RUNNING HEAD: AUDITORY CONTRIBUTIONS TO FOOD PERCEPTION & CONSUMER BEHAVIOUR

Extrinsic Auditory Contributions to Food Perception & Consumer Behaviour: An Interdisciplinary Review

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ABSTRACT

Food product-extrinsic sounds (i.e., those auditory stimuli that are not linked directly to a food or beverage product, or its packaging) have been shown to exert a significant influence over various aspects of food perception and consumer behaviour, often operating outside of conscious awareness. In this review, we summarise the latest evidence concerning the several ways in which what we hear can influence what we taste. According to one line of empirical research, background noise interferes with tasting, due to attentional distraction. A separate body of marketing-relevant research demonstrates that music can be used to bias consumers' food perception, judgments, and purchasing/consumption behaviour in various ways. Certain of these effects appear to be driven by the arousal elicited by loud music as well as the entrainment of people's behaviour to the musical beat. However, semantic priming effects linked to the type and style of music are also relevant. Another route by which music influences food perception comes from the observation that our liking/preference for the music that we happen to be listening to carries-over to influence our hedonic judgments of that which we are tasting. A final route by which hearing influences tasting relates to the emerging field of 'sonic seasoning'. A developing body of research now demonstrates that people often rate tasting experiences differently when listening to soundtracks that have been designed to be (or are chosen because they are) congruent with specific flavour experiences (e.g., when compared to when listening to other soundtracks, or else when tasting in silence). Taken together, such results lead to the growing realization that the crossmodal influences of music and noise on food perception and consumer behaviour may have some important if, as yet, unrecognized implications for public health.

KEYWORDS: AUDITORY; CHEMICAL SENSES; FOOD; NOISE; CROSSMODAL; MULTISENSORY; TASTE; FLAVOUR.

1. Introduction

What we hear affects what we taste, no matter whether we realise it or not (and the evidence suggests that mostly we do not, e.g., see North, Hargreaves, & McKendrick, 1997, 1999; Zellner, Geller, Lyons, Pyper, & Riaz, 2017). In fact, there is now an extensive body of literature highlighting the impact of the sounds that may be associated with food preparation (Wheeler, 1938; see Knöferle & Spence, in press, for a recent review), food packaging (i.e., being opened; Spence & Wang, 2015a, 2017a; see Wang & Spence, 2019, for a review), and food consumption (e.g., Youssef, Youssef, Juravle, & Spence, 2017; Zampini & Spence, 2004; see Spence, 2015a, for a review), on people's sensory-discriminative and hedonic ratings of a wide range of different food and drink products. Such product-intrinsic auditory contributions to food perception and consumer behaviour are undoubtedly important. However, the focus of the present review will be squarely on the effect of product-extrinsic sounds on what we taste, broadly construed.

In what is perhaps the earliest work in this area, Pettit (1958) had her participants taste and rate tomato juice, though no effect of modest levels of background noise was observed. However, despite such an inauspicious start some 70 years ago, research on the auditory contributions to food perception and consumer behaviour has exploded in recent years, thus necessitating an up-to-date review of the literature, as provided here. The topic has sparked interest in a diverse range of fields that include experimental psychology, cognitive neuroscience, design, music, marketing, gastronomy, branding, and beyond. Indeed, an extensive body of research published over the last half century or so has now convincingly demonstrated that the background sounds and music that happen to be playing in bars, restaurants, cafes, and stores bias what customers choose to purchase, order, and/or consume, not to mention what they think it tastes like, how much they enjoy – and would be willing to pay for – the experience (e.g., Biswas, Lund, & Szocs, 2019; Reinoso Carvalho, Dakduk, Wagemans, & Spence, submitted; see Spence, 2017a, for a review).

In the following sections, we review the evidence concerning four of the main ways in which what we hear, despite being seemingly unrelated to what we are tasting, can nevertheless still influence our perception of food and drink, as well as modifying various food-related consumer behaviours. We start by assessing the very general, and relatively stimulus non-specific, effects of background noise on tasting. Next, we assess the effects of background music on food perception and consumer behaviour. We review the effects of loud music on arousal, as well as briefly summarize the evidence showing that consumers' (food and beverage-related) behaviour is often entrained to the musical beat. In this section, we also look at those priming effects that appear to be associated with the type of music, as well as any other associations that may be primed musically in the mind of the consumer. Thereafter, we take a look at the phenomenon of 'sensation transference', sometimes referred to as 'affective ventriloquism' or the 'halo effect'. This is where our liking for whatever we are listening to carries over to influence our judgment of whatever we happen to be tasting. Finally, we review the rapidly evolving literature documenting the much more stimulus-specific effects of 'sonic seasoning' on multisensory tasting experiences.

While there have been a number of previous reviews summarizing various aspects of audition's interaction with/influence over tasting, and even a couple covering the same broad areas outlined here, it seems timely for an update given the sheer number of recently-published papers on the topic of sonic seasoning. This review also includes a recently unveiled model summarizing the way in which sonic seasoning might work, as well as providing a new analysis of experiment designs and effect sizes in this area of research.

Taken together, such crossmodal effects can be seen as particularly intriguing, given that the auditory stimuli concerned have no direct connection with food or drink (see Spence & Deroy, 2013a). In all such cases, the noise, music, or the especially composed soundscape, are extrinsic to the food products under consideration. This certainly contrasts with, e.g., the sound of a sizzling steak as it arrives at the table (Wheeler, 1938), the crunch of a celery stick in the mouth, or the pop of the Champagne cork as it leaves the bottle (see Spence, 2015a, for a review). At the outset, though, it is perhaps worth highlighting the fact that, while the four above-mentioned broad areas of research have remained relatively segregated in the academic literature over the decades, there are grounds for thinking that the distinctions between them may not always be as clear-cut as it at first may seem, especially at the boundaries. So, for example, think here only of how background music turns into 'noise' if played at a 'too loud' level. Similarly, one might also wonder whether the matching of types (or ethnicities) of music with types (or ethnicities) of cuisine (see Reinoso Carvalho, Van Ee, & Rychtarikova, 2016b, for evidence on this score) is not itself an example of a high-level crossmodal correspondence, one that is in some ways akin to the sonic seasoning we cover in a later section (see **Section 5**). We will address these uncertainties as they arise in the sections below.

2. Background noise and its impact on tasting

When what we hear becomes too loud, we usually frame it as 'noise', and the possibly detrimental effect of noise is perhaps the oldest concern of researchers working on the influence of sound on tasting (see Crocker, 1950; Pettit, 1958; Srinivisan, 1957, for early discussion and research). It is also perhaps the most nonspecific of product-extrinsic auditory stimuli in terms of its impact on food perception. While complaints about noise in restaurants and bars would appear to have been on the rise in the west in recent years (e.g., Belluz, 2018; Moir, 2015; see Spence, 2014a, for a review), it is worth noting that researchers have actually been commenting on overly loud restaurants for many decades now (see Pettit, 1958, for an early example). The research that has been published to date shows that loud background noise, regardless of whether it is airplane noise, white noise, or even the background noise of a restaurant, or bar, affects both the perceived taste of food and drink, as well as people's ability to discriminate various aspects of their tasting experience (Rahne, Köppke, Nehring, Plontke, & Fischer, 2018; Trautmann, Meier-Dinkel, Gertheiss, & Mörlein, 2017; see Spence, 2014a, for a review).

At around the same time as Pettit (1958) published her seminal early research, other commentators were suggesting that loud background noise distracted from tasting and/or interfered with the tasting experience (see Crocker, 1950; Peynaud, 1987).[1] Crucially, a series of empirical studies conducted over the last decade have illustrated the interfering effect of loud background noise on both tasting and smelling. For example, using a range of everyday

[1] Emile Peynaud, a famous French oenologist, hinted at the distracting effect of noise when he stated that: *"The sense of hearing can interfere with the other senses during tasting and quiet has always been considered necessary for a taster's concentration. Without insisting on absolute silence, difficult to obtain within a group in any case, one should avoid too high a level of background noise as well as occasional noises which can divert the taster's attention."* (Peynaud, 1987, p. 104).

foods, Woods, Poliakoff, Lloyd, Kuenzel, Hodson, Gonda, Batchelor, Dijksterhuis, and Thomas (2011) demonstrated that the ability of untrained participants (tested in the UK) to taste sweet and salt, as well as their perception of crunchy food, was suppressed under the influence of loud background white noise (in this case, presented over headphones at around 80-85 dB). The foods tasted in this study consisted of typical snack foods, such as Pringles Original Salted Crisps and Sainsbury's Nice Biscuits. Meanwhile, Yan and Dando (2015; building on predictions made by Spence, Michel, & Smith, 2014), reported that ratings of the subjective intensity of the five basic tastants (sweet, salty, sour, bitter, and umami) presented in solution were, in several cases, affected when accompanied by airplane noise at 80-85 dB (i.e., set at roughly the same level one would be exposed to in a commercial airplane). In particular, ratings of sweetness were suppressed significantly, while the umami solution was rated as tasting more intense amongst their North American participants.[2] Interestingly, this may help to explain why so many passengers seem to choose to drink tomato juice, or a Bloody Mary, while on an airplane (see Spence, 2017b, for a review).[3]

Research by Seo, Hähner, Gudziol, Scheibe, and Hummel (2012) has also shown that background noise can, at least under certain conditions, influence people's sensitivity to odours (see also Seo, Gudziol, Hähner, & Hummel, 2011). So, for example, Seo et al. (2011) played various kinds of background noise over headphones to participants who were performing an odour discrimination task. The participants had to pick the odd one out of three "Sniffin' sticks" (odorous felt-tip pens), two of which had the same odour, while the remaining one smelled differently. Verbal noise, consisting of someone reading an audio book at 70 dB, exerted more of a detrimental effect on participants' performance than party noise presented at the same level, which, in turn, was more detrimental than silence. By contrast, listening to Mozart's sonata for two pianos in D major K448 did not affect performance relative to a silent baseline condition.

