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The influence of soundscapes on the perception and evaluation of beers ☆

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ABSTRACT

The effect of soundscapes on the taste evaluation of beers was analyzed in the research reported here. Three experiments were conducted in which participants tasted a beer twice, and rated the experience, each time under the influence of a different sound stimulus. The participants were not informed that they were, in fact, tasting the same beer. The objective was to determine whether soundtracks that have previously been shown to correspond to the different basic tastes would significantly modulate the perceived sweetness, bitterness, sourness, and alcohol content of the beers. Overall, the soundtracks influenced the participants' rating of the beers' taste and strength. Furthermore, a control study involving tasting the same beers without sonic stimuli, confirmed that these results could not simply be explained in terms of order (or adaptation) effects. These results therefore point to sensation transference as the potential mechanism underlying the observed crossmodal modulations of taste by sound. The present study underlines the potential of sound to enhance eating/drinking experiences. In this way, those working in the food industry may feel progressively more confident in adopting new multisensory techniques while designing eating/drinking experiences.

1. Introduction

The multisensory nature of tasting experiences has become increasingly clear to researchers in recent years (e.g., Auvray & Spence, 2008; Spence & Piqueras-Fiszman, 2014). Food and beverage perception can be influenced by means of aromas, shapes, colors, and even sounds. In fact, a growing number of studies have now started to approach the question of how what we hear influences the taste and flavor of foods and beverages. The research that has been published to date suggests that external sound (i.e., beyond the sounds that are associated with eating) can, at least under the appropriate conditions, add value and pleasure to the overall eating/drinking experience (e.g., Spence, 2015a, 2015b, for reviews).

In recent years, a range of taste-related soundtracks have been composed by various artists, designers, and researchers, based on a growing list of crossmodal correspondences that have been documented between sound and taste (e.g., Crisinel & Spence, 2009; Crisinel & Spence, 2010; Knoeferle, Woods, Käppler, & Spence, 2015; Mesz, Sigman, & Trevisan, 2012; Wang & Spence, 2016). For instance, Crisinel and Spence (2010) reported that bitterness and sweetness were associated with low and high pitched-sounds, respectively. Further studies have investigated the influence of such soundtracks on the perception of real foods (e.g., Crisinel et al., 2012; Reinoso Carvalho, Van Ee, Touhafi, et al., 2015; Reinoso Carvalho, Van Ee, Rychtarikova, et al., 2015; Reinoso Carvalho et al., 2015; Wang & Spence, 2016) and beverages (Spence, Velasco, & Knoeferle, 2014; Wang & Spence, 2015a, 2015b). However, crossmodal correspondences are not the only mechanism that can operate when there is an interaction between sound and taste. In particular, the fact that people may or may not like music that is playing as part of a multisensory tasting experience can have significant effects on how taste is perceived. For example, Kantono et al. (2016) recently reported that sweetness can be perceived as more dominant intense when the music that is played is liked (or neutrally liked) by the participants, when tasting a chocolate ice cream (see Cheskin, 1972, for an early review on sensation transference).

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Of particular interest here, both Crisinel et al. (2012) and Reinoso Carvalho, Van Ee, Rychtarikova, et al. (2015), have demonstrated that people's perception of the sweetness and bitterness of bittersweet foods (toffee and chocolate, respectively) can be modulated by means of customized sweet and bitter soundtracks. However, what is not, as yet, altogether clear, is whether the differences in taste ratings in these recent studies were attributable to the sweet soundtrack, the bitter soundtrack, or whether, in fact, both soundtracks exerted some influence over people's perception.

Recent studies have also approached the fact that what we hear can influence the perceived alcohol content of drinks. For example, two previous studies suggested that people's ability to judge alcohol strength was impaired in a task involving them listening to music and shadowing news stories at the same time (Stafford, Agobiani, & Fernandes, 2013; Stafford, Fernandes, & Agobiani, 2012). Furthermore, numerous studies have been conducted showing that sound can influence people's evaluation of the taste/flavor of alcoholic beverages such as wine (North, 2012; Spence et al., 2014; Wang & Spence, 2015a), vodka (Wang & Spence, 2015b), and whisky (Velasco, Jones, King, & Spence 2013).

The three experiments reported here were designed to assess whether soundtracks could alter people's perception of complex taste stimuli – in this case, Belgian beers (see Brown, 2012, for an example of music-beer matching based upon personal history). The experiments presented in this report constitute the first assessment of its kind made with beer. Here, the participants rated the taste of a beer twice, each time under the influence of a different sonic stimulus, without being informed that they were, in fact, drinking the same beer. Moreover, in addition to sweet and bitter soundtracks (as being the most common stimuli used in these type of experiments), we also included a sour soundtrack. The soundtracks were chosen to evoke specific tastes (see Wang & Spence, 2015a, 2015b, for the procedure). We assessed whether each soundtrack would exert a significant influence over the perceived levels of sweetness, bitterness, sourness, and alcohol content (i.e., the strength) of the beers. Each experiment used one type of beer, and a combination of two soundtracks, involving different combinations of perceived taste (bitter–sweet, sweet–sour, and bitter–sour). Part of this evaluation also assessed whether the participants would have been willing to pay significantly more for a beer when consumed with its own customized soundscape, and presented as part of a multisensory tasting experience. Furthermore, a control study that followed a similar protocol but where no soundtracks were played, was conducted in order to further understand the potential influence of order (adaptation) effects.

We hypothesized that each soundtrack would modify the evaluation of the corresponding taste (i.e., the same beer tasted while listening to sweet soundtrack would be perceived as sweeter than while listening to a different soundtrack). The experiment involving sour–bitter soundtracks is especially interesting as it is the first time that two sonic stimuli that usually – and roughly – share the same valence have been compared. That said, we also hypothesized that sensation transference (Cheskin, 1972) might be one of the mechanisms underlying the crossmodal modulation of taste by sound. For example, if we were to observe a significant positive correlation between liking for the soundtrack, liking for the overall experience, and specific taste ratings, then one might well want to conclude that participants might have transferred their feelings towards the soundtrack onto the drinks.

