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What Is the Sound of Citrus?
Research on the Correspondences between the Perception of Sound and Flavour

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ABSTRACT

This study investigates systematic relationships between the perception of flavour and sound with regard to underlying inter-modal attributes and recognisability. The research was inspired by the question, if it is possible to express a flavour acoustically, which might be of practical interest, e.g., for audio branding applications. One preliminary and two main experiments were conducted, in which participants tasted or imagined two flavours ("orange" and "vanilla"), and had to perform several association and matching tasks. For the second main experiment, short audio logos and sound moods were specially designed to yield different citrus-like sounds.

A wide range of significant differences between the two flavour conditions were found, from which musical parameters could be extracted that are suitable to represent the flavours of "orange" and "vanilla". Furthermore, a few significant differences between imagined and tasted stimuli showed up as well, hinting at an interference of visual associations. In the second experiment, subjects were reliably able to identify the principal flavour attributes from sound stimuli alone and to distinguish different degrees of citrus-sounds.

I. INTRODUCTION

All sensory channels share one or more underlying properties, so called inter-sensual attributes, e.g., intensity (weak–strong), brightness (high–low), volume (size, coverage), roughness, density (Werner, 1966). This common ground of modalities is already reflected in everyday language metaphors and analogies (a "high" tone, a "sharp" sound, "warm" colour, etc.) There seem to be innate cross-modal mechanisms that are present in all of us, not just in proper synesthetes. Cross-modality matching experiments have shown that correspondences of stimuli from different modalities exhibit systematic patterns. High pitch is reliably associated with lighter colours, higher brightness with higher loudness and so on (Stevens, 1966). Von Hornbostel (1927) demonstrated in experiments that brightness as generic attribute could work to show inter-modal analogies between colour, pitch, and smell. Up to the present day only very few studies have examined correlations between the perception of sound and taste (Holt-Hansen 1968, 1976; Rudmin & Capelli 1983; Chrisinel & Spence 2009, 2010). The aim of the presented study is to validate methods for the investigation of the relationship between perception of sounds and flavours.

A. Aims and Questions

The starting point of the present study was the question "What is the sound of citrus? Is it possible to express a flavour acoustically? Is there a connection between the perception of flavour and sound?" The human perceptual system is designed to process multi-sensory data. The perceptions from different modalities have to be integrated to form holistic objects. When we eat an apple, we taste it, but we also hear the sound it makes of biting and chewing. We feel its surface, see its shape and colour, and smell it. All these perceptions pertain to the holistic mental object "apple", which is connected to a huge variety of possible associations of different kinds, e.g., cultural stereotypes or individual experiences. To discover correspondences in the perception of sound and flavour and to find out matching sounds for a certain flavour, the main idea was to use a "tertium comparationis", viz. generic attributes.

B. Preliminary Study

To corroborate the working hypothesis, that sound and flavour can be perceptually related with inter-modal analogies, a preliminary study was carried out. Three short sound samples of 4 seconds length each were chosen from a sound library, representing the flavour attributes "sweet", "sweet-sour", "sour". According to the concept of generic attributes and inter-modal analogies, it was supposed that a sound representing a sour taste should sound sharp and bright, a sweet should sound soft, warm, and round, and the sweet–sour sound should combine sweet and sour sounds. Hence, the sound samples should differ from each other in the psychoacoustic parameter sharpness, which increases with the proportion of high frequency content in the signal. A visual comparison of the spectrograms of the sound samples showed that the pre-selected sour sound contained the highest proportion of high frequencies and the sweet sound the least.

Fourteen participants (4 female, 10 male, age range 22-66) took part in the experiment, who had to judge the sound on six adjectives: "süß" ("sweet"), "sauer" ("sour"), "salzig" ("salty"), "bitter" ("bitter"), "scharf" ("hot, spicy"), "mild" ("mild"). If the subjects found no suitable match for an adjective, they could choose a "no flavour" option. The participants could listen to the sound samples as often as they wanted to. The labels (sweet, sweet-sour, sour) were not communicated to the participants. Results are shown in Fig. 1. The "sweet" sound sample was only labelled as "sweet" and "mild" by the subjects. The "sweet-sour" sound sample was accordingly labelled as sweet and sour. The "sour" sound sample scored highest in the attributes sour and bitter.