In a follow-up study, Seo et al. (2012) showed that performance on an odour sensitivity task wasn't affected by the presence of background noise (either verbal or non-verbal) when compared to a baseline silent condition. However, that said, in this case, a closer look at the data revealed that while verbal background noise significantly impaired the olfactory sensitivity of introverted participants, it had the opposite effect on the more extroverted participants. Elsewhere, Velasco, Balboa, Marmolejo-Ramos, and Spence (2014) instructed participants to rate six food-related odours (lemon, orange, bilberry, musk, dark chocolate, and smoked) while either listening to music or white noise (once again presented over headphones at 70 dB). These olfactory stimuli were rated as significantly less pleasant (by around 5%) in the presence of white noise than when either pleasant or unpleasant (consonant and dissonant) musical selections were played instead.

By-and-large, the results reported in this section would therefore appear consistent with the suggestion that loud background noise acts a crossmodal distractor or masking stimulus (e.g.,

[2] It is worth noting here that the latest evidence suggests that people's response to umami differs by culture/country (see Cecchini, Knaapila, Hoffmann, Federico, Hummel, & Iannilli, 2019).

[3] In this regard, one might speculatively want to consider airplane noise as a kind of 'sonic seasoning' (see **Section 5**). However, it is as yet unclear whether consumers consider airplane noise a particularly good match for the taste of umami, as would be needed if one wanted to establish the crossmodal correspondence underpinning this particular crossmodal effect.

see Hockey, 1970; Kou, McClelland, & Furnham, 2018; Plailly, Howard, Gitelman, & Gottfried, 2008; Spence, 2014a; see also Wesson & Wilson, 2010, 2011).[4] What is also still unclear is why noise suppresses our perception of certain attributes of the tasting experience while at the same time seemingly boosting others (e.g., umami). According to one evolutionary argument (Ferber & Cabanac, 1987), building on early work in the animal model (Kupferman, 1964), the suggestion has been forwarded that in times of stress, such as when exposed to loud noise, we may find those tastes that signal energy (e.g., sweetness) to be more palatable. The idea here being that such changes might serve an evolutionarily-useful function in helping an organism to secure sufficient energy in order to deal with the stressful situation. However, even though such a suggestions may sound intriguing, convincing evidence in support of this notion has yet to be forthcoming.

3. Background music

In this section, we move on from looking at the effects of background noise (be it defined as nonspecific, or unpleasant, type of sound), to a consideration of the impact that background music has both on consumer behaviour and food perception. The section is broken into three broad classes of crossmodal influence. We start with the effect of loud music on consumption, possibly mediated by arousal. Next, we take a brief look at the behavioural entrainment to the musical beat that has been reported in various food-related consumption contexts. Finally, we examine the sematic priming effects that are elicited as a function of the type of music that the consumer is exposed to.

3.1. Loud music

The laboratory research that has been published to date demonstrates that increasing the loudness of the background music results in participants drinking more (e.g., McCarron & Tierney, 1989). Crucially, real-world studies have also confirmed that consumers tend to drink more when the volume of the background music is turned-up (Guéguen, Jacob, Le Guellec, Morineau, & Lourel, 2008; Guéguen, Le Guellec, & Jacob, 2004). In fact, according to a report that appeared in *The New York Times,* the Hard Rock Café chain deliberately plays loud music because of the positive effect it has on sales.[5] Just take the following quote from the newspaper article itself: *'[T]he Hard Rock Café had the practice down to a science, ever since its founders realized that by playing loud, fast music, patrons talked less, consumed more and left quickly, a technique documented in the International Directory of Company Histories.'* (Buckley, 2012). Meanwhile, according to Clynes (2012): *'When music in a bar gets 22 per cent louder, patrons drink 26 per cent faster.'* Music that is very loud is sometimes also used in order to deter a certain profile of customers from drinking/dining in a particular venue (Forsyth & Cloonan, 2008).

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[4] However, while such an explanation may sound promising, it is perhaps worth noting that not everyone necessarily believes in the possibility of crossmodal masking; see McFadden, Barr, & Young, 1971).

[5] Note that the loud music is presumably also congruent with the brand, and this may be perceived positively as a result.

Nowadays, there would appear to be a growing groundswell of opinion suggesting that many restaurants/bars in North America, the UK, Australia, and beyond, are becoming louder (see Spence, 2014a, for a review of this literature). This is not solely due to chefs/restaurateurs speculating that loud music in the dining room is somehow a good idea (see Spence, 2015b). Rather, part of the 'blame' here should fall at the doors of those who prioritize the modern design aesthetic, whereby many of the sound-absorbing soft furnishings (curtains, cushions, and carpets) are replaced with 'minimalist' hard reflective surfaces (see Spence & Piqueras-Fiszman, 2014).

Stafford and his colleagues (Stafford, Agobiani, & Fernandes, 2013; Stafford, Fernandes, & Agobiani, 2013) have demonstrated that people find it harder to discern the alcohol content of drinks under conditions of loud background noise[6]. In particular, in 2012, Stafford et al. reported that their participants (N = 80) rated alcoholic beverages as tasting sweeter when listening to loud background music (comprising Drum & Bass, House, Hardcore, Dubstep, and Trance) than in the absence of background music. These results, note, seemingly contradict those obtained by Woods et al. (2010), reported earlier, in the sense that opposite effects on sweetness perception were documented in the two studies as a result of participants being subjected to loud sound.

Ultimately, of course, the most appropriate music loudness level may depend on the style of a given venue. So, for instance, 80 diners in one North American study spent around 15% more when quieter, as opposed to louder, background classical, or soft rock music, was playing (Lammers, 2003). In this case, it was suggested that the quieter the music, the better match with the 'serene' atmosphere of this ocean-side California restaurant.

The fact that listening to loud background music so often increases consumption may be attributable to the impact that music has on arousal. Music can, after all, be used to arouse or relax people (e.g., North & Hargreaves, 1997), with the suggestion here that people tend to consume more when they are more aroused. There may, of course, be social and societal factors relevant to the consumption of certain drinks (e.g., alcohol) in terms of social desirability, for instance, when in the presence of music. Alternatively, however, the effect of loud music might also reflect some kind of state-dependent learning/behaviour. Assuming that what people normally do at parties where the music is loud is drink, and eat, reinstating such sensory environmental cues may simply help to prime the associated behaviour (cf. Remington, Roberts, & Glautier, 1997). There is also likely a conditioning angle to the impact of auditory stimuli on the consumer. After all, Pavlov's dogs learned to associate a food-unrelated auditory cue (the ding of the bell) with the appearance of food, and hence started to salivate in response to the sound as a result (Pavlov, 1921/1927). Intriguingly, similar associative learning effects have also been demonstrated in fish (Frolov, 1924/1937).[7]

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[6] All of this, while at the same time performing a shadowing task involving listening to and repeating a news story. Pellegrino, Luckett, Shinn, Mayfield, Gude, Rhea, and Seo (2015) have also concluded that conversing is a preferred activity in eating atmospheres (see also Lindborg, 2016), although it can alter the consumer's ability to discriminate basic differences between foods or beverages. These results also suggest that the judgment of the flavour of foods that give rise to high levels of mastication sound tend to be less susceptible to the influence of background noise.

[7] Here, one might even consider recent findings that have shown that Pavlovian conditioning can give rise to hallucinations (Powers, Mathys, & Corlett, 2017). While, to date, such hallucinations have only been studied in the audiovisual domain, there would seem no good reason, *a priori*, as to why such perceptually vivid

Given the increasing noise levels in many restaurants and bars these days, there would seem to be a possible public health angle to this research as well.[8] As a case in point, Biswas et al. (2019) have recently published research showing that low volume background music/noise leads to an increased sale of healthy foods compared to high volume or no music/noise. The suggestion being that this was presumably due to the sense of relaxation that was induced in the shoppers. In contrast, high volume music/noise results in increased levels of excitement (what one might think of as increased arousal), and this led to an increase in the purchase of unhealthy foods. The role of music in nudging healthful behaviour is something we would like to highlight in this review, and we will return to later.