2. Materials and methods

2.1. Participants

The experiments, which were conducted at the Music Instruments Museum in Brussels, Belgium (MIM), were approved by the Social and Societal Ethics Committee at KU Leuven (SMEC). On the 30th of September, and the 2nd and 4th of October, 2015, visitors to the museum were invited to take part in a short experiment. They were informed that they would be given complimentary beer to taste while listening to soundtracks and answering a short survey. 340 participants (**45**% females, mean age of **36.3** years, standard deviation (SD) of **14.9**) took part in the study (113 participants in Experiment 1, 117 in Experiment 2, and 110 in Experiment 3). All of the participants were at least 16 years of age (the minimum legal age for drinking alcohol in Belgium). They gave their informed consent prior taking part in the study. None of the participants reported having a cold or any other impairment of their senses of smell, taste, or hearing at the time of the study. From four available language options (English, French, Spanish, and Portuguese), 64% of the participants answered the survey in English, 29% in French, and 7% in Spanish. When asked about their knowledge of languages, 71% reported being familiar with English, 49% with French, 20% with Spanish, 18% with Dutch, 12% with German, and 10% with Italian. Moreover, due to their knowledge of Belgian beer brands,[1] the presumption was that the majority of the participants were European tourists, mostly from Belgium and its surroundings.

2.2. Stimuli

2.2.1. Taste stimuli

Belgian beers were chosen for this study, as they tend to have a higher perceived quality and range of flavor experiences than the beers of many other nations, thus making their use in the present study highly appropriate. 'La Brasserie de la Senne' donated the three beers used in the present study. This is a small, modern brewery operated by two brewers from Brussels. As stated on the brewery's website,[2] they follow the traditional Belgian methods as far as brewing beer in concerned: Unfiltered, unpasteurized, free of any additives and using 'only the finest raw materials of the highest quality'. Three beers were chosen from the wide range of options made available by this brewer. This choice focused on having three fairly different beers in terms of alcohol content and taste. Taras Boulba (Beer A), is a Belgian Pale Ale, light blonde beer with 4.5% alc., generously hopped with the finest of aromatic hops, giving it a refreshing character and a scent that is reminiscent of citrus. Jambe de Bois (Beer B) is a blond Tripel, copper-colored, powerful, and full-bodied beer. It has the scent of ripe bananas and a subtle blend of old varieties of aromatic hops. As for taste, malt dominates, supported by a delicate bitterness. It has an alcohol content of 8.0%. Zinnebir (Beer C) is a golden blond Belgian Pale Ale, with 6.0% alcohol, malty, with a fine bitterness. The scent is complex, developing a fruity-hop intense fragrance.

From a technical point of view, the three beers are all Belgian bitter-dry beers. They difference in terms of their alcohol content, the perceived bitterness and, to a lesser extent, sweetness. Table 1 presents a flavor and alcohol content rank, based on their formulas. This explanation and rank was performed with the technical support of the head brewer of ''La Brasserie de la Senne", Mr. Yvan de Baets.

[1] When asked about their knowledge of Belgian breweries/brands, approximately 82% were familiar with Leffe, 71% with Duvel, 60% with Chimay, 48% with Orval, 43% with Westmalle, and 39% with Rochefort. Approximately 14% of the participants knew of Brasserie de la Senne, the brewery donating the beers for this study. The participants were asked about their level of expertise concerning various types and brands of beer. They were also asked how often they consumed Belgian beer. On 7-point rating scales, where 7 is the most familiar/often, the averages of responses for both cases were 3.1 (SD 1.5) and 3.2 (SD 1.7), respectively.

[2] Tasting notes retrieved from http://brasseriedelasenne.be/?lang=en (October, 2015).

2.2.2. Auditory stimuli

Wang and Spence's (2015) study compared and ranked 24 different soundtracks that had been previously designed to evoke taste attributes (comparison based on ratings made on a basic tastes scales). For our experiments, we chose the sweet, bitter, and sour soundtracks with the highest number of matches. The sweet one (that was chosen by 89 out of the 100 participants), was developed by Jialing Deng and Harlin Sun as a soundtrack for *Synaesthetic Appetiser*, part of Deng's Masters of Arts Thesis project (June, 2015). The bitter soundtrack (chosen by 42 out of 100 participants) was the one used by Crisinel et al. (2012) in their sound-taste modulation study. Finally, the sour soundtrack (chosen by 58 out of 100 participants) was designed by Bruno Mesz and used in the juice-mixing study by Kontukoski et al. (2015). The soundtracks were edited to last approximately 30 s each. They were also mastered and calibrated to have approximately the same sound pressure level (L_{eq30s} of approximately 70 ± 3 dBA). These soundtracks can be accessed via the following link: http://sonic-seasoningbeer.tumblr.com/.

2.3. Design and procedure

2.3.1. Design

Three experiments were designed. For each experiment, different participants tasted two identical beers (unfamiliar to them) in two trials, each time listening to one of the two soundtracks. The independent variable for each experiment was therefore sound condition, and the dependent variables were the ratings that the participants made for each trial (music liking, taste ratings, alcohol strength, etc.). In Experiment 1, the participants tasted Taras Boulba while listening to the sweet and bitter soundtracks. In Experiment 2, they tasted the Jambe de Bois beer while listening to the sweet and sour soundtracks. In Experiment 3, the participants tasted Zinnebir while listening to the sour and bitter soundtracks. Each beer was assigned to the experiment with the soundtracks that expressed the most prominent taste in the beer. Therefore, Taras Boulba, which was ranked as the most bitter, was used in Experiment 1, where the bitter and sweet soundtracks were played. Jambe de Bois, which was ranked as the sweetest, was used in Experiment 2, where the sweet and sour soundtracks were played. Zinnebir, which was ranked in between the two other ones, in both scales, was used in Experiment 3, where the bitter and sour soundtracks were played (see Table 1 for the beer taste ranks). The soundtracks were presented in a counterbalanced-random order.

All of the beers were served in 50 mL samples in opaque black plastic cups, in order to prevent the participants from basing their responses on the colors of the beers. Note that, since we are working here with beers of different alcoholic contents (up to 8%), the amount of the beer made available for each participant to drink was kept at its minimum, in order to keep the probabilities of alcoholic intoxication quite low, without compromising the tasting experience.

2.3.2. Procedure

The ninth floor of MIM was chosen as the site for the experiments. Due to its independent location inside of the museum, being located between the museum's restaurant on the top floor and the rest of the exhibitions below, it was possible to have a fairly peaceful environment during experimental hours. Three rectangular tables were placed in the experimental area, one for each experiment, with three computers on each table. The natural light present in the experimental area was enough in order to provide a more 'intimate' ambience. Therefore, artificial light was kept at its minimum. Fig. 1 shows the configuration of the experimental area.

