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RUNNING HEAD: DIGITIZING THE CHEMICAL SENSES

Digitizing the chemical senses:

Possibilities & pitfalls

Charles Spence (University of Oxford),

Marianna Obrist (University of Sussex),

Carlos Velasco (BI Norwegian Business School),

& Nimesha Ranasinghe (National University of Singapore)

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CORRESPONDENCE TO: Prof. Charles Spence, Department of Experimental Psychology, University of Oxford, Oxford, OX1 3UD, UK. E-mail: charles.spence@psy.ox.ac.uk

ABSTRACT

Many people are understandably excited by the suggestion that the chemical senses can be digitized; be it to deliver ambient fragrances (e.g., in virtual reality or health-related applications), or else to transmit flavour experiences via the internet. However, to date, progress in this area has been surprisingly slow. Furthermore, the majority of the attempts at successful commercialization have failed, often in the face of consumer ambivalence over the perceived benefits/utility. In this review, with the focus squarely on the domain of Human-Computer Interaction (HCI), we summarize the state-of-the-art in the area. We highlight the key possibilities and pitfalls as far as stimulating the so-called 'lower' senses of taste, smell, and the trigeminal system are concerned. Ultimately, we suggest that mixed reality solutions are currently the most plausible as far as delivering (or rather modulating) flavour experiences digitally is concerned. The key problems with digital fragrance delivery are related to attention and attribution. People often fail to detect fragrances when they are concentrating on something else; And even when they detect that their chemical senses have been stimulated, there is always a danger that they attribute their experience (e.g., pleasure) to one of the other senses – this is what we call 'the fundamental attribution error'. We conclude with an outlook on digitizing the chemical senses and summarize a set of open-ended questions that the HCI community has to address in future explorations of smell and taste as interaction modalities.

KEYWORDS: CHEMICAL SENSES; TASTE; SMELL; TRIGEMINAL; CROSSMODAL; VIRTUAL REALITY; AUGMENTED REALITY; MIXED REALITY.

Introduction

Both the popular press and the general public are fascinated by the possibilities associated with the digitization of the chemical senses (e.g., Berenstein, 2015; Cuthbertson, 2015; Lant & Norman, 2017; Marks, 2013; Obrist, Tuch, & Hornbæk, 2014; Platt, 1999). And indeed, much research has been conducted in this area in recent decades (as documented by the many papers and sessions at the technology conferences in HCI such as ACM CHI, UIST, and TEI, not to mention, by the various papers referenced in this review). That said, there are still a number of key questions with regard to the digitization of the chemical senses that will need to be addressed before any real progress can be made in delivering plausible (i.e., commercially viable and appealing) solutions to market. These include: *What do you want to digitize? Why do you want to digitize it? How do you plan to digitize it? What are the limitations, both technical and psychological, to digital transmission/delivery that are relevant to the chemical senses?* It is only by addressing such questions that the various pitfalls that have been highlighted by a number of the high-profile failures in this area in recent years can be avoided (e.g., Dusi, 2014; Twilley, 2016; Velasco, Obrist, Petit, Karunanayaka, Cheok, & Spence, 2016).

Introducing the chemical senses

At the outset, when thinking about the digitization of the chemical senses, it is important to note that there are at least three senses that may be the target of any digital intervention: 1) Stimulation of the sense of taste (gustation); 2) Stimulation of the sense of smell (olfaction via either the orthonasal or retronasal route; e.g., Rozin, 1982; Small, Gerber, Mak, & Hummel, 2005); and 3) trigeminal stimulation (responsible for detecting sensations such as heat and cold along with various food textures that are related to biting and chewing actions; e.g., Burdach, Kroeze, & Koster, 1984; Dodd & Kelly, 1991; Lundström, Boesveldt, & Albrecht, 2011; Spence & Piqueras-Fiszman, 2016; Viana, 2011).

The delivery of ambient scent is the simplest application of digitizing the chemical senses, since it requires only orthonasal olfactory stimulation (e.g., as when we inhale/sniff). Such scents might or might not be food (i.e., flavour) related. To date, digitally-controlled scent delivery[1] have been used to augment the immersion in audio-visual entertainment/training applications (Cole, 2016; see Ischer, Baron, Mermoud, Cayeux, Porcherot, Sander, & Delplanque, 2014, for a review). More generally, ambient scents have been used to trigger specific moods, emotions (Herz, 2002; Leenders, Smidts, & El Haji, in press; Moss, Cook, Wesnes, & Duckett, 2003; Rétiveau, Chambers, & Milliken, 2004), nostalgia/memories (Chu

[1] When considering the digitization of smell, it would seem natural to consider digitally-controlled chemical delivery systems, electric (or perhaps thermal) stimulation, or a combination of both. Chemicals are naturally processed by our olfactory system, nevertheless, researchers have also explored direct electric stimulation of the olfactory receptors as means to evoke odour sensations (Hariri, Mustafa, Karunanayaka, & Cheok, 2016). It is important to recognize, though, that such stimulation does not give rise to the perception of odours as does following chemical stimulation (Weiss et al., 2016). In that sense, as for to date, it seems more plausible to digitizing the sense of smell via digitally-controlled chemicals.

& Downes, 2000, 2002; Doop, Mohr, Folley, Brewer, & Park, 2006; Tortell, Luigi, Dozois, Bouchard, Morie, & Ilan, 2007), induce hunger, and even bias our everyday behaviours (Holland, Hendriks, & Aarts, 2005).

By contrast, stimulation of the sense of taste, retronasal olfaction,[2] and possibly also the trigeminal sense are needed in order to deliver an authentic-tasting flavour experiences (e.g., Bult, de Wijk, & Hummel, 2007; Piqueras-Fiszman & Spence, 2016). Just think, for example, about simulating the minty sensation associated with compounds such as *1-methol* (the principal flavour in mint). All three of these sensory systems are needed if one is to deliver the characteristic minty aroma, the slightly bitter taste, and the cooling mouth-feel (involving the tactile thermal nociceptors) associated with the experience of this particular stimulus (Nagata, Dalton, Doolittle, & Breslin, 2005). Of course, it is not enough simply to stimulate these senses; The relative intensity of these digital stimuli also needs to be right, as does the time-course of increasing and decreasing sensation (see Obrist, Comber, Subramanian, Piqueras-Fiszman, Velasco, & Spence, 2014; Stuckey, 2012), if one wants to simulate a genuinely-compelling (i.e., authentic) minty sensation.

Taste (strictly-speaking, gustation) and flavour (the latter referring to the combined input of gustatory, olfactory, and possibly also trigeminal stimulation) are undoubtedly complex concepts to try and disentangle, both at the theoretical and at the empirical levels (see Spence, Smith, & Auvray, 2015, for a review). Matters are made more confusing by the existence of phenomenon such as oral referral (of odours to the oral cavity; see Spence, 2016a, for a review), and the fact that different terms are sometimes used in different languages to refer to these two percepts (e.g., Rozin, 1982; Spence, 2017a). Here it is perhaps helpful to bear in mind that stimulation of the taste-buds on the human tongue may only give rise to the sensation of sweet, bitter, salty, sour, and umami.[3] Everything else that we enjoy while tasting – the meaty, the fruity, the floral, the herbaceous, and the roasted etc. – are all delivered by the sense of smell instead.[4] That is, by volatile molecules hitting the olfactory receptors embedded in the nasal mucosa. It is one of the tricks of the mind that so much of this information, transduced by the olfactory receptors in the nose is referred to the mouth, giving us all the illusion that we are tasting (this is what it is referred to as 'oral referral'). So, when talking about the digitization of the chemical senses, one needs to keep taste distinct from tasting (the latter normally used to refer to the flavour perceived; see Spence et al., 2015). It is worth bearing in mind that it has widely been estimated that 75-95% of what we think we <u>taste</u> really reflects information delivered by the sense of <u>smell</u> (see Spence, 2015a, for a review). Finally, if one wants to deliver the trigeminal hit of chilli, cinnamon, or ginger,

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[2] Retronasal olfaction is based on the volatile-rich air that is pulsed out from the back of the nose whenever we swallow (e.g., Bojanowski & Hummel, 2012).