3.2. Musical tempo

Several studies have demonstrated that a range of consumer behaviours tend to become somewhat entrainment toward the tempo of the background music (Roballey, McGreevy, Rongo, Schwantes, Steger, Wininger, & Gardner, 1985; see also Knoeferle, Paus, & Vossen, 2017). For instance, participants in laboratory studies drink more rapidly when high (rather than low) tempo music is played. Similar results have also been documented in more ecologically-valid studies conducted in a variety of bars and restaurants (e.g., Bach & Schaefer, 1979; Caldwell & Hibbert, 2002; Milliman, 1986). For instance, in one of the largest studies of its kind, Milliman reported a 30% increase in average dollar spend on the bar tab amongst 1,400 diners when slow, rather than fast, tempo music was played. Milliman hypothesised that the slower tempo music may have encouraged the diners to linger for longer. That some food chains really do try to control the flow of customers through their premises, is suggested by the following quote from Chris Golub, the man responsible for selecting the music that plays in all 1,500 Chipotle branches in the US: *'The lunch and dinner rush have songs with higher BPM because they need to keep the customers moving.'* (quoted in Suddath, 2013). Here it is worth thinking about the public health implications here: To the extent that people chew faster and/or for less time before swallowing in the presence of loud music, this is likely to have an impact on satiety, possible also subsequently on digestion, and hence eventually on consumption. That said, we are not aware of any carefully-controlled empirical evidence on this score.

3.3. Musical style

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hallucinations (or vivid sensory mental imagery) wouldn't also extend to the chemical senses as well (see also Spence & Wang, 2018, on the topic of imagined flavours complementing directly perceived flavours).

[8] In recent years, it has become increasingly easy to capture big data concerning people's eating behaviours via, for instance, smartphones. Nowadays, most smartphones have a microphone capable of measuring ambient noise levels, and a platform for recording one's food habits, not to mention Instagramming the dishes that one has chosen/eaten (e.g., see Ofli, Aytar, Weber, Hammouri, & Torralba, 2017). Especially relevant here, "Soundprint," offers the opportunity for the crowd-sourced measurement of noise levels in restaurants. Analysis of such data, collected using the novel SoundPrint smartphone app, has already started to reveal a number of intriguing findings, such as the fact that the average noise level recorded in more than 2250 restaurants and bars in New York City, was 78 dBA in restaurants and 81 dBA in bars. Note that such sound levels do not allow ready conversation and may pose a danger for noise-induced hearing loss and other non-auditory health issues (Fink, 2017). Worryingly, managers were also found to underestimate the actual sound levels in their venues (Farber & Wang, 2017).

The type, or style, of music that happens to be playing in the background has been shown to exert a surprisingly pronounced effect on consumer choice behaviour in a range of real-world environments (e.g., see North et al., 1997, 1999; Zellner et al., 2017). The type or style of music has also been shown to influence what people have to say about the tasting experience itself (e.g., North, 2012; Yeoh & North, 2010). Here, though, one might want to distinguish between those associations that may be primed by the sonic attributes of the music, and the more complex sematic associations that may be primed by the style of music (be it, for instance, ethnic or classical music; Hutchison, 2003; Labroo, Dhar, & Schwartz, 2008; Lucas, 2000).

In their now classic studies, North et al. (1997, 1999) demonstrated a marked reversal in sales of French and German wine in a British supermarket as a function of whether French accordion vs. German Bierkeller music happened to be playing in the background. What is more, only six of the 44 consumers who agreed to be questioned after leaving the tills thought that the atmospheric music had influenced their purchasing behaviour. More recently, Zellner et al. (2017) demonstrated that people (N=275 North American students and faculty) given a choice of Spanish vs. Italian meals (seafood paella vs. chicken parmesan; or other dishes) in a university canteen were significantly more likely to choose the paella when instrumental Spanish, rather than Italian, music was playing (34% vs. 17%, respectively). Once again, the majority of diners (82 out of the 84 interviewed afterwards) denied that the background music had influenced their meal choice. No effect of musical congruency on hedonic responses to the chosen dish was reported in this study (cf. Yeoh & North, 2010, for weak evidence on this score). However, it is worth noting that this latter null result may simply reflect the fact that (as Zellner and her colleagues themselves readily acknowldged) the background music was not especially (or even necessarily) audible in the dining area where the hedonic ratings were made in this study. Other laboratory research, meanwhile, has demonstrated that the type (or genre) of background music can modulate flavour pleasantness and people's overall impression of various food stimuli (Fiegel, Meullenet, Harrington, Humble, & Seo, 2014; see also Martens, Skaret, & Lea, 2010). One possibility here, of course, is that the style of music might bias the eye-movements and visual search behaviour of consumers (cf. Knoeferle, Knoeferle, Velasco, & Spence, 2016, for evidence concerning visual search biased by sonic logos).

A number of real-world studies have shown that playing background classical music (e.g., when compared to Top-40 hits) leads to consumers spending more on their food and beverage purchases, no matter whether they happen to be in wine shop (Areni & Kim, 1993), a university cafeteria (North & Hargreaves, 1998; North, Sheridan, & Hargreaves, 2016; North, Shilcock, & Hargreaves, 2003), or even an African-themed restaurant (Wilson, 2003). The suggestion that is often put forward here is that playing classical music semantically primes notions of quality and class, which nudges consumers into spending more than they otherwise might. At the same time, however, it is perhaps also worth pointing out how classical music can be used as a deterrent. For instance, McDonalds plays classical music outside a number of their more popular 24-hr inner city establishments in order to try and reduce the likelihood of youths gathering (Taylor, 2017). Classical music being semantically incongruent with most people's notion of what McDonalds stands for.

North (2012) conducted a study showing that background music can be used to prime, and hence bias, attributes of the tasting experience, such as assessments of how 'powerful and heavy' or 'zingy and refreshing' a wine appears to be. In his study, North had 250 students studying in Scotland evaluate a glass of either white or red wine, while at the same time listening to music that had been pre-determined to be associated with one of four metaphorical categories ('powerful and heavy', 'zingy and refreshing', 'subtle and refined', and 'mellow and soft'). The students' judgments of the wine were influenced by the music, with the students rating both wines as tasting more 'powerful and heavy' when listening to *Carmina Burana* by Karl Orff, and as tasting more zingy and refreshing when listening to *Nouvelle Vague's* 'Just Can't get Enough'. While it is assimilation effects such as these that are normally reported, there is an open question here as to whether contrast effects might also be documented as well under the appropriate conditions (see Piqueras-Fiszman & Spence, 2015, for a review).

4. Sensation transference

Over the years, a number of researcher have addressed the question of whether *'If you like the music more, do you like what you are eating/drinking more too?'* (e.g., Kantono, Hamid, Shepherd, Hsuan, Lin, Brard, Grazioli, & Carr, 2018; Kantono, Hamid, Shepherd, Yoo, Carr, & Grazioli, 2016; Kantono, Hamid, Shepherd, Yoo, Grazioli, & Carr, 2016b; Kantono, Hamid, Shepherd, Lin, Yakuncheva, Yoo, ... & Carr, 2016c). Such crossmodal effects can be thought of as an example of 'sensation transference'. Seo and Hummel (2009) have also reported transfer effects, showing that auditory cues can modulate odour pleasantness (see also Seo & Hummel, 2011, 2015; Seo, Lohse, Luckett, & Hummel, 2014). In their 2009 study, for example, Seo and Hummel demonstrated that the hedonic valence associated with auditory stimuli can transfer to the odours, and that such transference doesn't seem to be dependent on people's hedonic evaluation of the odour.

It is, though, currently an open question as to whether sensation transference effects may also be observed for other attributes such as, for example arousal (see Spence & Wang, 2015c). Indeed, elsewhere in the literature, it is clear that sensation transference effects do not necessarily occur between all pairs of stimuli/stimulus dimensions (e.g., see Fritz, Brummerloh, Urquijo, Wegner, Reimer, Gutekunst, Schneider, Smallwood, & Villringer, 2017; Marin, Schober, Gingras, & Leder, 2017, for a couple of examples).

Reinoso-Carvalho et al. (submitted) conducted a series of recent experiments in which consumers tasted and rated one of a range of beers while listening to either a positively (or negatively) valenced piece of music. In these experiments, participants generally liked the beer more, and rated it as tasting sweeter, when listening to music having positive, as compared to negative, emotion.[9] The same beer was rated as tasting more bitter, as having a higher alcohol content, and as having more body when experienced with the music having negative, as compared to positive, emotion. Importantly, from a marketing perspective, the participants in this study were also willing to pay 7-8% more for the same beer tasted while listening to positive, as compared to negative, music. Meanwhile, in another recent study, Ziv (2018) reported that cookies were rated as tasting better when people listened to pleasant background music. Interestingly, however, in this study a larger difference in the evaluation of the cookies was observed when the first cookie was tasted with pleasant (as compared to unpleasant) background music. In another example linking physiological measures, self-rated emotion, and perceived tastes, participants listened to liked, disliked, and neutral music while rating gelato

[9] Note that the valence of the music had been established by Reinoso Carvalho et al. (submitted) in their study, by having the participants evaluate each song using the positive and negative affect schedule (PANAS).

using the method of temporal dominance of sensations (Kantono et al., 2019). The authors found that positive emotions were associated with the dominance of sweet and milky flavours whereas negative emotions were associated with bitter and creamy flavours instead.