Table 1
The three Belgian bitter-dry type beers used in the present study. Chemically, Jambe de Bois is almost as bitter as Taras Boulba, but its full body and malt dominance may result in it being perceived as sweeter. Therefore, Jambe de Bois can be considered to be the sweetest of the three beers, while Zinnebir comes out second due to its alcohol-plus-malt formula. Finally, in terms of sourness, the relevant data is the pH of the beers, since no technical data was available regarding the volatile acidity of the beers. A potential sour ranking based on their pH would, however, be extremely narrow, and there may not be detectable differences on the perceived sourness of the three types of beer. Therefore, it is not feasible to accurately rank them on the basis of sourness.

Rank	Bitterness	Sweetness	Alcohol content
First	Taras Boulba	Jambe de Bois	Jambe de Bois (8.0%)
Second	Zinnebir	Zinnebir	Zinnebir (6.0%)
Third	Jambe de Bois	Taras Boulba	Taras Boulba (4.5%)

Each participant was seated in front of a computer screen. Each participant had a pair of headphones, a computer mouse and keyboard to interact with the survey. Each computer was set to 50% of its volume. The soundtracks were presented over **SONY MDRZX310** headphones. Note that the participants were not able to hear the sounds from the other participants' headphones. The survey consisted of an electronic form containing three main steps. The answers were reported mainly by means Likert-scales, multiple choice and YES–NO questions.

In the first step of the survey, the participants were instructed to read and accept the conditions of the informed consent before entering their demographic details.

In a second step, they had to respond to a pre-questionnaire, in which they described their profile (e.g., how often they bought products from this brewer, etc. – see supplementary material for detailed questionnaire).

For the third step, the participants were randomly assigned to one of three experiments (depending on which table they were asked to sit). Here, they were instructed to rate the perceived levels of the two tastes involved (e.g., in Experiment 1, they rated the perceived levels of bitterness and sweetness, because they were listening to the putatively bitter and sweet soundtracks, and so on). These responses were based on 7-point scales, with 1 being 'not at all' and 7 'very much'. In order to check on the consistency of the ratings, the participants also had to rate the perceived taste on a taste contrast-scale (e.g., in Experiment 1, they rated the beer on a bitter–sweet scale in addition to individual sweet and bitter scales, and so on). These responses were also based on a 7-point scale, where 1 was referenced as predominantly of the first taste, 7 as predominately of the second taste, and 4 as balanced. For instance, in Experiment 1, number 1 was referenced as predominantly bitter, number 7 as predominantly sweet, and number 4 was balanced sweet and bitter. As part of the participants' evaluation, they also had to rate the strength of the beer (it was explained that, by strength, we meant the beer's perceived alcoholic content). These rates were based on 7-point scales, being 1 'not at all' and 7 'very much'). After tasting each beer, the participants rated how much they enjoyed the entire sound/beer experience (answers based on a 7-point scale, being 1 'not at all' and 7 'very much'). The participants also had to evaluate the soundtracks by means of two 7-point rating scales. They rated how much they liked the soundtrack and how much it matched the flavor of the corresponding beer (being 1 'not at all' and 7 'very much'). Finally, the participants were asked how much they would be willing to pay for this type of sound/beer experience (in euros).

Together with the written guidelines concerning the experiment, at least one supervisor was present during the experiment in order to provide guidance and support. Upon finishing the experiment, the participants were instructed to leave the room without discussing any details with the next group of participants. The experiment lasted for around 10 min.

Fig. 1. Configuration of the experimental area during the sampling days. It is possible to see the three tables with participants. There was also a waiting area in the back of the room (middle right). Furthermore, there was a bar area, where the beers were carefully served, before being brought to the participants (top left).

2.3.3. Data analysis

A multivariate repeated-measures analysis of variance (RM-MANOVA) test was performed for each experiment, with soundtrack condition as factors and participant ratings (two taste ratings, taste contrast rating, experience liking, soundtrack liking, beer alcoholic content, and willingness to pay) as measures. Furthermore, we calculated Pearson's correlation coefficients for participant ratings in order to understand any relationships behind participant evaluations. All of the post hoc pairwise comparisons were Bonferroni corrected.

3. Results

3.1. The influence of the soundtracks on the multisensory tasting experience

We ran a RM-MANOVA in each of the three experiments. For each experiment, in each one of which participants listened to the same two soundtracks in different orders, soundtrack condition was a significant within-participant factor (Experiment 1: Pillai's Trace = .41, $F(7,105) = 10.54$, $p < .0005$, partial $\eta^2 = .41$; Experiment 2: Pillai's Trace = .62, $F(7,109) = 25.36$, $p < .0005$, partial $\eta^2 = .62$; Experiment 3: Pillai's Trace = .25, $F(7,102) = 4.83$, $p < .0005$, partial $\eta^2 = 0.25$). The results are addressed in related groups below.

3.1.1. Taste ratings

In Experiment 1, the participants rated the beer as significantly sweeter when listening to the sweet soundtrack than when listening to the bitter soundtrack. This result can be seen in both the single sweet scale ($p = .001$), and in the bitter–sweet contrast scale ($p = .001$). In Experiment 2, the participants rated the beer as tasting significantly sweeter while listening to the sweet soundtrack than while listening to the sour soundtrack. This can also be seen in both the single sweet scale ($p = .001$), and in the sour–sweet contrast scale ($p = .018$). By contrast, no significant differences were found when comparing taste ratings in Experiment 3. Fig. 2 shows the results from both the single-taste and taste-contrast ratings.

3.1.2. Perceived alcohol levels

This comparison only achieved statistical significance in Experiment 3, where the participants rated the beer as significantly more alcoholic while listening to the bitter soundtrack (Mean = 4.2, SE = 0.1) than when listening to the sour soundtrack (Mean = 3.8, SE = 0.1, $p = .003$).

3.2. Hedonic ratings

Here we present the comparison of hedonic evaluations while listening to the two different soundtracks. Table 2 shows the different means and standard errors (SE) for the three experiments. When comparing how much the participants liked the experience while listening to the two different sonic stimuli, we see that the sweet soundtrack may have had a more positive influence on the tasting experience, in Experiment 2. As a matter of fact, this was the only comparison that achieved statistical significance ($p < .0005$).

