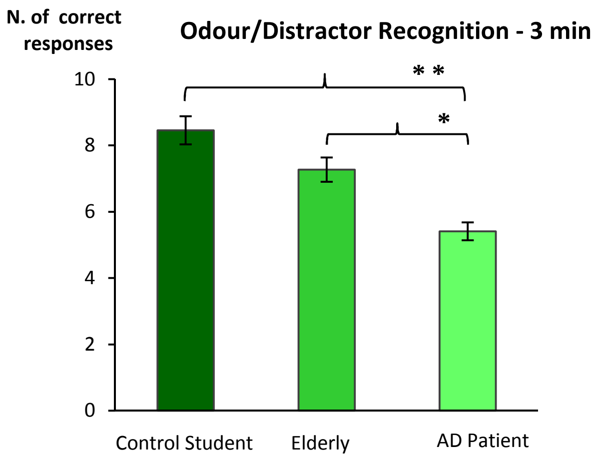


Figure 34 – B The participants' mean of odour target plus distractor with 3 min of delay between stimulus presentation and recognition. Asterisks represent significant differences at: * $p < .05$; ** $p < .001$

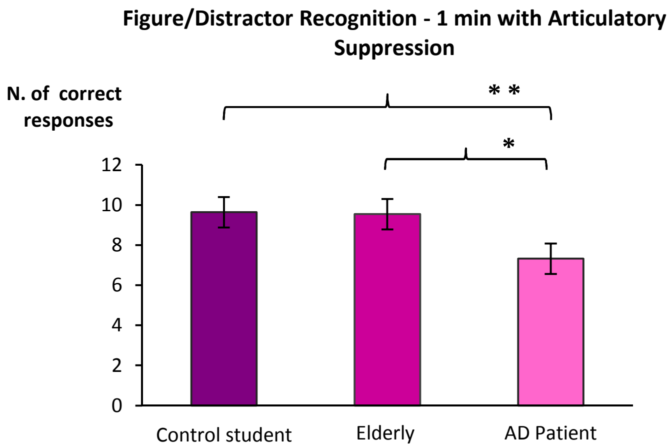


Figure 34 – C The participants' mean of odour target plus distractor with 1 min of delay and articulatory suppression between stimulus presentation and recognition. Asterisks represent significant differences at: * $p < .05$; *** $p < .0001$

3. Experiment 2

3.1 Participants

The same Sixty-six participants of Experiment 1 took part in Experiment 2.

Experiment 2 lasted as Experiment 1 for approximately 65–75 min and was administered in the same session.

3.2. Stimuli

The stimuli consisted of thirty cards belonging to *Le Nez du Vin*® wine taster kit and visually representing the odours used in Experiment 1. For example, the card that corresponds to the odour of lemon shows a lemon illustration (see Fig. 32).

3.3. Procedure

The procedure followed a between-participants design and consisted in a delayed figure recognition task. Exactly the same procedures as those used in Experiment 1 were adopted in Experiment 2.

3.4. Results

The participant's means response to the figure recognition task (correct target identification and correct recognition of distractors) were submitted to a mixed repeated measures ANOVA with Temporal Delay as within factor and Group as between factor. The results revealed a significant main effect of Group [$F(2,63) = 62.83$, $p < 0.0001$), Temporal Delay [$F(2,126) = 22.09$, $p < 0.0001$], and a significant interaction between Group and Temporal Delay [$F(4,126) = 7.52$, $p < 0.0001$].

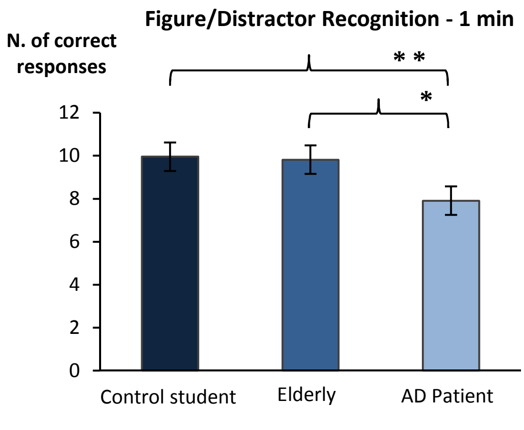


Figure 35 – A The participants' mean of figure target plus distractor with 1 min of delay between stimulus presentation and recognition. Asterisks represent significant differences at: * $p < .05$; ** $p < .001$