It might be suggested that the sensation transference effects that have been reported so far in this section can be considered as a kind of 'affective priming'. According to such a view, the only difference from the results reported in the previous section is that what is being primed is valence rather than the type (i.e., ethnicity or class) of music.[10] Note here that when sensation transference relates specifically to valence, it is also described as the halo effect (Clark & Lawless, 1994) and affective ventriloquism (see Spence & Gallace, 2011). Here, though, there is uncertainty as to whether it is what people think about the music that is being transferred to what they think about what they are tasting. Alternatively, however, one might also argue that the emotion conveyed by the music influences the emotional state of the taster, and it is that, that affects their taste ratings (see Konečni, 2008). Elsewhere, after all, it has been shown that sweetness is rated as more intense (while sourness is rated as less intense) by those tasting after their hockey team has won, as compared to the ratings given when the fan's team has just lost (Noel & Dando, 2015). Such results would appear to provide some support for the latter account. However, presumably, these explanations should not be considered as being exclusive. It is also important to note here that sensation transference is certainly not restricted just to music. In a crossmodal study involving both visual and auditory stimuli with matched valence, Wang and Spence (2018) were recently able to demonstrate that participants rated juice samples as tasting sweeter and less sour when they were exposed to pleasant stimuli, regardless of whether they saw images of a happy (vs. sad) face or listened to consonant (vs. dissonant) music.

Congruent music may, of course, affect people's responses to the service environment too (i.e., and not just the food and/or drink served in a particular environment). In turn, what the diner thinks about the environment may then itself result in sensation transference which biases people's ratings of the food/drink. So, for instance, Demoulin (2011) investigated the impact of congruent musical choices on the emotional and cognitive responses of diners to the environment (specifically a healthy fast-food restaurant in France offering balanced meals with quality products and trendy recipes). Musical congruency, as assessed by a small number of the restaurant's regular customers (congruent music was described as 'modern, pop and dynamic' whereas the incongruent music was made up of 'old-fashioned timeless hits') led to lower arousal and increased pleasure. This, in turn, increased customers' evaluation of the environment quality and service quality. This, then, provides another example of the way in which the environment 'as a whole' may have an impact on food evaluation, though the lines between sensation transference and crossmodal congruency/correspondences are sometimes blurred.

One other question to consider here is what exactly the difference is between hedonic "sensation transference" and those crossmodal correspondences that would appear to be mediated by affect (see **Section 5**). It is not clear that anyone has a good answer here yet, but

[10] Alternatively, however, it might be argued that 'sensation transference' is a qualitatively different phenomenon that the semantic priming that was discussed in the preceding section.

it is perhaps nevertheless still worth bearing this in mind as one of the blurry boundaries between the four ways in which sound affects food perception that have been outlined here.

5. Crossmodal correspondences between audition and the chemical senses

A recently-discovered fourth route by which what we hear can influence what we taste is based on the notion of 'sonic seasoning.' This is where pieces of music, or soundscapes, are especially chosen, or even composed, in order to correspond crossmodally with the taste, aroma, mouthfeel, or flavour of a particular food or drink (see **Table 1** for an overview of recent studies demonstrating sonic seasoning).

INSERT TABLE 1 ABOUT HERE

To be clear, crossmodal correspondences are defined as the connections that many of people appear to experience between features, attributes, and/or dimensions of experience in different sensory modalities that do not share anything obviously in common (see Parise & Spence, 2013; Spence, 2011). It is because they initially seem so surprising that people often consider them, incorrectly in our opinion, as a kind of synaesthesia (see Deroy & Spence, 2013). Interesting questions here concern where such surprising correspondences come from[11], and the conditions under which corresponding/congruent versus incongruent (or no music) influences the tasting experience (e.g., Hauck & Hecht, 2019; Höchenberger & Ohla, 2019; Spence & Deroy, 2013a; Watson & Gunter, 2017).

The earliest studies in this area by Kristan Holt-Hansen (1968, 1976) provided some initial evidence that people (N=16) associated a higher-pitched pure tone (640-670 Hz versus 510-520 Hz) with a beer that was more alcoholic, and that drinking the beer while listening to the matching tone led to higher pleasantness ratings for at least some of the participants. A few years later, Rudmin and Capelli (1983) partially replicated these results and extended them to a broader range of foods including the same beers, plus non-alcoholic beer, grapefruit juice, hard candy, and dill pickle. The small sample of participants (N=10) chose significantly higher frequencies for the acidic foods (grapefruit juice, candy, pickle) compared to the beers. More recently, still, we have extended this approach to matching with a range of Belgian beers and other drinks (e.g., Reinoso Carvalho, Velasco, Van Ee, Leboeuf, & Spence, 2016c; Reinoso Carvalho, Wang, Van Ee, & Spence, 2016e; Reinoso Carvalho, Wang, De Causmaecker, Steenhaut, Van Ee, & Spence, 2016d), not to mention with sample sizes that are much larger.

For a more systematic approach, one should perhaps consider simpler gustatory stimuli consisting of basic tastes. A series of tests involving basic tastes was conducted by Anne-Sylvie Crisinel at the Crossmodal Research Laboratory at Oxford. Implicit Association Tests revealed an association between high pitch and sweet, and sour taste descriptors, food names,

[11] Are they, for instance, based on the statistics of the environment (Ernst, 2007; Spence, 2011), or perhaps reflect some sort of innately determined correspondence? Or are they the product of transitive properties (e.g., bitterness corresponds with low pitch because both correspond with dark colours or negative emotion; see Palmer, Schloss, Xu, & Prado-León, 2013)?

as well as an association between low pitch and bitter food names (Crisinel & Spence, 2009, 2010a). That said, a potential confound here is that participants might have matched pitches to the linguistic features of the food names themselves, rather than the (imagined) tastes of the foods. Simner, Cuskley, and Kirby (2010) demonstrated that phonetic features were reliably matched to basic tastes at two different concentrations, especially with sweet tastes being matched to lower values in terms of vowel height, vowel front/backness (where lower values correspond to more back in vowel space), and spectral balance compared to sour tastes (see also Motoki, Saito, Nouchi, Kawashima, & Sugiura, 2018).

In order to make sure that participants were matching sounds to imagined food tastes rather than of linguistic features of the food names, Crisinel and Spence (2010b) conducted another study using actual taste and aroma solutions. In this case, the participants had to match each taste sample to a musical note (one of 13 notes from C2 to C6, in intervals of two tones) and a class of musical instruments (piano, strings, winds, and brass). The results demonstrated that for a number of these tastes and aromas, the participants were consistent in terms of the notes and instruments that they felt went especially well together. So, for instance, sweet and sour tastes were mapped to higher-pitched sounds, while bitter tastes were mapped to lower-pitched sounds. In addition, sweet tastes were mapped to piano sounds whereas bitter and sour tastes were mapped to brass instruments. In terms of aromas, fruity notes such as apricot, blackberry, and raspberry were all matched with higher (rather than lower) musical notes, and with the sounds of the piano and often also woodwind instruments, rather than with brass or string instruments. By contrast, lower-pitched musical notes were associated with musky, woody, dark chocolate, and smoky aromas, bitter tastes, and brassy instruments instead (see also Crisinel & Spence, 2012a, for an extensive exploration of wine odour-musical note matching; and Burzynska, 2018, for practical explorations in this space).

Approaching the sound-taste correspondence problem from a somewhat different angle, Mesz, Trevisan, and Sigman (2011) had nine professional musicians improvise freely on the theme of basic taste words (bitter, sweet, sour, and salty). The resulting improvisations were analysed, revealing consistent musical patterns for each taste. Specifically, bitter improvisations were low-pitched and legato, salty improvisations were staccato, sour improvisations were high-pitched and dissonant, and sweet improvisations were consonant, slow, and soft. A follow-up experiment had 57 non-musicians choosing a basic taste word that best matched a subset of the improvisations. The participants performed significantly better than chance (around 68% correct, as compared to chance level of 25%; see Mesz, Sigman, & Trevisan, 2012). Similarly, Knoeferle, Woods, Käppler, and Spence (2015) reported on a study in which regular participants matched auditory properties (pitch height, roughness, sharpness, discontinuity, tempo, sharpness, and attack) to basic taste words (sweet, sour, salty, and bitter) by using a series of sliders to control the auditory properties of a short chord progression. More recently, Guetta and Loui (2017) created violin soundtracks consisting of the same melody played in four different styles that were informed by previous studies on basic taste and music associations. The participants in this study were shown to reliably match auditory clips to taste words (sweet, sour, bitter, salty) at above chance levels, as well as matching the auditory clips to custom-made chocolates expressing the same basic tastes.

In an overarching survey of taste-corresponding soundtracks, Wang, Woods, and Spence (2015) conducted an online study in which 100 participants listened to samples from 24 soundtracks and chose the taste (sweet, sour, salty, bitter) that best matched each sample.