Table 3 presents the means and SE of the ratings on how much the participants liked the soundtrack (Liking Soundtrack) and how much it matched the flavor of the corresponding beer (Beer-Soundtrack match). In general, the results revealed that most participants liked the sweet soundtrack. They did not like the bitter soundtrack and really did not like the sour soundtrack. These comparisons were significant in all the experiments ($p < .0005$).

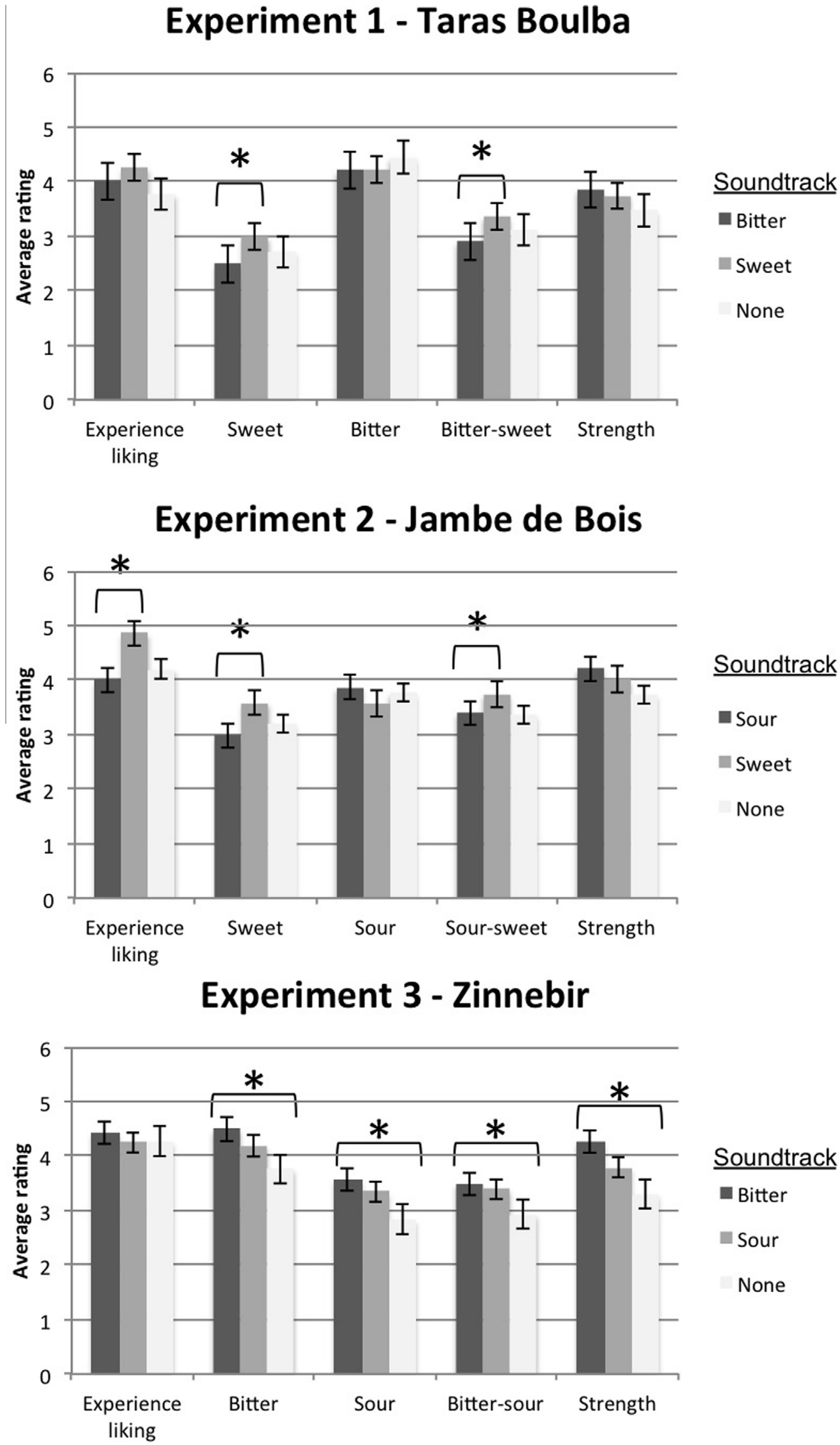

Fig. 2. Comparison of beer ratings (means and standard error bars) made while listening to soundtracks versus silence. All ratings were made on a 7-point scale, with "1" = not at all and "7" = very much. The asterisk '*' indicates a significant difference ($p < .05$).

Table 2
Hedonic evaluation of the experience reported while listening to each soundtrack, per experiment (statistical significance is indicated with an asterisk '*'; p < .0005).

	Soundtrack	Mean (SE)
Experiment 1	Bitter	4.0 (.2)
	Sweet	4.2 (.2)
Experiment 2*	Sour	4.0 (.2)
	Sweet	4.9 (.1)
Experiment 3	Bitter	4.4 (.2)
	Sour	4.3 (.2)

Table 3
Means and SE of ratings related to the participants' evaluation of the soundtracks (on 1–7 scales). In general, the sweet soundtrack was liked more than either the sour or bitter soundtracks. However, the sweet soundtrack was only a better match when it was compared to the sour soundtrack, not when it was compared to the bitter soundtrack. Summarizing, even though the bitter soundtrack was liked less than the sweet soundtrack, the participants did not rate it as a worse match than the sweet soundtrack. Significant comparisons marked with an asterisk '*' (p < .0005).

Experiment	Liking Soundtrack	Mean (SE)	Experiment	Beer-Soundtrack match	Mean (SE)
1*	Bitter	2.5 (.2)	1	Bitter	3.7 (.2)
	Sweet	3.9 (.2)		Sweet	3.6 (.2)
2*	Sour	2.0 (.2)	2*	Sour	2.9 (.2)
	Sweet	4.4 (.2)		Sweet	4.0 (.2)
3*	Bitter	3.1 (.2)	3	Bitter	3.9 (.2)
	Sour	2.2 (.1)		Sour	3.5 (.2)

Regarding their matching evaluations, the average ratings were in around the middle of the scale (3.5 < Mean < 4), except for the sour soundtrack.

Regarding their willingness to pay, the participants rated an average of 2.57 (SD = 1.08), 2.57 (SD = .92), 2.68 (SD = .98), in Experiments 1, 2, and 3, respectively. No significant differences were reported when comparing these ratings (ANOVA, $F(2,285) = .460$, $p = .632$, partial $\eta^2 = .003$).