A Bonferroni post hoc test on the main effect of Group revealed that the overall performance of the Alzheimer patients group was worse than elderly ($p = 0.0001$) and control students ($p < 0.0001$). A

Bonferroni post hoc test on the main effect of Temporal Delay demonstrated that in general, all participants committed significantly more errors in the 3-min experimental condition, as compared to the 1-min condition ($p < 0.0001$) and 1 min with articulatory suppression ($p = 0.004$).

A Bonferroni post hoc test on the interaction between Group and Temporal Delay showed that in the 1-min experimental condition AD patients' performance was lower than control students' performance ($p < 0.0001$) and elderly group's performance ($p < 0.002$) (see Fig. 35A); in the 3-min experimental condition, AD patients performed worse than control students group ($p < 0.0001$), and the elderly group ($p < 0.0001$) (see Fig. 35B); performed better in the 1-min plus articulatory suppression experimental condition, AD patients committed significantly more errors than control students ($p < 0.0001$) and elderly ($p < 0.001$) (see Fig. 35C).

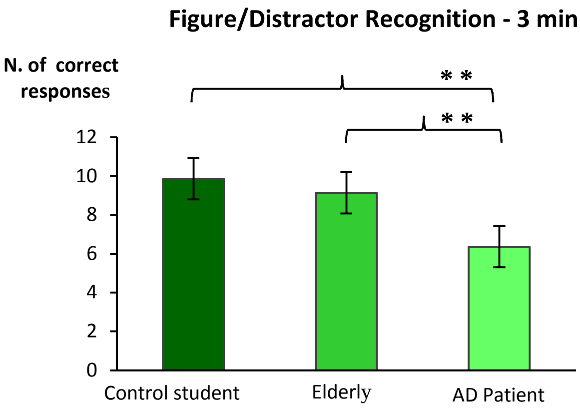


Figure 35 – B The participants' mean of figure target plus distractor with 3 min of delay between stimulus presentation and recognition. Asterisks represent significant differences at $p < .001$

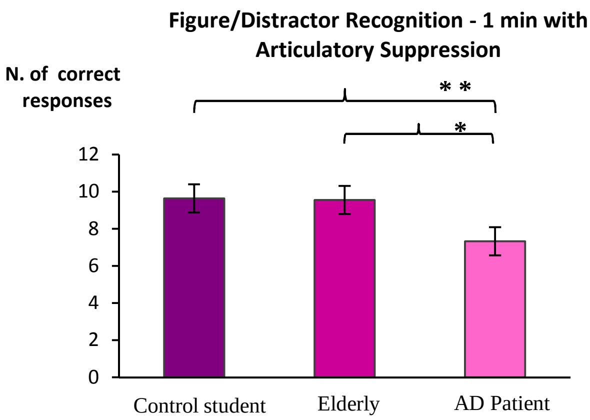


Figure 35 – C The participants' mean of figure target and distractor with 1 min of delay plus articulatory suppression between stimulus presentation and recognition. Asterisks represent significant differences at: ** $p < .001$; *** $p < .0001$

4. Experiment 3

4.1. Participants

Sixty-six participants divided into three equal groups took part in Experiment 3; Group 1 was composed by graduate and undergraduate students from University of Milano Bicocca and voluntary randomly recruited by means of social network in the city of Milan, in total twenty-two with a mean age of 26.07 years (*SD* = 7.31, 14 female). Graduate and undergraduate students received course credits for their participation in the study. Group 2 was composed by twenty-two elderly participants (over 65 years) with a mean age of 71.23 years (*SD* = 6.45, 14 female), recruited by means of social network. Group 3 was composed by twenty-two participants affected by Alzheimer disease with a mean age of 82.55 years (*SD* = 6.88, 15 female), participants were recruited at Protected Core of the shelter residence 'Agostoni' located in Lissone a small city near Milano, at the Memory Clinic of the Geriatric Ward of the Bolzano Central Hospital and by means of social network in the city of Milan. Participant's inclusion criteria for AD patients were the same of Experiment 1 and 2. The patients' scores to MMSE ranged from 11 to 24. The Experiment described here was performed in accordance with the ethical standards laid down in the 2008 Declaration of Helsinki and approved from the local ethical committee. People who claimed to be affected by any olfactory or taste dysfunctions, as well as people suffering from cold or flu were excluded from taking part in the experiment.