[3] That said, a growing number of researchers now believe that oleogustus, or fatty acid, should be considered as the sixth taste (e.g., Keast & Costanzo, 2015; Running, Craig, & Mattes, 2015). Then there is kokumi, not to mention the recently-discovered taste for glucose oligomers (Lapis, Penner, & Lim, 2016). However, while we may well be able to discriminate these stimuli in taste tests, it is not so clear that they are all necessarily associated with a clearly identifiable taste percept.

[4] It is currently unclear whether the metallic sensation one sometimes gets is a taste, a retronasal aroma, or a flavour (see Skinner, Lim, Tarrega, Ford, Linforth, & Hort, in press; Spence et al., 2015).

say, then you also need to stimulate the trigeminal sense as well (Cometto-Muñiz & Cain, 1995).

Apart from the senses of taste and smell (or aroma, i.e., food-related smells), simulating the texture of food can also be very important. The trigeminal sense detects heat and cold sensations (e.g., the cool sensation associated with mint, or the burning heat of a good chilli) and is also responsible for detecting the texture of food (e.g., think crunchiness and creaminess; see Spence & Piqueras-Fiszman, 2016, for a review of the literature on oral-somatosensation). Intriguingly here, a number of researchers working in the field of HCI have investigated the consequences for perception of either warming the receptacle in which a drink is held, say, or else warming the air around the nostrils (see Suzuki, Narumi, Tanikawa, & Hirose, 2014).[5] The texture and oral-somatosensory mouthfeel that is such a distinctive feature of many foods, while little studied to date (at least relative to the amount of research on the other flavour senses), is undoubtedly important of our everyday experience of food. After all, it is a key part of what makes chocolate and ice-cream so desirable. Food textures are also a key feature driving people's food dislikes (see Prescott, 2012, for an overview; and Iwata, Yano, Uemura, & Moriya, 2004; Niijima & Ogawa, 2016, for some of the first attempts to simulate the experience of food texture digitally). Hence, there are grounds for thinking that unless any digital delivery system can replicate real foods they will be 'thin' – that is, lacking in substance. Note here only the research showing that people are mostly unable to identify many everyday foods in the absence of the appropriate food texture (Stuckey, 2012).

In the context of exploring the digitalization of the chemical senses, another key distinction needs to be made between *flavour expectations* and *flavour experiences*. So far, we have been mostly focused on the senses that directly contribute to flavour perception while eating/drinking. However, we rarely put something in our mouth without having an idea of what it is first. These flavour expectations then anchor our subsequent flavour experience when we actually come to taste (see Piqueras-Fiszman & Spence, 2015, for a review). Vision, orthonasal olfaction, and, to a lesser extent, sound are the key senses in terms of setting such expectations (see Spence, 2015c, d, for reviews). As we will see later, given the powerful role of flavour expectations in modulating our flavour experiences, one potential route to digitally modifying our experience of the chemical senses, is by directly targeting the expectation rather than, or in addition to, the experience. However, again, these approaches may or may not stimulate a similar experience in the mind of the user, and hence further experimentation is definitely still needed in order to evaluate their effectiveness in a digital context.

What do you want to digitize?

There are at least two principle suggestions here: 1) Ambient scent delivery (of either food-related aromas or food-unrelated scents); and 2) Tasting experiences. Over the last couple of

[5] So, for example, the "Affecting Tumbler" by Suzuki et al. (2014) is designed to alter the perceived flavour of a drink by delivering thermal sensations around the nose.

decades, many researchers have turned their attention to question the opportunities inherent in terms of enhancing the sense of presence afforded by the introduction of virtual olfactory displays (e.g., see Barfield & Danas, 1996; Cater, 1992; Jones, Bowers, Washburn, Cortes, & Satya, 2004; Lombard & Ditton, 1997; Matsukura, Takayasu, & Ishida, 2016; Nambu, Narumi, Nishimura, Tanikawa, & Hirose, 2010; Zybura & Eskeland, 1999), and/or even, on occasion, by stimulating a user's taste buds – either directly with food stimuli in mixed reality applications, or virtually (via digital controller electrical and thermal taste interfaces), as we will see below (see Hoffman, Hollander, Schroder, Rousseau, & Furness, 1998; Narumi, Miyaura, Tanikawa, & Hirose, 2014; see also Hashimoto, Inami, & Kajimoto, 2008; Hashimoto Nagaya, Kojima, Miyajima, Ohtaki, Yamamoto, *et al*., 2007).[6] The hope, which in several demonstration cases has actually been illustrated empirically, has been to increase/enhance the sense of presence and/or possibly also the sense of immersion/realism (Nakamoto & Yoshikawa, 2006; see Gallace et al., 2012; Ischer et al., 2014, for reviews).

A number of those developing contemporary VR simulation training environments have already started to add congruent ambient olfactory cues with the aim of enhancing the sense of presence / authenticity of their simulations (e.g., see Evans, 2010; Fox, 2005; Jones et al., 2004; Washburn, Jones, Satya, Bowers, & Cortes, 2003). Interestingly, however, Baus and Bouchard (2016) recently suggested that unpleasant ambient scent may work better in terms of increasing immersion than pleasant aromas. There has also been interest from some quarters in the use of olfactory cues to enhance educational outcomes, as when incorporated as part of a multisensory intervention (e.g., Richard, Tijou, Richard, & Ferrier, 2006). Certainly, there is growing evidence that the intelligent delivery of various scents/fragrances can enhance performance across a range of work/exercise situations (e.g., Sakamoto, Minoura, Usui, Ishizuka, & Kanba, 2005; see Spence, 2002, for a review of the older literature).

Over the last half-century or so, there has also been periodic fascination around the delivery of scent in the cinema, in VR theatres, and even in front of the small screen (e.g., see Burgess, 2016; Gilbert, 2008; Nakamoto & Yoshikawa, 2006; Sebag-Montefiore, 2015; see also Hone, 2006; Park, Ko, Kim, Ahn, Kwon, & Kim, 2002).[7] And, coming from a more serious (deadly serious one might say) perspective, there has been interest in the use of scent to enhance the sense of presence/immersion, and consequently the beneficial effects of various military training applications (e.g., Vlahos, 2006).[8] In a similar vein (if you will

[6] Hoffman et al. (1998) compared a condition in which the participants were allowed to physically bite into a virtual candy bar in an immersive VR environment to one in which they merely had to imagine biting into a virtual candy bar instead (i.e., the candy bar was only presented visually in VR). The former condition gave rise to a significantly higher sense of presence when compared to performance in the latter condition.

[7] In fact, in 2015, an exhibition at the Tate Museum in London, called Tate Sensorium, had a couple of the paintings from the collection carefully paired with digitally-delivered fragrance (Davis, 2015; Obrist, Gatti, Maggioni, Vi, & Velasco, 2017; Spence, 2017b).

[8] The suggestion here is that the addition of a scent collar to standard VR equipment (e.g., goggles offering a stereoscopic view, headphones providing binaural sounds, and movement sensors) could potentially help to create a more immersive multisensory environment in which soldiers can be prepared for the kinds of situations that they may subsequently encounter in a war zone. The sweet smell of decaying corpses….or the smell of a cigarette giving away the presence of an enemy combatant. (Text adapted from Vlahos, 2006).

excuse the pun), others have considered introducing olfactory cues in order to help enhance the efficacy of tele-surgery (e.g., Keller, Kouzes, Kangas, & Hashem, 1995). Such examples, then, hint at the range of potential usage cases for the introduction of scent to various digital situations.