3.3. Correlations between participants' ratings

In order to potentially find new patterns regarding how these results may be related, for each experiment (and type of beer), we assessed the correlations between the participants' ratings (see Table 4). For all three experiments, significant correlations were documented between soundtrack liking, experience liking, and beer-sound matching. In addition, correlations between single taste scales and contrast scales confirmed, once again, that the participants were responding consistently. Interestingly, perceived beer strength appeared to be positively correlated with both sour and bitter tastes, and negatively correlated with sweet tastes. These results can be associated with a recent report (Reinoso Carvalho et al., submitted for publication-A), in which dark-bitter beers (e.g., dark ales) were usually perceived as high in alcohol, even though, in reality, they may not be so strong.

3.4. Summary of the results

These results revealed that the soundtracks had a significant effect on the beer's taste. In particular, participants rated the beer as significantly sweeter when listening to the sweet soundtrack in Experiments 1 and 2. Furthermore, the participants rated the beer as significantly stronger while listening to the bitter soundtrack, in Experiment 3. It would also appear that the sweet soundtrack may have had a more positive influence on the overall tasting experience in Experiment 2. In general, the results show that most of the participants liked the sweet soundtrack, in comparison with the bitter and sour ones. In terms of correlations, we saw significant positive correlations between soundtrack liking, experience liking, and beer-sound matching are in all three experiments.

4. Control study

In order to compare the ratings of beers while listening to the soundtracks with how the beers might be rated when tasted without any explicit external sonic stimuli, a batch of control experiments was developed (namely silent control experiments, SCE). With this control study, we were interested in understanding any potential order effects that might be associated with drinking the same beer twice. It is possible that habituation might have played some role in determining participants' ratings, in addition to the soundtrack.

4.1. Procedure for the control study

Here, we used the same beers and a similar protocol (see Materials and methods, Section 2). The difference is that, this time, there were no soundtracks[3] involved. 48 participants took part in this study (36 male, mean age 23.4 years old, SD 7.8). 18 participants experienced the SCE 1, 15 the SCE 2, and 15 the SCE 3.[4]

4.2. Data analysis

A RM-MANOVA test was performed for each SCE, with sequence/order as the independent variable and participant ratings as dependent variables. We also compared the results of principal and control studies with a MANOVA test, with sound condition as the between subject factor and participant ratings as dependent variables.

4.3. Results

No significant main effect of time was observed in SCE 1 (Pillai's Trace = .35, $F(5,13) = 1.42$, $p = .28$, partial $\eta^2 = .35$). A significant main effect of order was found in Experiment 2-control (Pillai's Trace = .66, $F(5,10) = 3.88$, $p = .033$, partial $\eta^2 = .66$). Specifically, a significant difference was obtained between beer liking ratings in SCE 2 ($F(1,14) = 9.58$, $p = .008$, partial $\eta^2 = .41$), where the participants reported liking the beer significantly less when tasting it the second time around (M = 3.67, SE = .47) as compared to when tasting it the first time (M = 4.73, SE = .42). No significant main order effect was found in SCE 3 (Pillai's Trace = .48, $F(5,10) = 1.87$, $p = .19$, partial $\eta^2 = .48$). These results are shown in Fig. 3.

In summary, the results of the Control Study revealed a single significant order effect (SCE 2) in terms of liking. Therefore, when analyzing the main results (Section 3) we can, now, assume that any taste-modification effects that were observed cannot simply have been attributed to the order in which the participants experienced the soundtrack/beer pairings.

4.3.1. Comparison between main and control results

The Control Study also allowed us to compare the ratings of beers tasted while listening to soundtracks with how the beers were rated in silence (see Fig. 2). The results from the two trials

[3] The control study was performed in a quiet and isolated area of the Vrije Universiteit Brussel restaurant. Nevertheless, and even though here there were no sonic stimuli involved, the participants were instructed to use headphones, in order to further diminish any possible influence of background noise (Spence et al., 2014).

[4] Experiment 1 (bitter–sweet rating while drinking Taras Boulba); Experiment 2 (sweet–sour ratings while drinking Jambe de Bois); Experiment 3 (bitter–sour ratings while drinking Zinnebir).

Table 4
Pearson correlation coefficients between participants' ratings for each of three experiments. Bold indicates significant correlations at the .05 level.

Experiment 1 (n = 113)	Experience liking	Soundtrack liking	Soundtrack-beer match	Sweetness	Bitterness	Bitter–sweet	Strength
Experience liking	1	**.340**	**.362**	**.287**	−.029	**.347**	**.136**
Soundtrack liking		1	**.324**	**.221**	.098	**.267**	.101
Soundtrack-beer match			1	.105	.104	.115	**.196**
Sweetness				1	−**.299**	**.597**	.022
Bitterness					1	−**.403**	**.333**
Bitter–sweet						1	−.117
Strength							1
Experiment 2 (n = 117)	**Experience liking**	**Soundtrack liking**	**Soundtrack-beer match**	**Sweetness**	**Sourness**	**Sour–sweet**	**Strength**
Experience liking	1	**.392**	**.305**	**.259**	−.090	**.304**	.068
Soundtrack liking		1	**.472**	**.235**	−.100	**.249**	.050
Soundtrack-beer match			1	**.220**	−.037	**.218**	.086
Sweetness				1	−**.369**	**.681**	−**.149**
Sourness					1	−**.488**	**.308**
Sour–sweet						1	−**.144**
Strength							1
Experiment 3 (n = 110)	**Experience liking**	**Soundtrack liking**	**Soundtrack-beer match**	**Bitterness**	**Sourness**	**Bitter–sour**	**Strength**
Experience liking	1	**.332**	.127	−.078	−.129	−.025	−.106
Soundtrack liking		1	**.395**	−.029	.005	.067	.123
Soundtrack-beer match			1	−.041	−.082	−1.09	.079
Bitterness				1	.031	−**.235**	**.362**
Sourness					1	**.482**	**.188**
Bitter–sour						1	−.010
Strength							1

in the Control Study were averaged to compare with the results from the main study. For each experiment, a multivariate ANOVA test was conducted to compare the ratings from each soundtrack to the ratings from the Control Study (see Table 5). We did not include ratings for soundtrack liking and soundtrack-beer match in this comparison.