4.2. Stimuli

The stimuli consisted of fifteen olfactory stimuli taken from to *Le Nez du Vin*® wine taster kit (i.e., Jean Lenoir Éditions, Carnoux-en-Provence, FR). The odours used were: mushroom, cinnamon, strawberry, butter, pineapple, chocolate, lemon, vanilla, apple, honey, rose, coffee, banana, orange, licorice. Every odour was contained in a small glass bottle.

4.2. Procedure

Exactly the same procedures as those used in Experiment 1 were adopted during the pre-test. None of the participants showed any problem in odour recognition.

The procedure followed a between-participants design and consisted in an odours denomination task. The study was conducted in an experimental booth for the student control group, at their home in a quiet place for the elderly group, and alternatively in their private room at the 'Agostoni' shelter residence in Lissone, in a study of the Bolzano Hospital or at home for the Alzheimer patients group. The participants sat comfortably on a chair at a desk in front to the experimenter and have to repeat aloud the name of the odour presented to their nostril. Every odour was held at about 3 cm under the participant's nose for 5 seconds with 1 min between every odour presentation. The investigator recorded the participants' responses on a sheet of paper. The olfactory stimuli were administered in a single experimental block for a total of 15 odours presentations and were completely randomized. Experiment 3 lasted for approximately 25-30 min and was administered in the same session of the Experiment 4. The entire experimental session lasted approximately 50-60 min, this duration comprises an initial overview of the experimental setup, the explanation of the instructions, the explanation and signature of the ethical forms and a final 10–15 min of debriefing regarding the main aims of the experiments.

4.3. Results

The participants' means of the three experimental groups (control student, elderly, AD patients) in the odour naming task were submitted to an univariate ANOVA with odour denomination as independent variable. The results of the analysis revealed a significant main effect of group [$F(2,63) = 33.85$, $p < 0.0001$]. A Bonferroni post-hoc test revealed that control student group committed less errors in odour naming, as compared to elderly ($p = 0.025$) and AD patients ($p < 0.0001$), and elderly group committed less errors in odour denomination than Alzheimer patients ($p < 0.0001$) (see Fig. 36).

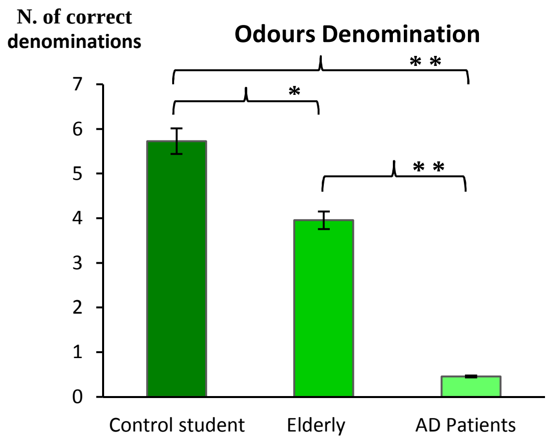


Figure 36 - The participants' mean of odours denomination in the control student, elderly and AD patients groups. Asterisks represent significant differences at: * $p < .05$; ** $p < .001$; *** $p < .0001$

5. Experiment 4

5.1. Participants

The same Sixty-six participants of Experiment 3 took part in Experiment 4.

5.2. Stimuli

The fifteen cards with drawn a figure used during the Experiment 4 belong to *Le Nez du Vin*® wine taster kit (i.e., Jean Lenoir Éditions, Carnoux-en-Provence, FR) and correspond to the olfactory target stimuli used in Experiment 3.