Although never a commercial success, one of the first attempts to introduce scent was in Heilig's (1962) *Sensorama* simulator (see **Figure 1**). As Heilig described it at the time: *"The present invention, generally, relates to simulator apparatus, and more particularly, to apparatus to stimulate the senses of an individual to simulate an actual experience realistically."* This device consisted of a machine in which the user was presented with 3D images, smells, stereo sound, wind, and vibrations. One of the few films made especially for Sensorama involved the experience of riding a motorcycle through Brooklyn. The sense of presence was enhanced by blowing wind through the user's hair, by presenting the sounds and importantly, the smells of the city, and by simulating bumps in the road by means of a vibrating chair. Olfactory stimulation was also introduced into early cinema, with Smell-o-vision, though with little success (e.g., Gilbert, 2008; see also discussion below).

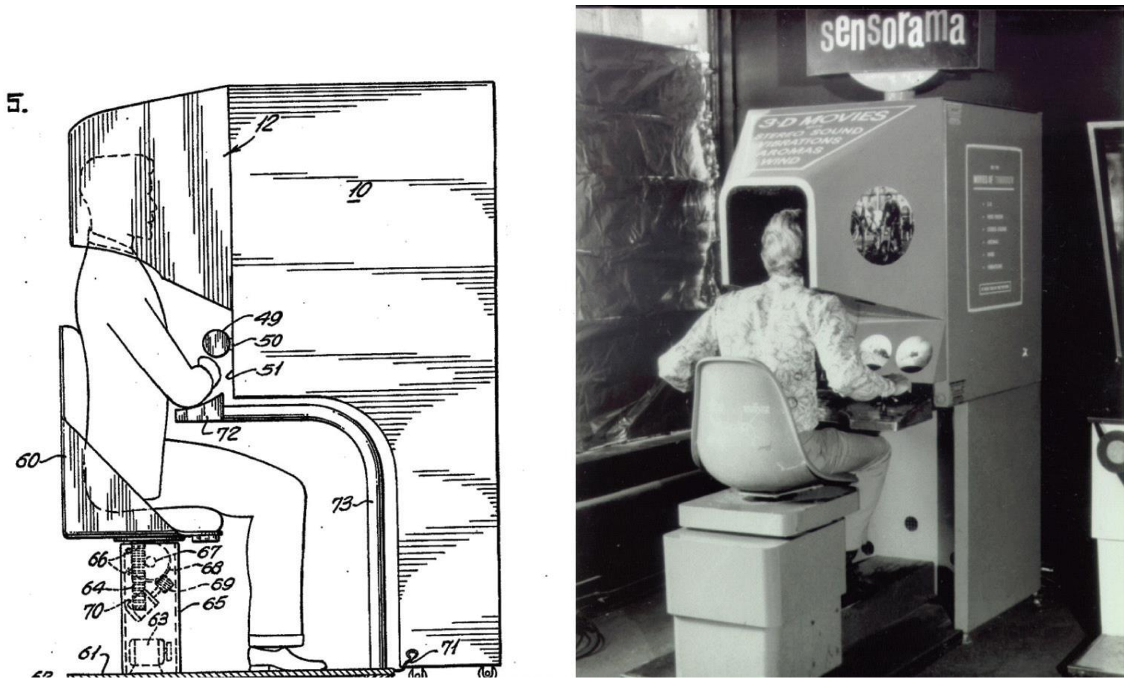

Figure 1. Sketch (on the left) and picture (on the right) of the Sensorama Simulator patented by M. L. Heilig (1962). This invention is widely credited as being the first simulator designed to stimulate multiple senses. [Figure reproduced from Heilig (1962, Figure 5), Patent 3,050,870.]

While the technological solutions available to digitize the delivery of the chemical senses have certainly come a long way over the last half century or so, it is fair to say that ambient fragrance still isn't widespread in our everyday digital multimedia experiences (Kaye, 2004).

There are three main reasons for this: 1) Technological limitations such as using chemicals in an interactive system is not practical as it requires complicated storing, mixing, and delivery mechanisms (cf. Anon., 2001); 2) Physiological drawbacks such as the adaptation of the sense of smell over time, and over-exposure to smells causing symptoms similar to dizziness, nausea, and even allergic reactions (Wilkie, 1995); and 3) Even if the technical and physiological limitations could be overcome,- there is still the fundamental attribution error to contend with. The latter term refers to the fact that even though it has now been demonstrated that stimulation of the chemical senses enhances people's experience across a range of situations, the latter will typically attribute their experience (e.g., pleasure) to one of the other senses (often vision, given our status as primarily visually-dominant creatures). As such, it is unlikely that they will be willing to pay for the refill, or invest in, olfactory-enabling technology. Until someone finds a way of overcoming this problem, it seems unlikely that digital olfaction will gain much traction in the marketplace.

Why digitize the chemical senses?

It is at this point in the discussion that it is important to distinguish between two routes to the 'digital' stimulation of the chemical senses: 1) Chemical stimulation (substances) can be released under computerized/digital control; and 2) The taste buds can be stimulated electrically and thermally without any need for chemical stimuli. Notably, whilst the latter might be interesting, it has proved to be extremely difficult to deliver without the aid of additional sensory inputs. Indeed, one of the limitations of the available digital taste interfaces is that participants tend to experience mostly sour or metallic sensations from electric stimulation (Ranasinghe, Cheok, Nakatsu, & Do, 2013; Stillman, Morton, Hay, Ahmad, & Goldsmith, 2003) and the other tastes (bitter, salty, sweet, and umami), which can also be elicited by means of thermal inputs, are not experienced by all people (e.g., Bajec & Pickering, 2008). Nevertheless, from the perspective of HCI, both routes might be used to transmit olfactory and gustatory sensory stimuli over the Internet. Over the years, researchers have put forward a number of reasons / case studies for why the digitization of the chemical senses via one of these two routes might prove beneficial / advantageous. These include research explorations as illustrated by the following nine cases:

1) For purposes of 'data ediblization' (e.g., Wang, Luo, Ma, & Qu, 2016; see also Jaschko & Stefaner, 2014a b; http://taste-of-data.tumblr.com/). Relevant here, the sonification of data has achieved some notable successes over the last couple of decades or so (e.g., Ballas, 1994; Fitch & Kramer, 1994; Jamieson, 2016; Kramer, Walker, Bonebright, Cook, Flowers, Miner, *et al.*, 1999). It is natural, therefore, to consider whether making data edible might also convey some benefit, at least under certain conditions (cf. Roberts & Walker, 2010; Roberts, Ritsos, Badam, Brodbeck, Kennedy, & Elmqvist, 2014). A little over a decade ago, Washburn and Jones (2004) queried whether olfactory cues could potentially be introduced in order to help in data visualization. However, given the very limited bandwidth of the chemical senses (see **Table 1**), it is our view is that this approach, while undoubtedly fun /

engaging for the user, is unlikely to deliver any real benefits in terms of enhanced data transmission (or interpretation).

An additional limitation to worry about currently is the fact that most digital olfactory displays are limited to a very small range of possible olfactory stimuli (see Ischer et al., 2014; Nakamoto, Otaguro, Kinoshita, Nagahama, Ohinishi, & Ishida, 2008; see the "**What are the limitations?"** section, for further discussion of this point).[9] And, as if that were not enough, individual differences in perception, both of stimulus quality and intensity would seem to be more pronounced in the chemical senses than for the other, higher, senses (see Reed & Knaapila, 2010; Spence, 2017a). As such one might always worry whether edible data was being perceived correctly.