Most significantly, there were differences in Experiment 3, between ratings made while listening to the bitter soundtrack versus in silence (featuring Zinnebir). This beer was rated as tasting significantly more bitter while listening to the bitter soundtrack ($p = .01$), significantly more sour on the unidimensional sour scale ($p = .014$), significantly more sour on a bitter–sour contrast scale ($p = .027$), and significantly stronger/more alcoholic ($p < .0005$) than when tasted in the silent control experiments. To summarize, while the beers tasted under the influence of the sweet soundtrack were rated as sweeter than the beers tasted under the sour/bitter soundtracks, only the bitter soundtrack made any difference when compared to beers tasted in the absence of any external soundtrack.

5. Discussion

The results of the present study demonstrate that soundtracks that had been previously designed to evoke specific taste attributes can, indeed, influence the participants' beer tasting experience by modulating its perceived taste and strength, and these results could not simply be explained in terms of order effects.

In particular, the sweet soundtrack enhanced the participants' evaluation of sweetness in the beers, as compared to both the bitter and sour soundtracks (see Section 3.1). The sweet soundtrack was also liked significantly more than either the bitter or sour soundtracks (see Table 3). Finally, there were positive correlations between soundtrack liking, overall experience liking, and sweetness ratings (see Table 4).

Taken together, these results argue in favor of a sensation transference account (Cheskin, 1972). That is, while listening to the pleasant sweet soundtrack, the participant transfers his/her experience/feelings about the music to the beer that they happen to be tasting. This, in turn, results in higher pleasantness and also higher sweetness ratings (when compared to the relatively less pleasant sour and bitter soundtracks). Furthermore, the significant correlations reported between soundtrack liking, experience liking, and beer-sound matching enabled us to point out crucial factors that enhanced the participant's experience. For example, it can be seen that the pleasantness of the soundtrack, and its appropriateness to the beer, are both positively correlated with the overall pleasantness of the experience (see Section 3.3). From a design perspective, future creators of similar food-music experiences might well want to take into account the suggestion that a positive hedonic evaluation of the sonic stimuli, and positive matching of the stimuli involved, may help the participant better appreciate the overall multisensory tasting experience.

Again, from the results of the correlation analysis (see Section 3.3), the perceived alcohol content (strength) of the beers was positively correlated with both sour and bitter tastes, and negatively correlated with the sweet taste of the beer. Furthermore, the results of Experiment 3 revealed that the alcohol strength was perceived as higher with the bitter soundtrack, as compared to the sour soundtrack. Interestingly, the same bitter soundtrack did not affect the perceived alcohol content of the beer in Experiment 1. This suggests that the strength enhancement is likely related to the particular beer tested. Experiment 3 involved Zinnebir with 6% alcohol whereas Experiment 1 involved Taras Boulba with 4.5% alcohol, so it is possible that the soundtrack only influenced alcohol perception when the beer was already fairly alcoholic to begin with. Still, the bitter soundtrack used in the present study may provide a useful reference point for producing sonic stimuli that can be used to make beer appear a little more alcoholic. One possible explanation is that people are generally poor at estimating alcohol content of beers by means of taste cues. Therefore, high-impact flavor (such as hoppiness/bitterness in the case of beer) might have been used as proxies for alcohol content. As a matter of fact, Stafford et al. (2012) previously reported that music led to higher sweetness – and bitterness – ratings in vodka accompanied with different types of fruit juice. It could be that a sonic cue that has been produced to be congruent with a specific taste attribute (i.e. bitterness), is most likely to have enhancing effects on the strength of alcoholic beverages that are in the same tasting range. Summarizing, it would seem that people tend to