Overall, sweet soundtracks tended to have the most consensual response (participants chose sweet 56.9% of the time for sweet soundtracks, compared to 25% random chance), whereas bitter soundtracks were the least effective (participants chose bitter 31.4% of the time for bitter soundtracks). Moreover, a follow-up study demonstrated that associations between soundtracks and tastes were partly mediated by pleasantness for sweet and bitter tastes, and emotional arousal for sour tastes. Over the last few years, researchers have also started to explore the crossmodal correspondences that link to a number of more complex gustatory qualities such as spicy (Wang, Keller, & Spence, 2017), creamy (Reinoso Carvalho, Wang, Van Ee, Persoone, & Spence, 2017), and oak (e.g., in a wine; Wang, Frank, Houge, Spence, & LaTour, submitted). Other food-and-beverage qualities that are potentially relevant that have now been rendered in auditory form include temperature (see Wang & Spence, 2017b) and even wine styles (Spence, Richards, Kjellin, Huhnt, Daskal, Scheybeler, Velasco, & Deroy, 2013; Wang & Spence, 2015a, 2017a; see Spence & Wang, 2015b, for a review).

One other crossmodal correspondence that has not, as yet, received much empirical interest is the sound/taste correspondence that is based on perceived intensity. Wang, Wang, and Spence (2016), for instance, gave people solutions containing one of the five basic tastes at one of three different stimulus intensities. The results revealed that participants chose louder sounds to match the more intense tastes. Elsewhere, it has been noted that when the music or soundscape is presented while people are tasting, the latter's ratings of taste intensity tend to be higher than when tasting in silence instead (though note here that different results may be obtained if what is heard is classified as noise; e.g., see Yan & Dando, 2015).

As has been noted already, beyond a subjective feeling that certain auditory stimuli match a particular corresponding taste quality, such correspondences have also been documented using Implicit Association Test (IAT)-type tasks (Crisinel & Spence, 2009, 2010b). More recently, Padulo, Tommasi, and Brancucci (2018) went on to demonstrate that the speed with which participants (N = 86 participants) classified food images as either salty or sweet was facilitated by playing the matching rather than mismatching music, neutral environmental sounds, or else when performing the task in silence. The participants in this study were significantly faster to classify images as salty when accompanied by a 'salty' sound than by a 'sweet' sound, neutral environmental sound (that in pre-testing was equally matched with each taste), or silence. Finally, here, beyond the effect of sonic seasoning on the consumers' tasting experience, there is also some preliminary evidence to suggest that the music playing in the background might also influence the way in which those in the kitchen, or bar, season the food and drink they prepare (Kontukoski, Luomala, Mesz, Sigman, Trevisan, Rotola-Pukkila, & Hopia, 2015; see also Liew, Lindborg, Rodrigues, & Styles, 2018).

North's (2012) results (reported in **Section 3**; see also Silva, 2018), might strike some readers as providing an example of 'sonic seasoning'. That said, Spence and Deroy (2013a) argued that crossmodal correspondences between basic sensory features of musical (or auditory) stimuli should perhaps be distinguished from the emotional attributes, or connotation, that may be associated with a piece of music. The latter may perhaps influence people as a result of priming, without there necessarily being any natural affinity between the stimuli concerned. However, the distinction is by no means cut-and-dried, and may benefit from further consideration of the similarities and differences between these two kinds of crossmodal influence. The waters become especially muddy, here, once one recognizes the growing interest amongst researchers in those crossmodal correspondences that appear to be mediated, at least in part, by the affective/emotional valence of the component stimuli.

5.1 When crossmodal correspondence becomes "sonic seasoning"

In terms of research on the crossmodal correspondences between sonic properties and gustatory/olfactory attributes, it is important to stress that the mere existence of a crossmodal correspondence[12] does not in-and-of-itself guarantee that playing the corresponding tone, soundscape, or musical excerpt will necessarily always modulate the taste/flavour (Knöferle & Spence, 2012). In order for such crossmodal effects on perception (or, at the very least, on people's ratings) to be observed, it would appear that certain conditions (or constraints) need to be met. **Figure 1** addresses some of the potential mechanisms with which sonic seasoning soundtracks can give rise to perceptual (or evaluated) differences. Wang's PhD thesis work (Wang, 2017) found evidence to support the notion that sound can change food evaluation via the mechanisms of sensory expectations, attention capture, and emotion mediation.

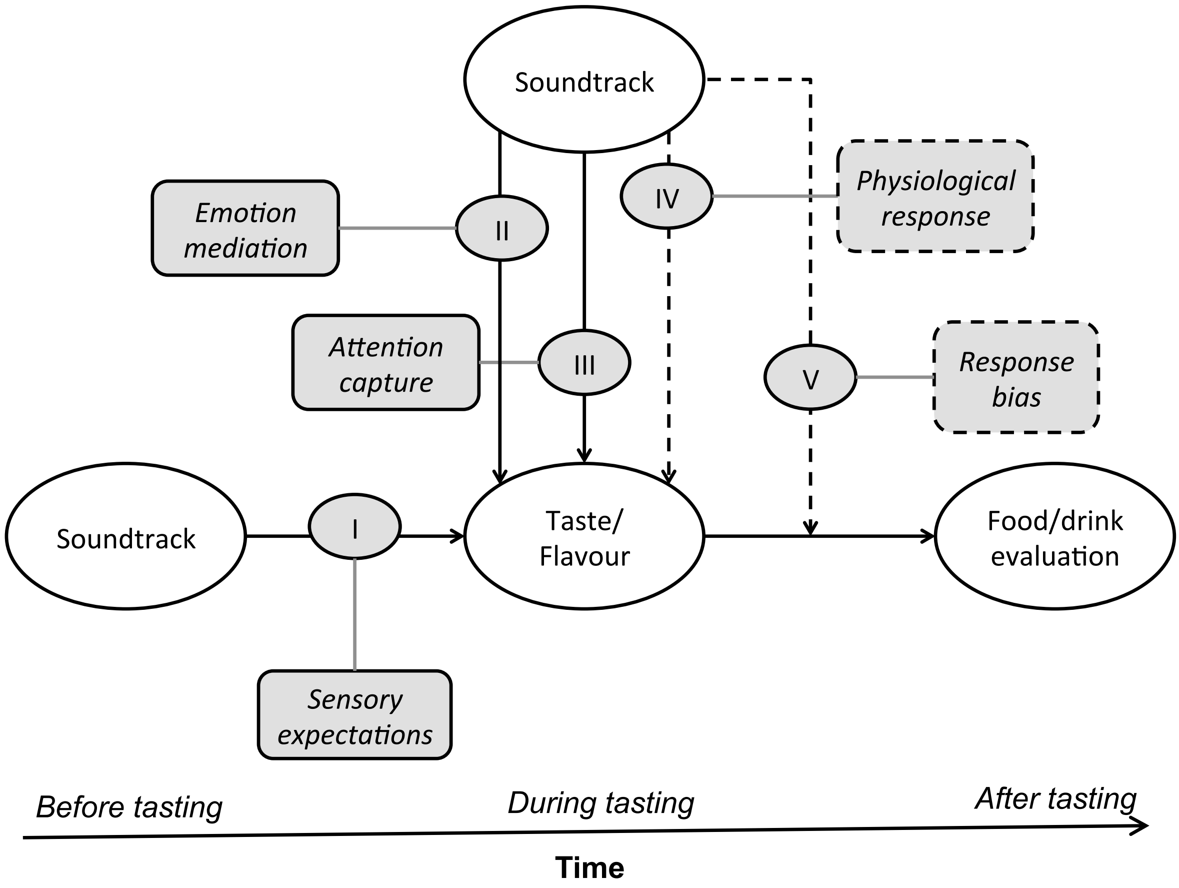

Figure 1. Schematic diagram summarizing the various ways in which sonic seasoning might influence tasting/flavour evaluation at different points in time, from Wang's Oxford University DPhil Thesis (Wang, 2017). Dashed lines denote mechanisms for which no evidence was found in research so far, whereas continuous lines denote those mechanisms garnering empirical support. For

[12] Defined as a 'feeling of rightness' that certain sound properties match, or go together well with specific taste properties; i.e., that bitter tastes seem to match low-pitched soundscape, or piece of music.

relevant studies, please see: Mechanism I – sensory expectations (Wang, Keller, & Spence, 2017), Mechanism II – emotion mediation (Wang, Wang, & Spence, 2016; Wang & Spence, 2018), Mechanism III – attentional capture (Wang, Mesz, & Spence, 2017a, b), Mechanism IV – physiological response (Wang, Knoeferle, & Spence, 2017), Mechanism V – response bias (see Wang, 2017, Chapter 4).[13]

One cannot simply turn water into wine by picking the right musical accompaniment. Rather, it would seem likely that the taste/aroma/flavour must be present in the food or beverage stimulus to begin with in order for the taster's experience of that attribute to be modified auditorily. Although no one knows for sure, what we suspect may be happening is that sound draws the taster's attention to something in their experience, and by so doing, it makes that element more salient (see Spence, 2014b; Wang, 2017, Chapter 6; cf. Klapetek, Ngo, & Spence, 2012). At the same time, however, by drawing a taster's limited attentional resources away from other elements in their experience, the latter are likely to become less salient components of the tasting experience. As such, our suspicion is that those multisensory tasting experiences that are more complex to begin with, in the sense of more flavours being present in the tasting experience (see Spence & Wang, 2018, for a review, of the various meanings of complexity as far as the chemical senses are concerned), may present more opportunity for selective attention to be drawn crossmodally (and presumably also exogenously; see Spence, 2014b) to one element in the experience, if compared to when a tasting experience presents only a unitary dimension to begin with.