Sensory system	N. of sensors	N. of afferents	Channel capacity (bits/s)	Psychophysical channel capacity (bits/s)	% Attentional capture	% Neocortex
Vision	$2*10^8$	$2*10^6$	10^7	40	70%	55%
Audition	$3*10^4$	$2*10^4$	10^5	30	20%	3.4%
Touch	10^7	10^6	10^6	5	4%	11.5%
Taste	$3*10^7$	10^3	10^3	1(?)	1%	0.5%
Smell	$7*10^7$	10^5	10^5	1(?)	5%	n.a.

Table 1. Table summarizing the number of sensors, number of afferents, information transmission rates/channel capacity (from Zimmerman, 1989), % of attentional capture (from Heilig, 1992), and % of neocortex (Felleman & van Essen, 1991) relative to each sensory modality. [Table reprinted from Gallace et al. (2012).]

2) As has come up already, a second popular suggested usage involves adding olfactory stimulation in order to enhance the sense of immersion / engagement in AR/VR applications (e.g., Heilig, 1962; Kapralos, Collins, & Uribe-Quevedo, 2017; Ranasinghe, Lee, Suthokumar, & Do, 2014). There is also interest from the gaming community in the possibilities around adding scent (e.g., Ikeda, 2017). However, here it is worth noting that the latest research suggests that bad smells may do a better job in this regard than pleasant odours (Baus & Bouchard, 2016).[10] In particular, Baus and Bouchard recently investigated the impact of pleasant (apple pie/cinnamon) and unpleasant aromas (urine) in a simulated VR kitchen scenario. Their results showed that only the unpleasant aroma of urine increased ratings of the sense of presence in this between-participants study. There is, of course, still

[9] It is important to mention that the key difference between digitizing olfaction and digitizing colour printing, say, is that while a small number of primaries can be used to render a very wide range of colours, researchers still have little idea how to combine a range of base olfactants in order to generate a wide range of aromas (see also Gallace et al., 2012; Ischer et al., 2014; Yanagida, Kawato, Noma, & Tetsutani, 2004).

[10] Note here that we appear to respond in qualitatively different ways to pleasant and unpleasant aromas (cf. Ehrlichman & Halpern, 1988). People have been reported to respond more rapidly to unpleasant odours (Boesveldt, Frasnelli, Gordon, & Lündstrom, 2010), and never adapt to unpleasant odours in the way that they do to neutral or pleasant scents (Dalton, 1996).

the question of whether people would willingly pay to be exposed to such unpleasant scents (Nosulus Rift should provide one answer to this question; see Natividad, 2016; http://nosulusrift.ubisoft.com/?lang=en-GB)! And, as might have been expected, the porn industry is also interested in harnessing the technology (Cole, 2016).

3) Another example uses olfaction to more directly target the more ‘emotional’ senses and/or trigger a specific mood, emotion, and/or perhaps memory (e.g., Phillips & Cupchik, 2004; Rumbelow, 1998; Spence, 2002; Spence & Youssef, 2015; Trebolazabala & Atxa, 2012). Relevant here, a number of practitioners are becoming increasingly interested in the use of scent to trigger feelings such as nostalgia (see Spence, 2017a, for a review). Neuroscientists point to the fact that smell, taste, and memory are closely interconnected in the human brain, hence making these chemical senses a potentially more effective route to triggering moods and memories than the other senses.

In a related vein, Braun, Pradana, Buchanan, Cheok, Velasco, Spence, *et al.* (2016) examined the potential beneficial effects of augmenting visual stimuli (e.g., pictures, specifically, digital images) with a matching scent. The expected benefits here might be in terms of the increased memorability, or emotional engagement with the subject matter of the image (see also Brewster, McGookin, & Miller, 2006; Geneva Emotion Research Group, http://www.unige.ch/cisa/gerg.html). One could also imagine how food images might be enhanced by the addition of matching, or augmented, food scents (Braun et al., 2016; Gallace, Risso, Covarrubius, & Bordegoni, 2016). Once again, though, the limited range of scents that can be delivered by plug-in digital smell delivery devices currently certainly limits the practicality of this outcome.

4) To provide a primary reinforcer (e.g., O’Doherty, Deichmann, Critchley, & Dolan, 2002). After all, there is little more primary as a reinforcer than the energy that is normally signalled by a sweet–tasting food. Thus, one could imagine the delivery of a sweet digital taste on completing a level in a game (Marks, 2013) or in one’s online homework assignment, say. However, the worry here is that the user’s brain will soon learn that few of the positive consequences that are normally associated with the ingestion of sweetness are occurring. As such, the stimulus, while clearly still identified as ‘sweet’, say, may soon lose some of its positive valence (and motivational power).

5) Interest has also been expressed in using the chemical senses as a modality/channel of communication (e.g., Bodnar, Corbett, & Nekrasovski, 2004; Duell, 2014; Ranasinghe, Cheok, & Nakatsu, 2012; Ranasinghe, Karunanayaka, Cheok, Fernando, Nii, & Gopalakrishnakone, 2011; Warnock, McGee-Lennon, & Brewster, 2013; Wei, Ma, & Zhao, 2014; see also Grimes & Harper, 2008). Once again, though, ambient scent would seem more appropriate as a means of <u>augmenting</u>, rather than necessarily of <u>replacing</u>, the other senses in this regard.

6) Given the limited range of olfactory stimuli currently available in most digital-scent delivery systems (i.e., digital control of chemical stimuli, presented in liquid, powder, or gel form), other uses for the digitized delivery of smell (where that limitation isn’t such a

problem), include scent-enabled mobile phones – where here one could imagine delivering a dose of one's partners perfume, say, whenever they called (Gray, 2007; though see Twilley, 2016, - see 5) above). The plug-in Oscar Meyer scent-enabled multisensory alarm clock app represents another entertaining usage case (see Griner, 2014). However, here the emphasis would seem to be very much on short-term marketing interventions rather than necessarily a serious long-term solution to waking-up in the morning – especially given research documenting that we are insensitive to olfactory stimuli when we are asleep (e.g., see Carskadon & Herz, 2004). Though that said, there are other companies out there who are thinking about scent delivery across the sleep cycle (Chang, 2017). However, in this as in many other situations, a case may need to be made for why a digitally-controlled solution is better than, say laundry powder that has the same scent and is used whenever you wash the bed sheets. (In the absence of a clear benefit from the digital solution, perhaps people will always tend to default to the low-tech solution?)

7) We presume that one might also consider the digital stimulation of the chemical senses in the context of sensory substitution. The promise from those working in this field is that such technologies may one day assist those with sensory disabilities (deaf, blind and in particular, people with deaf-blindness – who only have the senses of touch, taste, and smell to interact with the outside world) and so improve their quality of life. That said, Spence (2014) has highlighted a number of challenges associated with trying to substitute hedonic information (see also Elli, Benetti, & Collignon, 2014).

8) There has been some recent interest from plug-in fragrance delivery systems, such as the Ode designed to help older individuals, who might otherwise forget to eat, to maintain an independent home existence for a little longer before transitioning into long-term care (Franklin-Wallis, 2015). The plug-in home-use digital olfactory delivery device was designed specifically to remind whoever smells its olfactory emission to eat via the delivery of appetizing and familiar fragrances at different times of day. Note here how it is the pulsed delivery of the scent that is key to the success of this digital scent solution.[11] Of course, in the background, there is a concern that the savvy marketer might use such technological means of scent delivery to trigger an increase in people's appetite (Zoon, de Graaf, & Boesveldt, 2016; see Spence, 2015b, for a review).