5.3. Procedure

The procedure followed a between-participants design and consisted in a figure denomination task. Exactly the same procedures as those used in Experiment 3 were adopted in Experiment 4. The temporal delay between the target figure presentation and the recognition remained the same as Experiment 3. Between the beginning of a test and the other test were left 10 minutes for the participant's rest, to ventilate the room and to prepare the successive experimental setting.

5.4. Results

The participants means response to figure denomination (were submitted to an univariate ANOVA with odour denomination as independent variable and with the between subject factor of group (control student, elderly, Alzheimer patients). The results of the analysis revealed a significant main effect of group [$F(2,63) = 106.61$, $p < 0.0001$]. A Bonferroni post-hoc test revealed that Alzheimer patients committed significantly more errors in figures denomination than elderly ($p < 0.0001$) and control student ($p < 0.0001$) groups (see Fig. 37).

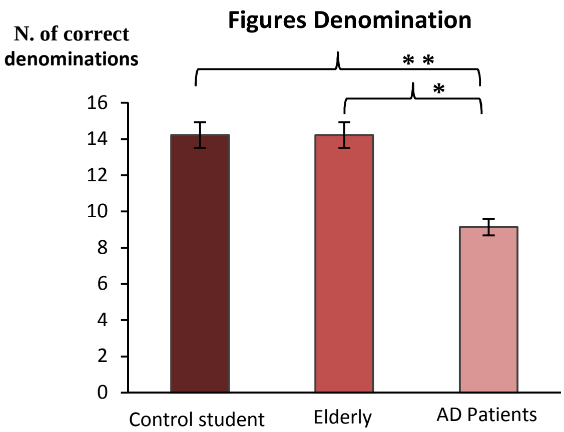


Figure 37 - The participants' mean of figures denomination in the control student, elderly and AD patients groups. Asterisks represent significant differences at: * $p < .05$; ** $p < .001$

6. General discussion and conclusion

The result of Experiment 1 showed that in the odour recognition task with 1 min of delay between stimulus presentation and test phase, the control student group performed better than the AD patients. In the condition with 3 min of delay between stimulus presentation and test phase, both control students and unpaired elderly participants performed better than AD patients. Lastly, the results of the condition with 1 min of delay plus articulatory suppression between stimulus presentation and test phase were similar to those of the condition with 3 min of delay.

AD performance in the condition with 1 min of delay between stimulus presentation and test phase is certainly an intriguing result. In fact, AD patients performed just as the elderly neurologically intact participants, even if, their results are significantly worse than those of control students. This means that within the time interval of about 1 min AD patients have a preserved ability (at least compared to participants of the same age group) to retain information regarding the specific odour perceived. This result do not fully agree with Djordjevic et al. (2008) study in which was found that AD performed significantly worse than normal elderly controls in odour discrimination. The inconsistencies between the two studies may underlie some methodological differences, since, in Djordjevic experimental paradigm pairs of same/different odours that participants had to smell were presented. Then, after 20s they sniffed again a pair of olfactory stimuli that could be the same or not with respect the previous pair, and participants had to judge whether the last two stimuli were identical to the previous two. It is then possible that the discrimination task of our study was slightly easier than that used by Djordjevic, leading to a better performance of the AD group.

The results of the comparison between the experimental conditions with 3 min and 1 min intervals with articulatory suppression between odours presentation and recognition, revealed that AD performed significantly worse than elderly and student controls groups. This result clearly suggest a possible impairment of olfactory memory in AD for relatively longer retention intervals. However, an additional possible explanation for this result is that AD patients may have lost their focus on the task during this interval. In fact, Alzheimer’s disease patients also suffer from a decline of attentional capacity that, especially in early stage of the syndrome, precede the impairment of the linguistic and perceptual functions (Baddeley, Baddeley, Bucks, & Wilcock, 2001; see Perry & Hodges, 1999 for a detailed review). Note also that, it was demonstrated that Alzheimer’s disease patients are heavily impaired when have to perform two simultaneous tasks (Baddeley et al., 2001).