It could also be imagined that sonic seasoning might be more effective under those conditions in which the taster is unfamiliar with exactly what they are tasting. Otherwise, should an easily recognized branded product like Coca-Cola be presented, say, then the taster might perhaps rely more on their memory of the taste/flavour, than on their actual tasting experience (though, that said, see McClure, Li, Tomlin, Cypert, Montague, & Montague, 2004, for evidence that branding effects work even with familiar brands of cola). Look carefully, and you will see that we often present unusual mixtures of fruit juice, or else serve wines blind, for just this reason (e.g., Wang & Spence, 2015a, 2016, 2017c). Indeed, elsewhere in the field of audiovisual research, there have been frequent demonstrations that expectations have a bigger influence on our sensory processing when the input stimuli are weak, noisy, and/or ambiguous (de Lange, Heilbron, & Kok, 2018).

Furthermore, it is also important to note that low pitch, for instance (as but one example of an auditory feature), does not only correspond to a bitter-tasting food or beverage product. Rather, it corresponds to a whole host of other attributes in a variety of senses (see Parise, 2016; Spence, 2011). Note that we usually ask our participants to estimate specific tastes and by so doing presumably draw their attention to that particular element in the tasting experience. Indeed, it is easy to imagine how the taste-relevant correspondence somehow needs to be made salient to the taster (cf. Schietecat, Lakens, IJsselsteijn, & de Kort, 2018). Otherwise, there might be a danger of the taster concentrating on the loudness of the sound or perhaps its duration instead, rather than necessarily on the relevant dimension, in this case, namely, the

[13] One interesting consideration here is the extent to which the influences outlined in **Figure 1** in the case of 'sonic seasoning' could also be applied to the case of the influence of background music, or even background noise, on tasting covered in **Sections 2** and **3**.

pitch. Crossmodal correspondences, in other words, are typically not established automatically (e.g., Getz & Kubovy, 2018; Spence & Deroy, 2013). In this regard, it is interesting to note that when the culinary artist Caroline Hobkinson served the bittersweet sonic cake pop at her pop-up dining experience at the House of Wolf restaurant, diners were actually encouraged to take out their phone and dial one number in order to listen to 'sweet' music while dialling another number if they wanted to bring out the bitterness in their dessert instead (see Spence, 2017a).

The fact that people may be able to choose which music they think best matches with different available food choices prior a sonic seasoning task, say, could have further implications in the overall multisensory tasting experience as well. For instance, in Reinoso et al.'s (2015b) study, three soundtracks were produced (one sweet, one bitter, and one in-between). The results revealed that what people heard exerted a significant influence over their taste ratings of three available types of chocolate. However, when the results were analyzed on the basis of the participants' individual music-chocolate matches (rather than the average response of the whole group of participants), somewhat more robust crossmodal effects were revealed.

There are also two further points that are perhaps worth mentioning here. One might well reasonably wonder whether sonic seasoning would work better when sounds are presented over headphones, so in some sense leading to the sound being located in the same location (i.e., inside the head) where the taste is experienced as originating from (Spence, 2016a). While we are not aware of anyone having tested this experimentally as yet, research from elsewhere in the world of multisensory perception clearly shows that spatial colocation (i.e., in the sense of sounds coming from headphones vs. external loudspeakers) can sometime modulate the magnitude of any crossmodal effects that are reported (Di Luca, Machulla, & Ernst, 2009; Soto-Faraco, Lyons, Gazzaniga, Spence, & Kingstone, 2002; Spence & Driver, 1997). At the same time, however, the very act of wearing headphones may perhaps lead participants to focus their attention toward their ears (and hearing), which could also enhance any influences of sound on the eating experience. Potentially relevant here, therefore, it is worth noting that Crisinel et al. (2012) used headphones to present the bitter and sweet soundscapes, whereas Höchenberger and Ohla (2019), in their attempt to replicate Crisinel et al.'s results, actually switched to presenting the sounds from external computer loudspeakers instead. Now, this may not turn out to matter much. Nevertheless, it is probably a factor that should be borne in mind (and, one presumes, noted by the researchers concerned).

The second point to bear in mind here is that crossmodal influences of audition on tasting are often quite subtle – showing up more often at the group level rather than necessarily as a striking change at an individual level (though the latter does, sometimes, occur). This may be attributable to the fact that we have an 'assumption of unity' concerning food and drink (see Woods, Poliakoff, Lloyd, Dijksterhuis, & Thomas, 2010). Namely, we expect most food and beverage products to taste the same from start to end.[14] As such, if people are aware that what they are tasting, or have very good reason to believe that what they are tasting, is the same, the unity assumption may well prove more powerful than the crossmodal effect of audition. In this

[14] Though drinks like quality wine are interestingly different in this regard, possibly due to their complex nature (see Wang et al., 2017a, b).

regard, sonic seasoning is quite different from something like the McGurk effect, where the illusion is so powerful that observers mostly cannot override it at will.[15]

Meanwhile, in terms of neural changes seen as a consequence of playing crossmodally corresponding music while tasting, some exciting preliminary neuroimaging results have recently started to appear (see Callan, Callan, & Ando, 2018). Given that sound has been shown to alter people's sensory expectations, we may expect to find some neurological evidence that is relevant. For instance, human neuroimaging and animal electrophysiology has shown that expectations (in terms of audiovisual studies, at least) can modulate sensory processing at both early and late stages of information processing, and the response modulation can be either dampened or enhanced depending on the context (see de Lange et al., 2018; Piqueras-Fiszman & Spence, 2015, for reviews). Similar expectancy effects have also been shown when participants are informed that a drink will have a specific taste. Namely, participants who are told to expect a very sweet drink when given a less sweet drink showed greater taste cortex activation, as compared to those who received the same drink without this expectation (Woods, Lloyd, Kuenzel, Poliakoff, Dijksterhuis, & Thomas, 2011; see Spence, 2016b, for a review; see also Geliebter, Pantazatos, McOuatt, Puma, Gibson, & Atalayer, 2013). Finally, Wang, Knoeferle, and Spence (2017) investigated a possible direct physiological effect of crossmodally corresponding music by measuring the rate of salivation while participants listened to a sour soundtrack, watched a muted video of a man eating a lemon, or else sat in silence. While the salivation rate was significantly higher during the lemon video condition than the silent baseline condition, no such difference was observed between the sour soundtrack condition and baseline condition.

5.2 Individual differences

One question that often crops up is whether such crossmodal effects between sound properties and taste are the same in different cultures (of course, a similar question might well crop up with regard to the different music styles discussed in **Section 3.3**). While a thorough analysis has yet to be conducted, Knoferle, Woods, Köppler, and Spence (2015) were at least able to demonstrate that four variations on a musical theme that had been designed to match each of the four basic tastes (e.g., sweet, sour, bitter, and salty) gave rise to almost as high agreement (or concordance/consensuality) about the matching, or corresponding, taste in a population from India as in a group from North America (note that, in this case, the compositions themselves had been generated in Germany).

Another individual difference here relates to genetic differences in terms of supertaster status. This has also been demonstrated to play a role in terms of sonic seasoning effects. For instance, using a mixed model design, Wang had 27 participants taste 70% and 85% cacao chocolate while listening to sweet and bitter soundtracks (Wang, 2017, Chapter 9). All participants then took a PTC taste strip test at the end of the study. The results revealed an intriguing split when

[15] Though it is perhaps worth noting here that the recent history of congruent vs. incongruent stimuli (presumably affecting the priors we hold about the likelihood that what we see and hear belong to the same speech event) has even been shown to modulate the magnitude of the McGurk effect (Gau & Noppeney, 2016; Nahorna, Berthommier, & Schwartz, 2012, 2015), one of the classic examples of multisensory perception. The strength and robustness of even the most reliable of multisensory illusions, or crossmodal effects, in other words, may also be subject to our beliefs about the causal structure of the world around us.

it came to the influence of music. While there were no differences between the two taste sensitivity groups for 70% chocolate, when it came to the more bitter 85% chocolate, the high taste sensitivity group appeared to be more influenced by the different soundtracks than the low sensitivity group (i.e., they found a bigger difference in the taste of the 85% chocolate between the bitter and sweet soundtrack; cf. Crisinel & Spence, 2012b).