9) One final use for ambient digital olfactory displays comes from driving (Dmitrenko, Vi, & Obrist, 2016; Funato, Yoshikawa, Kawasumi, Yamamoto, Yamada, & Yanagida, 2009). A number of the car companies have been considering releasing different scents inside the car to either match or modulate the driver's mood, or else to complement the scenery, and hence provide a more enjoyable multisensory driving experience (e.g., Baron & Kalsher, 1998; Bordegoni, Carulli, & Shi, 2016; Ho & Spence, 2013; Yoshida, Kato, Kakamu, Kawasumi, Yamasaki, Yamamoto, et al., 2011). In 2014, Mercedes was one of the first car companies to introduce such an olfactory display into certain models (Clark, 2013). However, it is

[11] Delivering pulsed fragrance digitally has the advantage of potentially being more effective than the continuous delivery of fragrance (Ho & Spence, 2005; Warm, Dember, & Parasuraman, 1991); Both in terms of the amount of fragrance that is needed and, more importantly, as mentioned already, the evidence suggests that we adapt to constant aromas (see Spence, 2002).

important to remember that olfaction is not a medium to deliver time critical information as the sense of smell in humans is considered as one of the slow responsive senses (see Bounds, 1996; Ho & Spence, 2008; Spence & Squire, 2003). That said, there might be some role for modulating a driver's alertness (Gould & Martin, 2001; Ho & Spence, 2005).

In summary, there are no shortage of potential uses should the chemical senses be successfully digitized; the wide spectrum of application areas range from education through entertainment, from enhancing everyday well-being, health, and performance through to uses in military simulation. There is even talk of electronic wearable fragrance delivery systems (Choi, 2015; Yamada, Yokoyama, Tanikawa, Hirota, & Hirose, 2006), and, of course, their widespread potential use in the world of sensory marketing (Martins, Gonçalves, Branco, Barbosa, Melo, & Bessa, 2017; Petit, Cheok, Spence, Velasco, & Karunanayaka, 2015). The question then becomes one of how to stimulate the chemical senses, and what the pitfalls might be.

How to digitize the chemical senses?

In this section, we will take a look at pure digital approaches to stimulating the chemical senses, starting with taste, then trigeminal, and finally olfactory. In recent years, progress has been made in terms of delivering electric taste sensations in a practical and increasingly well-designed manner (e.g., Murer, Aslan, Tscheligi, 2013; Ranasinghe & Do, 2016a; Ranasinghe, Nakatsu, Hideaki, & Gopalakrishnakone, 2012; Ranasinghe, Suthokumar, Lee, & Do, 2014) (see **Figure 2**). This contrasts, then, with the much more modest advance in the world of purely digital smell simulation technologies. One reason for this difference relates to the fact that it is simply much easier to access the taste buds on the human tongue than it is to get to the olfactory receptors situated high-up inside the nose.

There has actually been a long history of delivering taste sensation by directly electrically[12] stimulating the taste buds on the human tongue (e.g., see Bujas, Szabo, Kovacic, & Rohacek, 1974; Cardello, 1981; Lawless, Stevens, Chapman, & Kurtz, 2005; Plattig & Innitzer, 1976; von Bekesy, 1964, 1965, for early work).[13] However, it is important to remember that some taste sensations (like sour and salty) are simply much easier to elicit than others (Plattig & Innitzer, 1976; Ranasinghe & Do, 2016a). What is more, some people are more sensitive to

[12] Based on the idea that thermal changes on the tongue may elicit a sweet taste sensation and/or influence taste perception (Cruz & Green, 2000), there have also been attempts to digitize taste sensations via thermal stimulation of the tongue (Ranasinghe & Do, 2016b). Whilst it is not clear whether such thermal stimulation can, by itself, give rise to the perception of sweetness, it may at least be combined with chemically-based stimulation devices to modulate taste experiences. Future research on this topic will need to consider what has been described as "thermal taster status". This refers to individual differences associated with the perception of sweetness on the basis of thermal stimulation of the tongue (e.g., Bajec & Pickering, 2008).

[13] Much earlier still, Sulzer (1754), and thereafter Volta (1792), demonstrated that the induction of an electric current, by placing two different connected metals (or metal coins) on the tongue, could elicit a metallic or acidic taste (see Bujas, 1971, for a review). What is more, electro-gustometry, which refers to the assessment of taste sensitivity by applying an electrical current to the tongue, has been used in a clinical context for several decades now (e.g., Krarup, 1958). Generally-speaking, such electrical stimulation mostly results in participants experiencing just sour or metallic sensations from stimulation (Stillman et al., 2003).

electrical stimulation of their taste-buds than others (Jauhiainen, Allas, & Helsinki, 1967). Both of these factors, then, limit the widespread potential use of electric taste solutions. In fact, we would argue that it is perhaps easier to see it working in a conference demo than as a mass-market product, one might think.

Figure 2. *Left:* Digital Taste Interface: A method for simulating the sense of taste by actuating the human tongue through electrical and thermal stimulation (Ranasinghe, Karunanayaka, Cheok, Fernando, Nii, & Gopalakrishnakone, 2011). *Right:* AromaShooter, a smell-delivery device, contains six scent cartridges and connects to a computer via USB. (Developed by Aromajoin)

There is also work demonstrating that some aspects of trigeminal stimulation can be elicited using electrical stimulation (Iannilli, DelGratta, Gerber, Romani, & Hummel, 2008). However, as soon as it comes to smell, things soon become much more complicated. Especially relevant here, Weissl, Shushan, Ravia, Hahamy, Secundo, Weissbrod, *et al.* (2016), recently reported on the results of tests that they conducted on more than 1000 individuals in which electrical stimulation of the olfactory receptors gave rise to neural activation in olfactory-related brain areas, but never in the presence of electrically-generated olfactory percepts (this despite pronouncements to the contrary by some in the research community.) Here, it is important to note that while olfaction and gustation are both chemical senses, the neural transduction and coding mechanisms used by the two senses differ fundamentally. While individual receptor types code for each of the basic tastes (each taste papilla contains taste buds sensitive to each of the five basic tastes), olfactory perception relies on the stimulation of a whole array of different receptors – it is what Gordon Shepherd describes in his 2012 book *Neurogastronomy* (see Shepherd, 2006, 2012) as *'a pointillist system'*.

Most of those who have chosen to put a percentage on it would seem to believe that somewhere in the region of 75-95% of what we think we taste really reflects information delivered by the sense of smell (see Spence, 2015a, for a review). Consequently, it is the digitization of the latter that is likely going to provide a much richer range of sensory input. In fact, it is striking to note how little of a loss of flavour sensation many people report when they have lost taste sensation (see Brillat-Savarin, 1835; Pfaffmann & Bartoshuk, 1990;

though see also NPR, 2011). By contrast, we are all familiar with how food doesn't seem to taste of anything much whenever we have a cold that blocks our nose (see also O'Hare, 2005). It is important to bear such figures in mind when thinking about recent augmentation devices that some have been tempted to claim can transmit lemonade over the internet (see Lant & Norman, 2017; Ranasinghe, Jain, Karwita, & Do, 2017). Note that while this is an ingenious solution,[14] transmitting both a sour sensation electrically (via two electric strips on the rim of the tumbler), together with the appropriate colour (green, yellow, or cloudy in this case) via an LED embedded in the tumbler in which the drink is served (see **Figure 3**), no attempt was made to simulate, or actually deliver, the aroma of lemon. Change the colour of the light shining into the glass (to brown, say) and you could as well be transmitting malt vinegar instead. What differentiates these sour-tasting liquids, then, is largely the aroma (see Spence, 2015a). Without the delivery of the latter, the experience is likely to resemble drinking sour water more than anything else.