The worst performance found during articulatory suppression can be explained by the fact that this condition prevented the verbal processing and encoding of olfactory stimuli, thus lowering the AD performance. That is, a more complete (dual) coding of the stimuli was prevented under this condition of stimulus presentation. This result clearly suggests that olfactory stimuli are coded, also by AD patients by using, also a verbal coding strategy.

The data of the Experiment 2 on figure recognition showed that AD patients performed significantly worse than students control and elderly groups both with 1 min, 3 min and 1 min intervals with articulatory suppression between figures presentation and recognition. These results are in line with previous studies which demonstrated an early impairment of visual memory before the onset of the clinical symptoms of AD (Kawas et al., 2003). Importantly, while olfactory memory was similar between AD and elderly participants at 1 min intervals of retention, AD patients performed worse with figure recognition during the same interval, perhaps suggesting a better memory for odours than images in the first stage of this syndrome.

The data obtained in the odours denomination task (Experiment 3) showed that AD patients identified significantly less odours than control students and elderly groups; moreover, elderly performed worse than control students. These results are congruent with previous studies on odour naming (Doty, 2003; Larsson, et al., 1999; Mesholam et al., 1998). Incidentally, it is worth noting that odour naming is considered a very difficult task also for normal individuals (Lorig, 1999; Olofsson & Gottfried, 2015; Westervelt et al., 2005) This result clearly suggest a greater impairment in verbal rather than simply perceptual abilities in AD patients as compared to the other groups.

The results of Experiment 4 revealed that AD patients performed significantly worse than elderly and control students in the figure identification task. These data are in agreement with previous literature, since as demonstrated by Kawas et al. (2003) AD patients can exhibit a severe deficit in figures denomination up to 15 years before the onset of the clinical symptoms. Instead, the similar performances of Elderly and control students groups is not surprising. In fact, Schmitter-Edgecombe, Vesneski, and Jones (2000) found that young-old adults (ages 58-74 years) and old-old adults (ages 75-93 years) performed similarly to young adults (ages 18-22 years) in pictures naming test (Boston Naming Test).

In conclusion, the results found in the present study suggest that a number of previous assumptions that postulated that olfactory memory deficits represent early prodromal symptoms that precede AD onset, need to be carefully considered. Since, with respect to odours recognition in the condition of 1 min of retention interval, no significant differences were found between AD and elderly group in the present study. This results would seem to suggest that odours recognition decline in AD is similar to the olfactory recognition decline due to normal aging in elderly group. Such an evidence does not allow to argue that olfactory memory deficits can predict with a large time interval the clinical symptoms of AD.

The evidence that AD patients would seem to have e a preserved memory of for 1 min odour retention intervals might be used within applied settings, to compensate for others profound amnestic deficits of these patients (e.g., by, associating specific salient odours to particularly relevant tasks. Future studies on olfactory memory in AD should also include conditions in which only nameable or hard to name odours are used, in order to compare the results as a function of a high or low probability of the verbal processing of the olfactory stimuli.

CHAPTER VIII
GENERAL DISCUSSION

Discussion

The present doctoral thesis investigates by means of several studies different aspects of crossmodal integration in smell and taste perception as well as memory for odours. In particular, in Chapter II, Chapter III and Chapter IV evidence suggesting the presence of robust crossmodal interactions between different sensorial aspects of a beverage container and of its content were found. The findings gathered by the studies illustrated in Chapter V highlight instead, that crossmodal interactive effects in the chemical senses domain can be effectively studied by means of a new generation of portable systems that allow for the computerized control of olfactory stimuli administration. Lastly, the evidences drawn by the studies described in Chapter VI reveal as different experimental paradigms and the study of patients affected by Alzheimer disease can help to unveil the complex characteristics (comprising the duration of the storage and the coding strategies adopted by participants) of short and long term memory for odours.