Another question relates to the role of expertise, both in terms of musical expertise and in terms of taster expertise. In Wang et al.'s (2015) study, where 24 pieces of soundtracks were tested in terms of their taste associations, musical expertise was found to influence how participants made their sound-taste correspondences for one of the soundtracks. *Makea*, composed by musician and researcher Bruno Mesz, was a soundtrack featuring high-pitched piano instrumentation and dissonant chords putatively associated with sweetness. Results from testing 100 participants turned out to be subtler: those with no musical background were significantly more likely to match the soundtrack with sweetness than those with musical experience, for whom bitterness was the most common choice. This was probably due to the fact that musical novices tend to focus on timbre whereas experts tend to focus on melody and harmony instead (Wolpert, 1990). Therefore, perhaps the novices matched the high-pitched piano sounds to sweetness, while the more experienced listeners matched the dissonant chords to bitterness.

While there has not yet been a direct comparison between expert tasters with regular consumers, it has recently been demonstrated that even wine expert's judgments of the properties of wine could be influenced by the music playing in the background. In particular, Wang and Spence (2017c) tested 154 wine professionals attending the International Cool Climate Wine Symposium in two studies. Their first study replicated previously demonstrated effects of sweet and sour soundtracks, where participants rated an off-dry white wine as sweeter and less sour (on two independent scales), when they tasted while listening to the sweet soundtrack compared to the sour soundtrack. In a second study, the participants tasted a pair of chardonnays and evaluate wine-specific terminology (length, balance, body) while listening to two soundtracks with contrasting auditory textures (sparse versus full). Both wines tasted while listening to the sparser soundtrack were associated with fuller body, better balance, and longer length, compared to the soundtrack with fuller texture (see also Burzynska, 2018). The amount of wine tasting experience (in terms of years) did not moderate the influence of music on the participants' sensory wine evaluation.[16]

5.3 Tell me about the taste of the product vs. Tell me about your tasting experience

In many of the experiments that have been conducted to date on the topic of sonic seasoning, the participants have deliberately been given the impression that they are actually (or might well be) tasting a range of different food stimuli, or else used mixed-design models in which each participant gets to tasting multiple different foods (e.g., Reinoso Carvalho et al., 2015b; Wang & Spence, 2015a; Wang, Keller, & Spence, 2017). Contrast this with the situation in Höchenberger and Ohla's (2019) recent study in which, from the way in which the materials

[16] While the focus here is on tasting, it is worth noting that there is also a long history of researchers assessing the crossmodal correspondences between food-relevant odours and musical notes too (see Bronner, Bruhn, Hirt, & Piper, 2012; Crisinel & Spence, 2012a; Deroy, Crisinel & Spence, 2013; Piesse, 1891).

and method are described, the participants were simply presented with a tray of pieces of cinder toffee. Given this arrangement, where the participants were free to pick any piece on each of the 27 trials, one could presumably safely infer that the stimuli must be the same. As such, there arises an important distinction here, between two similar sounding judgments. If participants report on the taste/flavour of the chocolate, their response might be dissociated from how they actually subjectively experience the taste/flavour of the chocolate.

By analogy, imagine the different responses that you would be tempted to give if you just saw the lighting strike a long way off on the horizon, and then three seconds later heard the crack of the thunder. If asked what just happened, you will say that there was a single bolt of lightning (with simultaneous visual and auditory properties). However, if asked what you just perceived, then you would, we imagine, come out with a different answer, namely that you first saw the lightning strike, and a few seconds later you heard the crack of the thunder (Spence & Squire, 2003). Notice how, in this case, you are able to dissociate your knowledge of what is out there from your perception of the event, given your priors and beliefs about the world.

At the same time, however, there is a growing realization that certain food and beverage products have a temporally-evolving flavour profile (Wang, Mesz, & Spence, 2017a, b), and hence synchronizing the musical properties to the evolving attributes of the tasting experience becomes an increasingly important issue. Evidence from elsewhere in the field of multisensory research would appear to suggest that temporally synchronized soundscapes are likely to have a more pronounced influence over the tasting experience than when food is tasted at random points in the music (though see Houge & Friedrichs, 2013, for a discussion of the difficulty of synchronising music with food in a restaurant setting; see also Rozin & Rozin, 2018). Now, of course, all these caveats, likely mean that while 'sonic seasoning' has an important role in multisensory experience design (see Spence, 2019), there may be less that is directly applicable from a marketing perspective (or rather the application might be more on the advertising side than on the choice of music to play in-store/restaurant).

6. Conclusions

As this review of the rapidly-expanding literature documenting crossmodal contributions of audition to food perception and consumer behaviour has hopefully made clear, product-extrinsic sounds exert a profound influence over various aspects of people's perception of the aroma, taste, and flavour of a wide variety of food and drink items. The sonic properties of the ambient soundscape also exert often-unacknowledged effects on consumer behaviour across a wide variety of food-related contexts (e.g., see North et al., 1997, 1999; Zellner et al., 2017). Importantly, while many of these effects have been studied on participants in the laboratory, they have also been documented in customers in a number of more ecologically-valid settings too, such as restaurants, shops, bars, cultural institutions, and wine bars. It is perhaps because these sounds are mostly unrelated to the food or drink itself in these studies, people rarely seem to be aware of just how much influence music/noise can have over what they taste, and how much they enjoy the experience.

6.1. Neuroscientific explanations of the auditory influence on food perception and consumer behaviour

In the future, the results of neuroimaging research will likely also help to confirm whether we are indeed looking at four distinct routes (or mechanisms) underlying the crossmodal influence of auditory on food perception and consumer behaviour outlined here (see Callan et al., 2018, for some intriguing preliminary data). Alternatively, however, we should perhaps also remain open to the possibility that despite the background literatures (for these four categories; namely, background noise, background music, sensation transference, and crossmodal correspondences) being so separate, some meaningful consolidation can take place, either between these seemingly distinct areas of research, or at the very least, at their boundaries.

As yet, while the behavioural/psychophysical data documenting the influence of what we hear on what we taste continues to build up, our cognitive neuroscience understanding of the neural mechanism(s) underlying such crossmodal effects continues to lag far behind. To the extent that somewhat different physiological/neurophysiological mechanisms do underlie each of the identified routes by which what we hear influences what we taste and smell, then one might reasonable expect somewhat different networks of neural activity to be involved. Here it is perhaps interesting to note that while direct cortical connections between olfactory and auditory brain areas were discovered in the rat a few years ago (Wesson & Wilson, 2010, 2011), leading one excitable commentator to introduce the new term 'smound', for the combination of smell and sound (see Peeples, 2010; see also Cohen, Rothschild, & Mizrahi, 2011), their role and even the question of whether similar connections also exist in humans has not been addressed as yet, at least as far as we are aware. Moving forward, of course, having a better cognitive neuroscience understanding of what is going on in the brain while people taste, purchase, and of consume food and drink while different kinds of music or noise are present will likely help further our understanding in this area.

6.2. Product-extrinsic multisensory contributions to food perception and consumer behaviour

What is also worth noting is that all of the studies that have been reviewed here have manipulated only a single sense at a time, namely audition. However, in the real world, what we hear is clearly going to be but one element of the total multisensory atmosphere. The visual, olfactory, and tactile attributes of the atmosphere clearly also matter, and likely interact with the auditory soundscape in the taster's experience (see Spence, 2017a, for a recent review). Hence, researchers are now starting to assess how, for example, the visual attributes of the environment, combined with the auditory atmosphere, can influence a consumer's behaviour (e.g., Sester, Deroy, Sutan, Galia, Desmarchelier, Valentin, & Dacremont, 2013; Spence, Puccinelli, Grewal, & Roggeveen, 2014; Spence, Velasco, & Knoeferle, 2014; Wang, Mielby, Thybo, Bertelsen, Kidmose, Spence, & Byrne, 2019; Wansink & Van Ittersum, 2012; Wang & Spence, 2015b). Researchers have also started to assess different ways to effectively present music as part of a food/drink product's identity. This is being explored by means of semantically framing the music that is presented while tasting (i.e. by presenting the music as the main source of inspiration of a food/drink product's formula; and/or by including such music as part of a product's presentation – as in kind of multisensory packaging; see Reinoso Carvalho et al., 2015a, 2016c). This, though, undoubtedly adds to the complexity of the problem under study.

6.3. Multisensory experience design

Given the growing literature on music and soundscape's influence on the multisensory tasting experience, there is a growing interest in using technology to synchronize aspects of the auditory stimulation with the tasting experience (Velasco, Reinoso Carvalho, Petit, & Nijholt, 2016; Reinoso Carvalho, Steenhaut, van Ee, Touhafi, & Velasco, 2016a; see Spence, 2019, for a review). This is undoubtedly a rich area for creative practice. The Chocolate Symphony presented at the 2018 IMRF meeting in Toronto is a very recent example (see http://maximegoulet.com/symphonic-chocolates/). The city of Brussels (Belgium) also recently-funded a project entitled 'The Sound of Chocolate' (www.thesoundofchocolate.be), where chocolate boxes were sold alongside music that was designed to enhance certain aspects of these chocolate's taste and flavour.