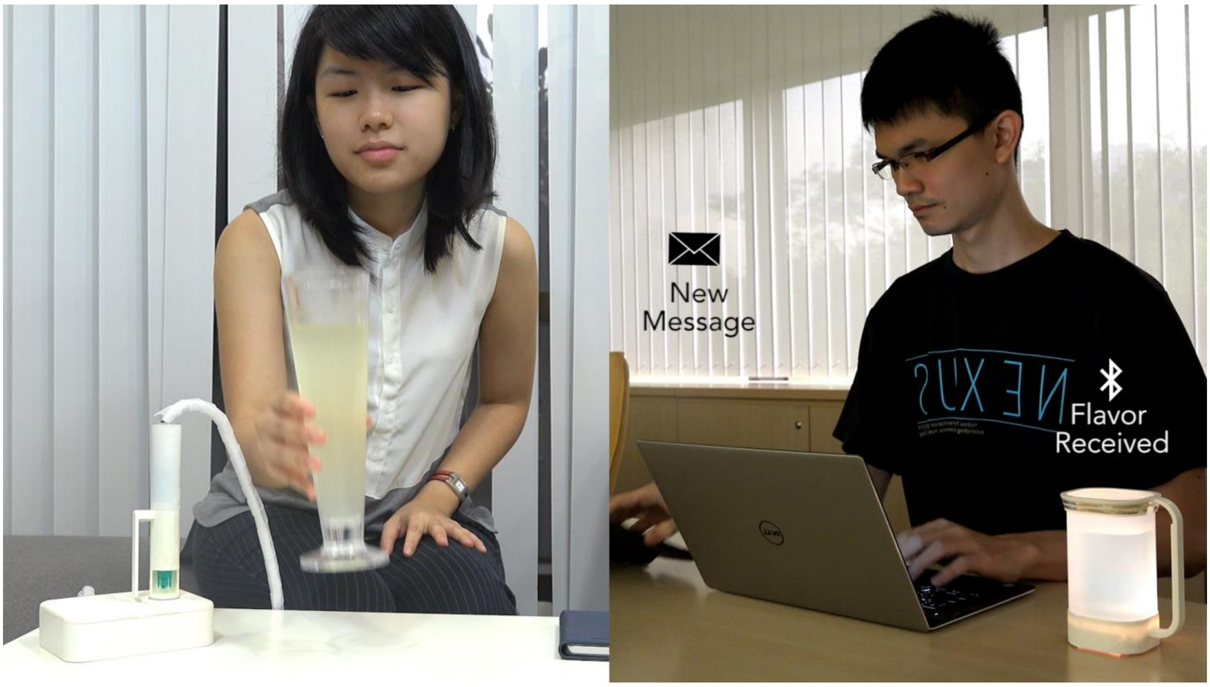

Figure 3. In the future, will we able to send others some virtual lemonade? Still image from Ranasinghe et al. (2017). Reprinted with permission.

So, given the difficulty of transmitting a range of aromas digitally, in the foreseeable future, the best solution may be to augment the taste of real food with cutlery or glassware that is

[14] And would, one imagines, be readily appreciated by all those people out there regularly uploading their gastroporn images onto their social media (Spence et al., 2016). How much better if one could actually share in the tasting experience of a drink rather than merely having to imagine it (O'Hara, Helmes, Sellen, Harper, ten Bhömer, & van den Hoven, 2012))! It is, though unclear how the chefs and cocktail makers would respond to this potential infringement of their culinary creative copyright.

capable of stimulating the taste buds directly (e.g., Bolton, 2015; Nakamura & Miyashita, 2011, 2013a, b; Ohla, Toepel, le Coutre, & Hudry, 2012; Sakurai, Aoyama, Miyamoto, Mizukami, Furukawa, Maeda, & Ando, 2016a; Sakurai, Aoyama, Mizukami, Maeda, & Ando, 2016b). That way, the real aromas, and flavours, of foods can be enhanced by digital (i.e., electrical) tastes. And while this fails, in some sense, to remotely transmit flavours (i.e., in terms of sending digital lemonade), it could one day potentially help to deliver health benefits by reducing unhealthy ingredients (think salt and possibly sugar) by delivering them digitally.[15] So perhaps the more appropriate analogy here would be *digital seasoning* rather than *digital flavour transmission*.

Digitizing detection: Electrical tongues and noses

Another important aspect to consider when digitizing the chemical senses is the sensing/detection of those sensations – mainly the smell and taste. Several sophisticated electronic nose and electronic tongue systems have been developed in recent years to analyze and sense the chemical composition of various foods, such as wine and tea, as well as for the detection of cancer (e.g., Davide, Holmberg, & Lundström, 2001; Westenbrink, Arasaradnam, O'Connell, Bailey, Nwokolo, Bardhan, & Covington, 2015; Legin, Rudnitskaya, Vlasov, Di Natale, Davide, & D'Amico, 1997). Most of these smell and taste sensors are developed with multichannel electrodes using lipid membranes and conductive polymers as transducers of smell and taste substances (volatile and sapid stimuli, respectively). Similar to the human olfactory and gustatory systems themselves, these sensors identify smell and taste sensations based on the recognition of the response patterns of electric signals that transform information about the available substances in a given sample (Toko, 2000). However, it is important to stress what a profound distinction there is between digitally 'sensing' the sugar content of a liquid, say, and predicting how sweet a flavourful solution will be perceived as being by a consumer (cf. Fuller, 2014). It is worth noting here that aromas such as caramel, vanilla, and strawberry are described as sweet (see Stevenson & Boakes, 2004), and adding such 'sweet-smelling' fragrances can change perceived sweetness of food and beverage items (see Piqueras-Fiszman & Spence, 2016).

What are the limitations?

It is at this point that it becomes crucial to highlight some of the key challenges, a number of which have cropped up already, in order to avoid the pitfalls that have beset a number of many previous attempts to digitize the chemical senses.

[15] Ranasinghe also foresees potential healthcare applications for his device. *"People with diabetes might be able to use the taste synthesiser to simulate sweet sensations without harming their actual blood sugar levels. Cancer patients could use it to improve or regenerate a diminished sense of taste during chemotherapy."* (quoted in Marks, 2013).

Attentional limitations

It is important to note that human observers/operators have only a limited pool of attentional resources with which to process incoming information (see Gallace et al., 2012; Spence & Driver, 1997, for reviews). As such, as technology – think the digitized delivery of the chemical senses – offers more potential channels of stimulation/communication then the increased requirements to monitor / attend to more senses is likely to impair performance, over both the short and longer term (e.g., Ashkenazi & Marks, 2004; Spence, Kettenmann, Kobal, & McGlone, 2000, 2001). Relevant here is research suggesting that people may simply neglect (that is fail to attend to) ambient olfactory and gustatory stimulation if they happen to be performing an attention-demanding visual task at the same time, say (see Sela & Sobel, 2010, for an overview). There is also evidence to suggest that perceptual load impacts the processing of gustatory stimuli (see Van der Wal & van Dillen, 2013), meaning that the more attention we pay to what we are looking at / listening to, the less attention we pay to whatever we are tasting.

It is important to note that just because people may not be able to consciously report on the presence of aroma it doesn't necessarily mean that it can't still affect their perception/performance in the other senses, providing the scent is presented at a level that is suitably close to threshold (see Li, Moallem, Paller, & Gottfried, 2007). It is, though, obviously going to be much harder to convince the consumer to buy the refill if they didn't realize that they had smelled, or tasted anything in the first place (see Baus & Bouchard, 2016, for one recent example of surprisingly low olfactory detection rates when introduced in a VR kitchen setting; see also Gagnon, Kupers, & Ptito, 2014). (This links back to the fundamental misattribution error.) Such challenges are presumably linked to the very limited channel/attentional capacity of the olfactory and gustatory senses, as compared to the three spatial senses of vision, audition, and touch (see **Table 1**).