Crossmodal effects in food and beverages perception received increased attention by psychologists and neuroscientist only in recent years. In fact, the number of studies in this domain has grown exponentially. Many experimental paradigms have started to show that taste perception can be differentially modulated by some characteristics of concurrently presented signals coming from other sensory modalities (colours, sounds, textures, odours) in the environment, as well as, by some features of the containers in which food and beverages are served (see Spence 2011a; Spence et al., 2015; Spence & Wan, 2015d for detailed reviews). In particular, research have started to debate about the role of odours in taste perception. Within this domain it has been postulated that taste perception is formed by basic tastes (sweet, sour, salt, bitter), smells, trigeminal, and tactile sensations inextricably united to form a given percept. The process leading to this final percept has been defined as 'flavour' perception (Auvray and Spence, 2007; Spence 2016; Spence et al., 2014). The 3 studies reported in Chapter II, III and IV clearly support the view that several kind of crossmodal effects also occur during the perception of a liquid such as mineral water, that is neutral in term of odours and basic tastes.

Several hypotheses have been suggested to account for the multisensory interactions occurring in different domains of perception, especially when the features of containers have shown to modulate certain aspects of the content: 'sensation transference' (Spence & Piqueras-Fiszman, 2012a), 'affective ventriloquism' (Spence & Gallace, 2011) or even evolutionary pressure (Maga, 1974; Spence et al., 2010). The results reported in our study are in agreement with most of these hypotheses and we claim that different explanations are likely to account for different conditions of stimulus presentation. We also believe that in the future research should concentrate on better isolating the various components of flavour perception in order to understand the relative weight of each component in determining our final perception (a complete statistical model of food and beverage information processing needs to be proposed).

Among other findings, in our studies we show that the colour of a container can affect our perception of the water presented inside. However, it remains unclear which (if one) specific aspect of colour (hue, intensity, brilliance, saturation, etc.) contribute the most to determine the modulation of flavour and how these different aspects interact with other characteristics of the container (shape, size etc.). The same principle should also apply for other studies reported in this thesis (as well as in the extant literature). Moreover, neuroscientific techniques should be used to understand the neural bases of this process. Especially, brain imaging techniques would need to be adopted in order to investigate the specific involvement of sensory and higher order areas during the multisensory modulation of food and beverage perception.

The Study of Chapter V is mainly focused on the use of different olfactory devices in order to assess crossmodal correspondances in different sensory modalities. The main issue here is related to the fact that while stimulus presentation in some senses results to be very easy now (see the case of vision, touch and hearing) the presentation of odours in a controlled experimental setup still represents a greater challenge. The control of different olfactory characteristics can be obtained by means of complex devices such as olfactometers. However, so far these devices result to be highly expensive, cumbersome and generally complex to be used. All of these aspects have certainly limited research on olfaction, and in particular on the interaction between olfactory and visual, tactile and auditory perception. In the present doctoral thesis we used a simple, relatively cheap and small olfactory device for addressing the question regarding multisensory interaction in food perception. More specifically, the device described in Chapter V was used to investigate the interaction among the orthonasal administration (through the nostrils) of odours and food and beverages perception (Auvray and Spence, 2007; Spence 2016; Spence et al., 2014). Intriguingly, the preliminary evidences obtained with such device showed that odours (chocolate, citrus or air) orthonasally presented together with food (candies and cracker) can modulate the participants perception of food pleasantness and sweetness. Interestingly, beverages (Sprite®, tonic water and sparkling mineral water) perception did not result to be affected by the concurrently presented olfactory stimuli. Importantly, however we demonstrate that our device can be successfully used for odour presentation under conditions of multisensory stimulation. Moreover, such device is able to effectively deliver chemicals that are stored in a solid rather than liquid form (and thus it helps to reduce the problems that are generally associated with handling chemicals in liquid forms for olfactory experiments) and to convey them directly to the nostrils of the participants by means of an air flow. We are sure that such a device can provide a positive impulse to the future developments of research in the topics of olfactory perception and multisensory integration.

Chapter VI and VII deals more specifically with a number of issues regarding the study of olfactory memory in humans. In fact, to date, the question of whether memory for odorants is organized in short and long term components (both functionally and under the profile of its neural architecture) such as it occurs for other sensory systems, is still controversial (White, 1998; White, 2009). Importantly, neuroscientific literature shows that primary olfactory cortex is very close, from an anatomical point of view to structures of the limbic system, such as the amygdala and the hippocampus, which are responsible for emotional processing, as well as for the encoding and storage of to-be-retained information. This observation might be taken to suggest that memory for odours is even more effective, and more difficult to be damaged, than memory in other sensory domains (Dade, et al., 2001; Kareken et al., 2003; Royet et al., 2003; Savic & Berglund, 2000; Seubert et al., 2008; Soudry et al., 2011; Weber & Heuberger, 2008).