In fact, in some cases, specially composed atmospheric soundscapes or specially chosen pieces of music, are now being developed to complement the dishes served on the ground (see Spence, Shankar, & Blumenthal, 2011; Spence & Youssef, 2016), and even in the air (FinnAir[17]; British Airways: Victor, 2014). A number of food and beverage brands have also started to capitalize on the opportunities provided by connecting their product offering with specific pieces of music (e.g., though sensory apps; see Spence, 2019, for a review). There is, though, at the same time a question, at least amongst some, of 'why bother?' (see Spence & Wang, 2015d, for a review of those who have taken such a position). Actually, it is here that the effort to reduce sugar intake via sound, and/or colour, by let's say using "smart" technologically-enhanced cups (reported by Blecken, 2017), not to mention the latest pitch-overeating effects that have been demonstrated by Lowe, Ringler, and Haws (2018), becomes so relevant. The latter researchers just reported a study that capitalized on pitch/size crossmodal associations in order to evaluate whether sounds of different pitches would lead to different serving sizes. As the authors predicted, lower-pitched ads led to larger serving sizes as compared to higher-pitched ads (see also Lowe & Haws, 2017).

6.4. Implications for public health

A case can be made that the loud, fast music so often piped-out at restaurants and bars may be exerting a negative effect over consumer perception and behaviour. As such, some have suggested that there may be important – if largely unacknowledged – consequences of the soundscapes in which we come into contact with food and drink products (all of this, from the shopping until the tasting process; Keller & Spence, 2017; Liu, Meng, & Kang, 2018; Mamalaki, Zachari, Karfopoulou, Zervas, & Yannakoulia, 2017). Here it is worth noting that long-term exposure to transportation noise has been linked to obesity, and that combined exposure to different sources of noise has been shown to be particularly harmful (e.g., see Pyko, Eriksson, Lind, Mitkovskaya, Wallas, Ögren, & Pershagen, 2017). One can make an analogy with the multiple sources of background noise in a Sports Bar, say, where music, background conversation, and the game showing on the screens all compete in an auditory cacophony. As far as we are aware, the question of the relevance/impact of the number of sources of noise/music in the environments in which we eat and/or drink has yet to be investigated. However, attention is starting to turn to the impact that loud background noise may be having

[17] Retrieved from https://www.finnair.com/cn/gb/stevenliu/en (August, 2018).

on children's fruit and vegetable consumption in the school canteen (Graziose, Koch, Wolf, Gray, EdM, & Contento, 2019).

On the flip side, however, it is presumably only by recognising the effect of the ambient soundscape on tasting that we will be in a better position to design those soundscapes that may have a better chance of promoting, let's say, healthy eating (see Blecken, 2017; Ragneskog, Bråne, Karlsson, & Kihlgren, 1996), or food shopping behaviour in all who hear them (see Spence, 2012). As a case in point, consider only the school lunch cafeteria or work canteen, where strategically playing the right sort of background music, or soundscape (whatever that might be) might encourage consumers to choose more vegetables or sustainably-sourced protein (here one need only think of Zellner et al.'s, 2017, study with Spanish vs. Italian meals served in the student cafeteria). Sonic seasoning might also play a role at the condiment station, where a sweet background track might just induce people to add less sugar to their coffee (see Blecken, 2017; Lowe et al., 2018). That said, long-term follow-up studies are urgently needed in order to ascertain whether these sonic influences longer-term effects that persist beyond the span of an individual laboratory experiment.

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Table 1. A summary of recent studies demonstrating sonic seasoning via the use of soundtracks/music (rather than product-induced sounds). Effect size (Cohen's d) provided where data is available for calculations. Cohen's d provides a measure of effect size indicating standardised difference between two means, which allows for comparison of effect sizes across different studies. % difference refers to the differences in attributes between the sound conditions listed under auditory stimuli. In the case of more than 2 soundtracks, explicit comparison conditions are listed in parentheses ().

Study	**Auditory stimuli**	**Food/drink**	**DV**	**Study design**	**Sample size**	**% difference**	**Effect size (Cohen's d)**
Crisinel et al., 2012	Sweet, bitter soundtracks	Cinder toffee	9 point scales: sweet-bitter, position, liking	Within participants	20	15% sweeter	0.5
North, 2012	4 pieces of music + silence	Wine (1 white and 1 red)	11 point scales: powerful/heavy, subtle/refined, zingy/refreshing, mellow/soft, wine liking	Between participants	250 (25 per cell)	40% more zingy/fresh, 32% more powerful/heavy, 29% more mellow/soft, 30% more subtle/refined (each soundtrack compared against all other conditions)	
Spence et al., 2013, study 2	Classical music matching wines, silence	Wine (1 white, 2 red)	11 point scales: sweetness, acidity, alcohol, fruit, tannin, enjoyment	Within participants	26	9% more enjoyable	
Fiegel et al., 2014	4 genres (jazz, classical, hiphop, rock), single or multiple performers	Emotional (chocolate) vs non-emotional (bell pepper) food	VAS scale 15cm: flavour intensity, pleasantness, texture liking, overall liking	Within participants (genre), between participants (single/multiple performers)	99		
Spence et al., 2014, study 1	White light, red light, green light + sour music, red light + sweet music	Red wine	7 point scales: fresh-fruity, intensity, liking	Within participants	1580		

Spence et al., 2014, study 2	White light, green light, red light + sweet music, green light + sour music	Red wine	7 point scales: fresh-fruity, intensity, liking	Within participants	1309		
Reinoso Carvalho et al., 2015	Sweet, bitter, medium soundtracks	Chocolate (bitter, medium, sweet)	9-point scale: bitter-sweet. 5 point scale: less-more bitter or less-more sweet	Within participants	24		
Wang & Spence, 2015	Classical music (Debussy, Rachmaninoff)	Wine (1 white and 1 red)	VAS scale 100 mm: wine-music match, fruitiness, acidity, tannins, richness, complexity, length, pleasantness	Between participants	64	15% more fruity, 42% more acidic	0.38 (fruitiness); 1.10 (acidity)
Reinoso Carvalho et al., 2016, experiment 1	Sweet, bitter sountracks	Belgian beer	7 point scales: sweet, bitter, sweet-bitter, strength, enjoyment	Within participants	113	20% sweeter (sweet scale), 16% (sweet-bitter scale)	0.40 (sweet), 0.41 (bittersweet)
Reinoso Carvalho et al., 2016, experiment 2	Sweet, sour soundtracks	Belgian beer	7 point scales: sweet, sour, sweet-sour, strength, enjoyment	Within participants	117	20% sweeter (sweet scale), 10% sweeter (sweet-sour scale), 22% more liked	0.42 (sweet), 0.28 (soursweet), 0.52 (liking)
Wang & Spence, 2016	Melodies with consonant and dissonant harmonies	Juice mixture	10 point scales: music liking, drink liking, sour-sweet scale	Within participants	39	19% sweeter	0.43
Reinoso Carvalho et al., 2017	Legato, staccato soundtracks	Chocolate	7 point scales: sweetness, bitterness, creaminess, liking, chocolate-music match, music liking	Within participants	116	11% creamier and sweeter, 8% less bitter	0.27 (creamy), 0.27 (sweet), 0.23 (bitter)

Wang et al., 2017, experiment 2	Spicy soundtrack, sweet soundtrack, white noise, silence	Salad	11 point scales for expected and actual ratings of: sweetness, spiciness, flavour intensity, liking	Between participants	180 (45 per cell)	30% spicier (expected, versus silent condition)	0.89
Wang et al., 2017, experiment 4	Spicy soundtrack, silence	Salsa, mild and medium spicy	11 point scales: flavour intensity, pleasantness, spiciness	Within participants	40	16% spicier	0.4
Wang & Spence, 2017	Melody with consonant and dissonant harmonies; images with hapy/sad child	Juice mixture	11 point scales: sour-sweet, liking	Within participants	49	18% sweeter	0.28
Hauck & Hecht, 2019	Classical music (Berg, Tchaikovsky)	Red wine, white wine, sugar water, citric acid solution	11 point scales: overall liking, sweet, sour, salty, bitter, foul, floral, aromatic, fruity, lively, gloomy, harmonic, light, zingy and refreshing, powerful and heavy, subtle and refined, mellow and soft	Within participants (misreported in paper as between participants!)	115	10% more liked	0.3
Höchenberger & Ohla, 2019, study 1	Sweet, bitter soundtracks, silence	Cinder Toffee	0-100 VAS: bitter-sweet, pleasantness	Within participants	20	8% sweeter	0.55
Höchenberger & Ohla, 2019, study 2	Sweet, bitter soundtracks, silence	Cinder Toffee	0-100 VAS: sweet, bitter, salty, sour, pleasantness	Within participants	20		

Wang et al., 2019	Sweet, bitter soundtracks, silence	Juice mixture	9 point scales: sweetness, bitterness, sourness, liking	Mixed (soundtrack, colour = within participants; aroma = between participants)	331 (~50 per cell)	8% sweeter (sweet vs bitter soundtrack), 4% sweeter (control vs bitter soundtrack)	0.27 (bitter vs sweet soundtrack), 0.16 (bitter vs control)