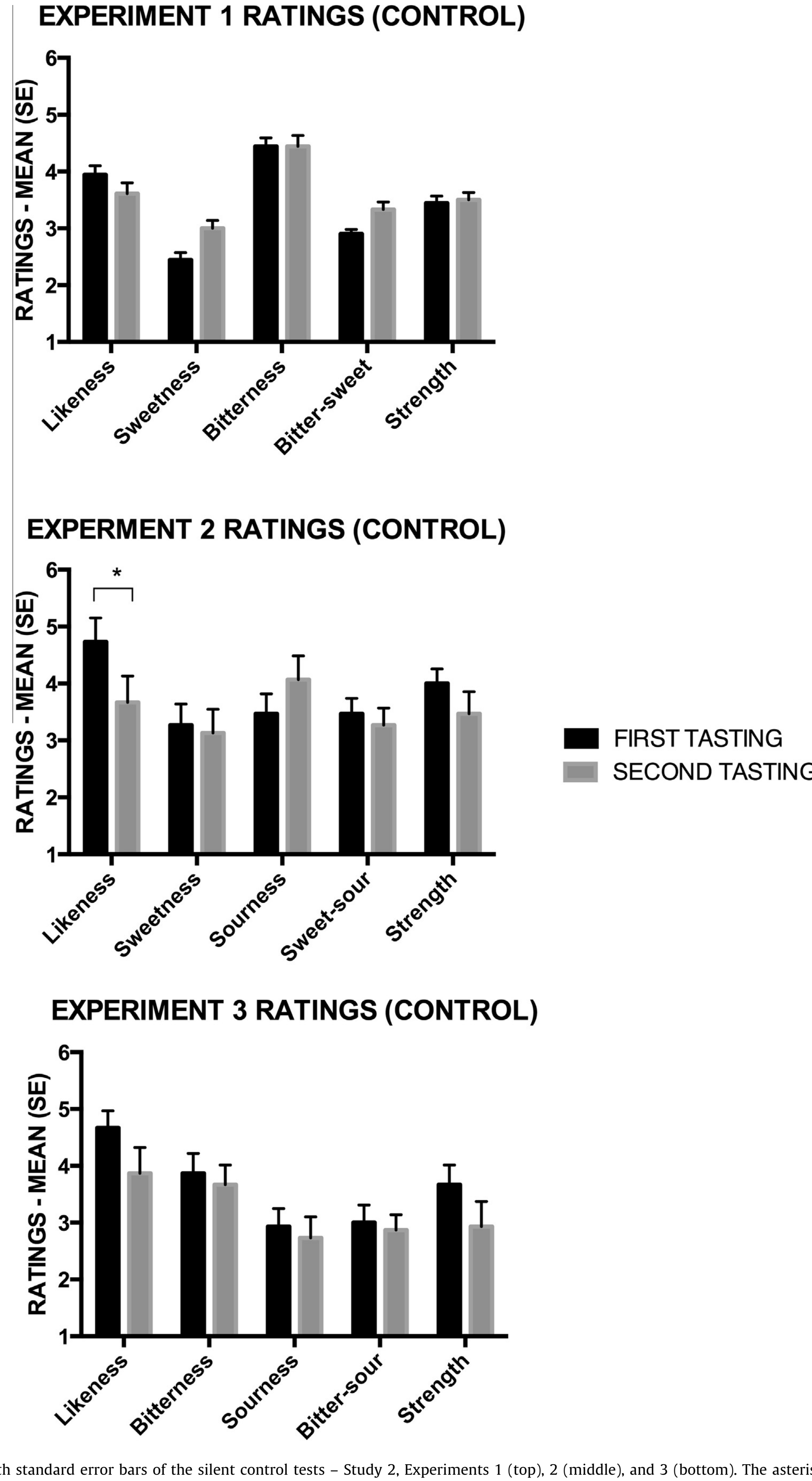

Fig. 3. Mean ratings with standard error bars of the silent control tests – Study 2, Experiments 1 (top), 2 (middle), and 3 (bottom). The asterisk '*' indicates a significant difference ($p < .05$).

Table 5
MANOVA results comparing measures of experience liking, taste ratings (single and contrast scale), and beer strength; between experiments while listening to a soundtrack versus no soundtrack. Bold text indicates statistical significance.

		F	Pillai's Trace	p
Experiment 1	Bitter soundtrack vs. control	F(5,143) = 1.46	0.05	0.21
	Sweet soundtrack vs. control	F(5,143) = 0.99	0.03	0.43
Experiment 2	Sour soundtrack vs. control	F(5,141) = 0.93	0.03	0.46
	Sweet soundtrack vs. control	F(5,141) = 1.16	0.04	0.33
Experiment 3	Bitter soundtrack vs. control	**F(5,134) = 5.44**	**0.17**	**<.0005**
	Sour soundtrack vs. control	F(5,134) = 1.62	0.06	0.16

associate alcoholic strength with flavor intensity. Future research in this area could perhaps focus on comparing, for example, how sweet/bitter songs are able modulate the perceived strength of sweet/bitter alcoholic beverages.

Some limitations that we encountered while analyzing our results are worth mentioning here. In particular, the fact that the bitter soundtrack enhanced both, bitter and sour ratings (see Fig. 2), might have to do with the fact that many people tend to confuse bitterness and sourness (Hettinger, Gent, Marks, & Frank, 1999; O'Mahony, Goldenberg, Stedmon, & Alford, 1979).[5] Since the sour and bitter soundtracks were mostly rated as unpleasant, we could also suppose that these soundtracks induced negative emotions, which could have diminished their potential modulatory effects (Storbeck & Clore, 2008). Future studies could focus on gathering more information about the emotional aspects involved in the experience of drinking beer while listening to music that we like versus music we dislike, in order to further analyze such implications of emotion on auditory taste modulation (i.e. Kantono et al., 2016; see Reinoso Carvalho, Touhafi, Steenhaut, Van Ee, & Velasco, submitted for publication-B).

Moreover, enhanced sweetness ratings were reported in Experiments 1 and 2. Yet, no effect on bitterness and sourness ratings were observed in any of the experiments. At first sight, this suggests that auditory taste modulation might be limited to cases of positive sensation transference (i.e., where the pleasant sweet soundtrack enhances sweet tastes but unpleasant soundtracks does not enhance unpleasant sour/bitter tastes). This suggestion is in-line with other recent findings (Crisinel et al., 2012; Reinoso Carvalho, Van Ee, Rychtarikova, et al., 2015; Wang & Spence, 2016). However, the beer's flavor itself might be part of the explanation for why no taste enhancement was observed by sour/bitter soundtracks. The Belgian beers used in the present study were already fairly bitter to begin with, so we might have encountered a ceiling effect with regard to bitterness ratings. On the other hand, sourness is not a common taste descriptor for most beers. For instance, future similar experiments could use a beer deliberately brewed for sourness – such as a lambic – and see if the assessments focusing on sourness are more conclusive. What is more, Fig. 2 shows that, while there were no significant differences between bitter and sour ratings in Experiment 3, the bitter soundtrack does, in fact, enhance both bitterness and sourness when compared to the control condition. This could be interpreted as an attentional bias, where the bitter soundtrack drew participants' attention to the bitter notes in the beer (see Spence & Wang, 2015, for a review of possible mechanisms behind the auditory modulation of taste).

One way to gain a better understanding of the underlying mechanism would be to refine the experimental design used in the present study. For instance, the sound stimuli can be systematically modified. The sweet soundtrack currently features high-pitched tinkling chimes. If the pitch is digitally lowered while keeping the consonant harmonies, would the soundtrack still evoke sweetness? Another idea would be to vary the timing of the sound stimuli onset. If participants hear the soundtrack only after tasting the beer, then any changes in taste ratings can probably be attributed to biased self-report – or the effect of sound on memory – rather than any genuine perceptual effects.

By now, this is one of many reports claiming to show that this may, indeed, be possible to produce soundtracks that make people perceive food/beverages as sweeter, more bitter, and/or more sour. Beyond using soundtracks that are made with such gastronomic objectives in mind (see Wang & Spence, 2015, for a comparison of such taste-specific soundtracks), it may also be possible to use, for example, pre-existing songs that were not necessarily produced with such specific objectives in mind, but which can be analyzed with the objective of understanding whether they might have the right sonic signature in order, for example, to modulate the perceived sweetness, bitterness and/or sourness (i.e., Mesz et al., 2012; Reinoso Carvalho et al., 2105c; Reinoso Carvalho et al., submitted for publication-A).

In summary, the results presented here demonstrate that soundtracks that had been specially developed to evoke a specific taste can effectively be used in order to influence the participants' beer tasting experience. Here, for the first time, we demonstrate that it is possible to systematic modulate the perceived taste and strength of beers, by means of customized sonic cues. Furthermore, we open possibilities of analyzing how the emotional aspects involved in sound-beer experiences can affect such multisensory correspondences. Since beer is widely consumed at gatherings, it is plausible to assume that music is commonly involved in beer tasting experiences. So, when we taste beer, we may be constantly under the multisensory effect of auditory cues. Therefore, more cases analyzing these potential modulatory effects, and others with special focus on how our emotional relation with music can have a significant impact on the perceived taste of beers, are still in demand.