Perceptual challenges: Perceived synthetic versus perceived natural

One important point to draw out here is that people's perception of odours, but also foods, depends on their belief about the natural versus synthetic nature of their origins. Of course, all aromas are constituted of chemicals; However, that doesn't necessarily mean that the public won't reject a particular scent, or flavour, as smelling unpleasant if, say, they believe that it has a chemical/synthetic/unnatural origin. The point here is that digitized tasting experiences are likely to fall directly into this space (priming notions of artificiality), and so may well prompt negative response from the customer/user (Spence, 2016b). This natural/artificial distinction (Classen, Howes, & Synnott, 2005) seems to be much more salient in the case of the chemical senses, presumably because they, unlike audition, vision, and touch, end up entering the body itself. What is more, many of the previous attempts to augment the experience of food or drink via scent-enhanced cutlery have not succeeded in the way anticipated (see Molecule-R, http://moleculargastronomy.com/molecular-shop/volatile-flavoring.html; see also Spence, 2016b, for a review), in part, because of the use of cheap synthetic scents to make augmented solutions to aroma delivery cheap enough (e.g., see Sebag-Montefiore, 2015).[16]

That said, in the right (marketer's) hands, the unusual nature of the sensations so delivered by digital stimulation of the chemical senses could perhaps be turned into a Unique Selling Point (USP), given consumer interest in new and unusual taste sensations (e.g., Beaugé, 2012; Fitzsimmons, 2003; Haden, 2005; MacClancy, 1992).[17] One other point to note here is that the synthetic/natural distinction may turn out to be more important in the food context than, say, than in the computerized context of augmented VR.

Technical challenges with scent delivery and clearance

Now, even if one were to have an effective means of digitally delivering scents, there are still a couple more problems remaining. One concerns the question of how to display/distribute the scent so that it arrives at the appropriate time (Ramic-Brkic & Chalmers, 2010). Then there is the problem of clearing out one scent (e.g., from a cinema) before the next one arrives, this one of the problems (of lingering scents) that resulted in the failure of early 4D cinematic experiences (see Gilbert, 2008, for an entertaining review of the early history of scent in the cinema).[18]

Modifying taste/flavour using digital stimulation of the other senses

Ultimately, given the limitations associated with digitally stimulating the chemical senses directly, one other solution that is worth considering here is to modify people's experience of actual food/beverage stimuli by more appropriately stimulating the other (more dominant) senses (one can think of this as a kind of mixed, or augmented, reality solution). So, for example, Zampini and Spence (2004) demonstrated that they could modify people's impression of the freshness and crispness of potato chips simply by modifying people's self-produced mastication sounds in real time (see also Demattè, Pojer, Endrizzi, Corollaro, Betta, Aprea, et al., 2014). Auditory cues are important to a wide range of tasting experiences – contributing to our enjoyment of crispy, crackly, crunchy, carbonated, squeaky, and even creamy foods (see Spence, 2015c, for a review). So why not use these 'dominant' senses to modulate digitally the tasting experience is some kind of mixed reality implementation.

[16] It would be interesting to know whether there may be any cross-cultural differences here.

[17] According to Fitzsimmons (2003): "*The snack food of the future could rely more on sensations in the mouth than flavour or texture. Food companies are experimenting with 'sensates'… to make your mouth tingle, warm, cool, salivate, or tighten… the next step is to manipulate the sensates to change the length of intensity of the sensation*."

[18] This challenge has gained new momentum, though, with Weiss and colleagues' proposed "olfactory white" (in some sense akin to 'white noise' in audition; Weiss, Snitz, Yablonka, Khan, Gafsou, Schneidman, & Sobel, 2012). Olfactory white has the potential to help research in the same manner as its auditory and visual counterparts (perhaps acting as a reset for the sensory system), and hence may make it an interesting anchor point for designers of human-computer interfaces involving olfaction.

Relevant here in terms of digital solutions to modifying our experience of the chemical senses, Iijima and Koike (2013) reported on their attempts to modify the mouthfeel of foods by means of cross-modal effect using mastication sounds and visual information associated with the foods. Meanwhile, Koizumi, Tanaka, Uema, and Inami (2011) came out with their own ‘chewing jockey’. This device measured the clenching of the jaw, and playing back a range of sounds in synchrony – everything from hearing the sound of screaming whenever you bite into a jelly baby through to hearing the sound of breaking glass that would apparently freeze people’s jaws mid-bite (see also Masuda, Yamaguchi, Arai, & Okajima, 2008). Hashimoto et al. (2007, 2008) developed a wonderful straw-like user interface. Users of this device were encouraged to choose a place mat displaying a dish of their choice; Then, they placed a straw over the mat and sucked through the straw. The device then delivered the appropriate sounds and vibrations congruent with the chosen, mashed, food being sucked through the straw. Others, meanwhile, with more of a health focus, have recently started to investigate the potential of synchronizing mastication sounds with the closing of the jaw for those of advanced age who may no longer be able to chew harder foods, and for whom an endless diet of liquidized/pulped foods may be less than appealing (Endo, Ino, & Fujisaki, 2016).

Then, of course, there is a lot of work looking at modifying the visual appearance of food and drink (e.g., Narumi, Kajinami, Tanikawa, & Hirose, 2010; Nishizawa, Jiang, & Okajima, 2016; Okajima & Spence, 2011). Once again, this kind of approach makes perfect sense in light of claims that we eat first with our eyes (see Spence, Okajima, Cheok, Petit, & Michel, 2016, for a review). There is, after all, an extensive literature on how changing the colour can change taste/flavour of a variety of foods and drink products (see Spence, 2015d, for a review). This extends from projecting over (or into) drinks to changing colour, recent work in projection mapping to change the apparent colour of solid textured foods, then augmented reality with people wearing a headrest, and hyper-realistic textures appearing superimposed over food (Okajima & Spence, 2011). (Note though that under such mixed/augmented solutions, there is no digital delivery of flavours, *per se*, rather there is a digital modification of the tasting experience.)

There is growing interest in augmented/mixed reality solutions in this space (e.g., Narumi, Nishizaka, Kajinami, Tanikawa, & Hirose, 2011). For instance, Narumi *et al.* developed a pseudo-gustatory display that gave a drink a ‘virtual’ colour (via a wireless LED embedded in the bottom of a transparent plastic cup). The results could be taken to suggest that the perceived flavour of the drink in the mind of the user could be changed via the virtual change in the colour of the drink. Others, meanwhile, have built on the latest research findings emerging out of the crossmodal correspondences (see Spence, 2011, 2012) in order to project more abstract colour/shape/music combinations over a food product (Huisman, Bruijnes, & Heylen, 2016). These researchers also found that they could digitally season the foods that people were tasting. The projection shown in **Figure 4** (together with the accompanying sound) brought out the sourness in a sample of yoghurt that they have been given to taste (see also Crisinel, Cosser, King, Jones, Petrie, & Spence, 2012; Reinoso Carvalho, Van Ee, Rychtarikova, Touhafi, Steenhaut, Persoone, et al., 2015, on the notion of digital sonic seasoning; and Sakurai, Narumi, Ban, Tanikawa, & Hirose, 2013, 2015, on the enhancement of tasting experiences by means of projection mapping).