In the studies reported in Chapter VI we investigated short and long term memory for odours, by means of different experimental paradigms. In Experiment 1 of Study 1 (olfactory single probe serial position task for nameable odours), we found a lack of the classic serial position effect for sequences of to-be-remembered odours (generally found for visual and verbal presentation of the stimuli). Interestingly, we found that odours presented in the middle of the sequence gave rise to the best participants' performance in a delayed recognition task (that is, no primacy and recency effects were found; Gabassi & Zanuttini, 1983; Reed, 2000; see Miles & Hodder, 2005). In Experiment 2 of Study 1 (olfactory single probe serial position task for hard to name odours) we found that odours presented in position 3 and 6 were remembered better than odour presented in the first position. That is, just as in Annett and Lorimer (1995) and White and Treisman (1997) studies, recency, but not primacy effects were found. Intriguingly, the performance for odours presented in position 3 again was found to be unusually high and similar to that of odours in position 6. A classic model of STM (responsible for the recency effect) and LTM (responsible for the primacy effect) memory cannot be used to support such results.

In Study 2 we found that: 1) olfactory short term memory is affected by certain verbal aspects of the stimuli (e.g., their nameability), suggesting the presence of a multimodal representation of olfactory stimuli; 2) olfactory long term memory is not necessarily affected by verbal processing or encoding strategies. In fact, we found that performances obtained with nameable and hard to name odours is similar when the recall occurs after 7 days of retention. Again, also this result would seem difficult to be interpreted in terms of a classic account of STM and LTM distinction.

In the four experiments reported in Chapter VII we compared the performance of Alzheimer's disease patients, unimpaired elderly and control students groups in three different conditions of retention of olfactory information. Moreover, we also investigated the presence of differences between visual and olfactory memory in these three groups of participants. The main aim of the study was to assess whether olfactory memory problems arise relatively early in AD patients, or rather if olfactory memory is better preserved as compared to other forms of memory in this group of patients. The more interesting result to arise from this study was that AD patients performed similarly to unpaired elderly participants in odours recognition memory under conditions where the stimuli needed to be retained for an interval of 1 minute (i.e., interval between stimulus presentation and recognition). On the basis of this result, we suggest that previous assumptions which postulate that olfactory memory deficits may represent early prodromal symptoms of AD onset, should be considered with caution (Atanasova et al.2008; Djordjevic et al., 2008; Naudin et al., 2014; Serby et al., 1996; Zucco & Negrin, 1994). Taken together, all of the studies reported in Chapter VI and VII provide important insights on the issue related to a double coding (Paivio, 1986) of olfactory stimuli. In particular, it seems that only under certain conditions of stimulus presentation and within certain retention intervals, the presence of verbal information (e.g., mediated by verbal labeling of the stimuli) can provide support to the storage of olfactory material. It is however likely, that other unconsidered aspects play an important role in the processing subserving olfactory memory. For example, our research did not investigate the impact of the emotional valence of the olfactory stimuli on stimulus encoding, storage and retrieval. This is certainly a topic that deserves the attention of researchers in the future. The neural systems responsible for different aspects of olfactory memory need also to be further investigated in the years to come.

In conclusion, the present work contributes to shed light on several aspects of crossmodal interaction in taste and smell perception. In particular the present thesis has contributed to clarify how certain aspects of the environment (such as variations of colour, weight or texture of a container or of concurrently presented odours) can affect taste perception of food and beverage. Moreover, the results reported here have also contributed to determine how olfactory information is stored in our neurocognitive systems and in particular on how verbal information processing interacts with olfactory memory. Finally, this work represents one of the first attempts to introduce new (small, cheap and portable) technological devices in the study of olfaction and flavour perception.

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