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[5] On the other hand, sourness seems to be more difficult to evaluate when tasting beer. While sampling, more than one participant (especially French-speaking ones) inquired for more details when asked to rank the perceived sourness of the beer, from which we could deduce that sourness is not obviously perceived while tasting beer, while bitterness certainly is. It is intriguing, though, that Reinoso Carvalho et al. (submitted for publication-A) reported recently that a beer was perceived as significantly more sour, when consumed while listening to a song, versus when drinking in silence. In that case, the beer was produced in collaboration with a band – that composed the aforementioned song –, and a Belgian brewery. This beer was crafted using the same song as source of inspiration for its formula.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.foodqual.2016.03.009.

References

Auvray, M., & Spence, C. (2008). The multisensory perception of flavor. *Consciousness and Cognition, 17*, 1016–1031.

Brown, P. (2012). *Ale, ale, rock and roll!* Word Magazine. 28 March, 28–29.

Cheskin, L. (1972). *Marketing success: How to achieve it*.Boston, MA: Cahners Books.

Crisinel, A.-S., Cosser, S., King, S., Jones, R., Petrie, J., & Spence, C. (2012). A bittersweet symphony: Systematically modulating the taste of food by changing the sonic properties of the soundtrack playing in the background. *Food Quality and Preference, 24*, 201–204.

Crisinel, A.-S., & Spence, C. (2009). Implicit association between basic tastes and pitch. *Neuroscience Letters, 464*, 39–42.

Crisinel, A.-S., & Spence, C. (2010). As bitter as a trombone: Synesthetic correspondences in non-synesthetes between tastes and flavors and musical instruments and notes. *Attention, Perception, & Psychophysics, 72*, 1994–2002.

Hettinger, T. P., Gent, J. F., Marks, L. E., & Frank, M. E. (1999). A confusion matrix for the study of taste perception. *Perception & Psychophysics, 61*, 1510–1521.

Kantono, K., Hamid, N., Shepherd, D., Yoo, (JY)M., Grazioli, G., & Carr, T. B. (2016). Listening to music can influence hedonic and sensory perceptions of gelati. *Appetite*. http://dx.doi.org/10.1016/j.appet.2016.02.143.

Knoeferle, K. M., Woods, A., Käppler, F., & Spence, C. (2015). That sounds sweet: Using crossmodal correspondences to communicate gustatory attributes. *Psychology & Marketing, 32*, 107–120.

Kontukoski, M., Luomala, H., Mesz, B., Sigman, M., Trevisan, M., Rotola-Pukkila, M., et al. (2015). Sweet and sour: Music and taste associations. *Nutrition and Food Science, 45*, 357–376.

Mesz, B., Sigman, M., & Trevisan, M. A. (2012). A composition algorithm based on crossmodal taste-music correspondences. *Frontiers in Human Neuroscience, 6* (71), 1–6.

North, A. C. (2012). The effect of background music on the taste of wine. *British Journal of Psychology, 103*(3), 293–301.

O'Mahony, M., Goldenberg, M., Stedmon, J., & Alford, J. (1979). Confusion in the use of the taste adjectives 'sour' and 'bitter'. *Chemical Senses and Flavour, 4*, 301–318.

Reinoso Carvalho, F., Velasco, C., Van Ee, R., Rychtarikova, M., Leboeuf, Y., & Spence, C. (submitted for publication A). Music influences hedonic and taste ratings in beer. *Frontiers in Psychology*.

Reinoso Carvalho, F., Touhafi, A., Steenhaut, K., Van Ee, R., & Velasco, C. (submitted for publication B). Using sound to enhance taste experiences: An overview. *Proceedings of CMMR 2016*, São Paulo, Brazil.

Reinoso Carvalho, F., Van Ee, R., Rychtarikova, M., Touhafi, A., Steenhaut, K., Persoone, D., et al. (2015). Does music influence the multisensory tasting experience? *Journal of Sensory Studies, 30*(5), 404–412.

Reinoso Carvalho, F., Van Ee, R., Rychtarikova, M., Touhafi, A., Steenhaut, K., Persoone, D., et al. (2015). Using sound-taste correspondences to enhance the subjective value of tasting experiences. *Frontiers in Psychology, 6*, 1309.

Reinoso Carvalho, F., Van Ee, R., Touhafi, A., Steenhaut, K., Leman, M., & Rychtarikova, M. (2015). Assessing multisensory tasting experiences by means of customized sonic cues. In *Proceedings of Euronoise 2015* (352, pp. 1–6). Maastricht.

Spence, C. (2015a). Eating with our ears: Assessing the importance of the sounds of consumption to our perception and enjoyment of multisensory flavour experiences. *Flavour, 4*, 3.

Spence, C. (2015b). Multisensory flavor perception. *Cell, 161*(1), 24–35.

Spence, C., & Piqueras-Fiszman, B. (2014). *The perfect meal: The multisensory science of food and dining*.Oxford, UK: Wiley-Blackwell.

Spence, C., Velasco, C., & Knoeferle, K. (2014). A large sample study on the influence of the multisensory environment on the wine drinking experience. *Flavour, 3*, 8.

Spence, C., & Wang, Q. (J.) (2015). Wine & music (II): Can you taste the music? Modulating the experience of wine through music and sound. *Flavour, 4*, 33.

Stafford, L. D., Agobiani, E., & Fernandes, M. (2013). Perception of alcohol strength impaired by low and high volume distraction. *Food Quality and Preference, 28*, 470–474.

Stafford, L. D., Fernandes, M., & Agobiani, E. (2012). Effects of noise and distraction on alcohol perception. *Food Quality & Preference, 24*, 218–224.

Storbeck, J., & Clore, G. L. (2008). The affective regulation of cognitive priming. *Emotion, 8*(2), 208–215.

Velasco, C., Jones, R., King, S., & Spence, C. (2013). Assessing the influence of the multisensory environment on the whisky drinking experience. *Flavour, 2*, 23.

Wang, Q. (J.), & Spence, C. (2015a). Assessing the effect of musical congruency on wine tasting in a live performance setting. I-Perception, *6*, 3.

Wang, Q. (J.), & Spence, C. (2015b). Assessing the influence of the multisensory atmosphere on the taste of vodka. *Beverages, 1*, 204–217.

Wang, Q. (J.), & Spence, C. (2016). 'Striking a sour note': Assessing the influence of consonant and dissonant music on taste perception. *Multisensory Research, 29*, 195–208.