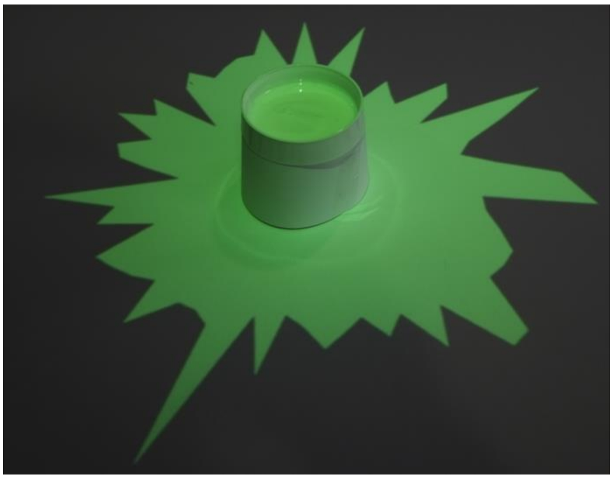

Figure 4. Digital seasoning from Huisman et al. (2016). Colour, shape, and sound are all used to prime notions of sourness, and by so doing modify people's perception of the sourness of the yoghurt that they are tasting. [Figure reprinted from Huisman et al. (2016) with permission.]

Elsewhere, Narumi, Ban, Kajinami, Tanikawa, and Hirose (2012) provided some preliminary evidence that they could modify the perception of satiety by changing apparent size of food using augmented reality (see also Schöning, Rogers, & Krüger, 2012; Suzuki, Narumi, Sakurai, Tanikawa, & Hirose, 2014). And we should also think of the growing body of literature on sonic seasoning – often reproducing music digitally in order to enhance the taste of the food in a systematic manner (Crisinel, Cosser, King, Jones, Petrie, & Spence, 2012; see Spence, 2017c, for a review).

Conclusions

As noted earlier (e.g., Kortum, 2008; Obrist, Velasco, Vi, Ranasinghe, Israr, Cheok, Spence, & Gopalakrishnakone, 2016), there has, to date at least, been little relatively interest in the digitization of the chemical senses (at least when compared to the digitization of the other senses). On the one hand, this likely reflects the not inconsiderable technical challenges associated with the effective digital stimulation of the chemical senses. However, it is also consistent with a more general neglect of the chemical (what are sometimes described as the 'lower') senses, that one finds in the fields of HCI, experimental psychology, and cognitive neuroscience (see Spence, 2017a, on this theme).

Nevertheless, the last few years have seen something of an explosion of interest in the digitization of the chemical senses, with various solutions to digitally delivering, or enhancing, taste, flavour, and aroma perception being discussed in the various academic outlets / conference proceedings, not to mention enthusiastically reported on by the press / popular science community. These solutions divide into pure digital stimulation solutions, and the digitally-controlled analogue delivery of chemical stimuli. The former is more promising in terms of dispensing with the need to buy the refill, but harder, if not impossible, to fully deliver technically, at least at the present time.

While important technical challenges no doubt still exist, the larger issue, at least from our joint perspective, is the limited information processing bandwidth of the chemical senses (see Gallace et al., 2012), not to mention the more fundamental uncertainty over whether users/consumers will value the digital stimulation of their chemical senses enough to want to 'buy the refill' (in the case where one is looking at the digital control of the delivery of an analogue, or chemical, signal). This, ultimately, is one of the problems that sank earlier attempts to offer digital olfactory stimulation (e.g., see Dusi, 2014; Platt, 1999). And even though scientists may be able to demonstrate the enhanced experience associated with, say, a digital olfactory plug-in (e.g., simulating the smell of fresh-cut grass) while watching the World Cup on TV (Ramic-Brkic, Chalmers, Boulanger, Patttanaik, & Covington, 2009), the real issue will be in convincing the consumer that their enhanced enjoyment resulted from the stimulation of their chemical senses rather than something else. There is always a tendency to attribute our enjoyment to the dominant senses of vision (and to a lesser extent audition; see Posner, Nissen, & Klein, 1976). As such, unless consumers can be correctly taught to assign the source of their enjoyment to the digital stimulation of their chemical senses, it is unlikely that digital olfactory solutions will make it much further than the demonstration tables at the tech conferences. This is the so-called *'fundamental attribution error'*.

Of course, perhaps the focus for development should not be so much on augmenting the experiences for those with their senses intact, but rather on catering to the section of the population who might be blind or partially-sighted, deaf or deaf-blind (going beyond current efforts for the sense of touch, cf. Hamilton-Fletcher, Obrist, Watten, Mengucci, & Ward, 2016; Wall & Brewster 2006), as this is the group who may appreciate the possibilities associated with the digital modulation of their residual chemical senses the most (see Keller, 1923, 1933). That said, it should be born in mind that sensory substation devices have never really made it out of the research laboratories, despite many enthusiastic pronouncements to the contrary (Elli et al., 2014; Spence, 2014).

What exactly does the future for digitization and the chemical senses hold, especially for the designers, developers, innovators working in the field of HCI? Can it be used to help us eat less unhealthy ingredients while, at the same time, feeling no less satisfied (see Booth, 2016)?[19] Will it contribute to the growing field of food-interaction design (e.g., Comber, Ganglbauer, Choi, Hoonhout, Rogers, O'Hara, & Maitland, 2012; Hupfield & Rodden, 2012) and its augmentation in VR (Narumi, 2016)? Can the digitization of the chemical senses be harnessed to help the growing aging population whose senses, not to mention teeth, may have

[19] Should ambient food-related olfactory cues become more widespread then we may need to start worrying about the dangers of olfactory digital marketing (see Spence, 2015b). However, we may never get there, as it can prove tricky to create realistic aromas for digital delivery.

started their inevitable decline – with many older individuals finding it difficult to chew food (e.g., Cuthbertson, 2015; Endo et al., 2016)? Or will ambient orthonasal olfactory cues find a place in enhancing entertainment, VR, educational, and training simulations?[20] One important consideration to bear in mind here is that sugar is often added as a bulking agent (i.e., not just for its taste), while salt is sometimes added (e.g., in bread) for its structural properties. Whatever it is, two clear questions will need to be answered first: First, does the customer want a solution that involves the digitization of the chemical senses, and second, how can you ensure that the benefits for us visually-dominant creatures are really perceived as being worth the price of the refill in the minds of the target audience? Ultimately, we will need to figure out a way of getting over the fundamental misattribution error associated with ascribing to the higher senses, the pleasures derived from the stimulation of the lower chemical senses. Perhaps, as a community, we should think less of digitizing the chemical senses, at least as far as flavour is concerned, and more about the development of digital seasoning. For example, imagine your eating utensils and drinking vessels such as a spoon, chopsticks, soup bowl, or beverage bottle enhance the taste, and possibly also the flavour, digitally (Ranasinghe, Lee, Suthokumar, & Do, 2016; https://www.youtube.com/watch?v=I0vqAyo0948).

In conclusion, the use of vision and audition for interaction has dominated the field of HCI for decades now, this despite the fact that nature has provided us with many more senses for perceiving and interacting with the world around us (Obrist, Gatti, Maggioni, Vi, & Velasco, 2017). HCI researchers have started trying to capitalize on touch, taste, and smell when designing interactive tasks, especially in gaming, multimedia, and art environments. While the fascination with the chemical senses is growing, especially to move them from an analogue to a digital design space, there are several potential pitfalls, challenges (both biological and technical), and limitations to consider. Yet, we are convinced that the time is ripe to push the limits of current interaction paradigms, following the inspiration by Donald A. Norman *"we should not try to avoid complexity, but rather tame complexity through good design"* (Norman 2010, p. 4; cited in Vermeulen, Luyten, van den Hoven, & Coninx, 2013).

[20] The all-new Nosulus Rift headset delivers aroma via a sleek black space-age headset; the only problem that it only emits a single unpleasant smell to go with a *South Park* video game called *The Fractured but Whole* (see http://nosulusrift.ubisoft.com/?lang=en-US#!/introduction).

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