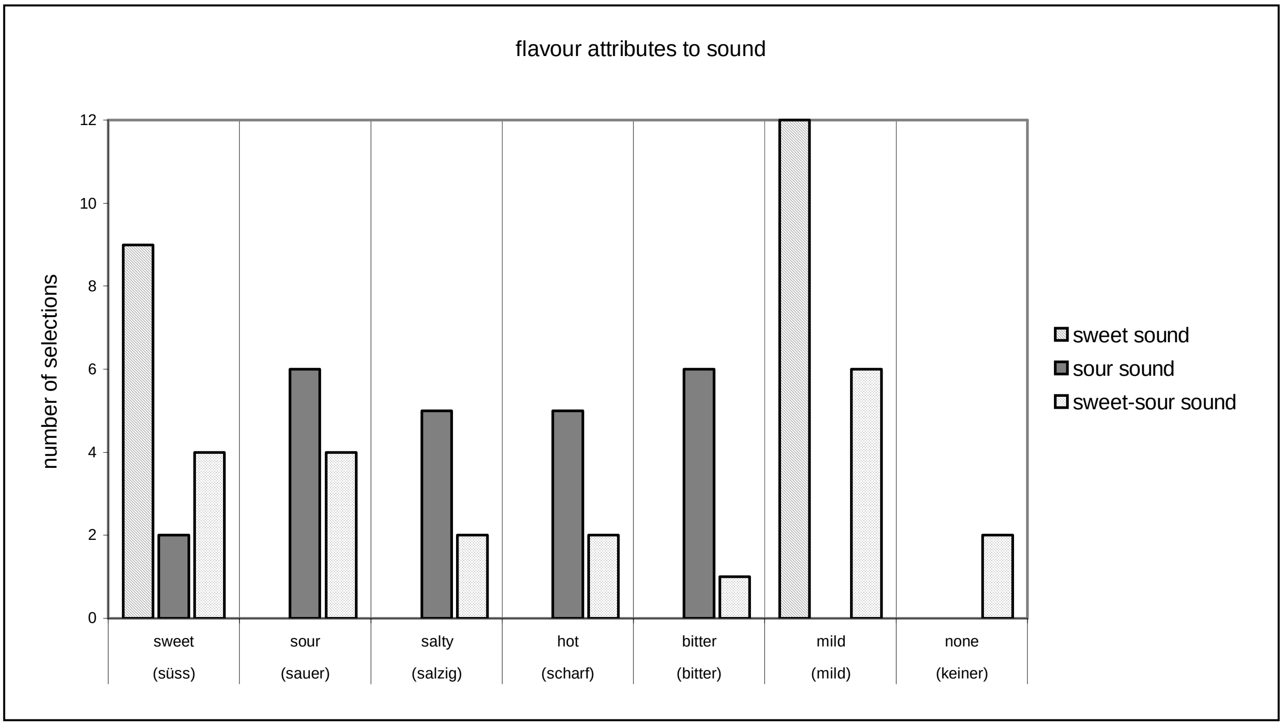

Figure 1. Results of the preliminary study. Associations to different "flavoured" sounds.

The results indicated that the sound samples elicited distinct flavour associations, mainly the difference between sweet/mild and sour/bitter was salient. The results showed consistent and plausible patterns which encouraged the investigators to conduct a main study in order to examine the relation of the perception of sound and flavour in more details.

II. MAIN STUDY

The main study comprised two stages. Based on the results of the first stage different pieces of sound were composed that served as stimuli for the second stage.

A. Experiment

1) Participants. 85 subjects participated in the first experiment: 55 male, 30 female, age range: 6 subjects between 14-29 years, 29 between 20-29, 29 between 30-39, 13 between 40-49, 4 between 50-65, 4 subjects were older than 65 years. There was a prevalence of high level of education in the sample: 61% of the participants were university graduates. With respect to age and gender, the participants were spread as equally as possible over four groups.

2) Procedure. The four groups of participants were exposed to four different experimental conditions. Two groups were presented drinks as main stimuli. One group had to evaluate an orange flavoured drink (water, sugar, orange flavour, citric acid E-330) the other a vanilla flavoured drink (water, sugar, vanilla flavour). Both drinks were colourless and presented in transparent plastic cups. The subjects were not told which kind of flavour they received. The other two groups had to imagine either the flavour of orange or the flavour of vanilla. Sound stimuli and questionnaires were the same for all four groups.

Questionnaires, tasks and sound stimuli were presented via a web browser on computer screens and headphones. The ratings and selections of the subjects were recorded in an online database. Before the participants started with the tasks, they had to answer questions about their gender, age, education and current occupation. Then they could hear a probe tone in order to adjust the sound level and to check the proper working of the system.

The experiment started with a free association task. The participants had to list associations that came to their minds in response to the flavour stimuli. In the following task the participants should evaluate the flavour stimulus (real resp. imagined) on a set of 10 bipolar adjective pairs using a five point rating scale: *high–low* ("hoch–tief"), *dark–bright* ("dunkel–hell"), *acute–dull* ("spitz–stumpf"), *light–heavy* (leicht–schwer), *cold–warm* ("kalt–warm"), *quiet–loud* ("leise–laut"), *regular–random* ("geordnet–chaotisch"), *complex–simple* ("komplex–einfach"), *angular–round* ("eckig–rund"), *smooth–rough* ("glatt–rau"). In the next six tasks, subjects should select one of three sound samples that matched best their respective flavour stimulus. In each task a certain musical or acoustical parameter such as timbre, brightness, rhythm, articulation (legato-staccato) was presented in three different degrees. Directly after the selection of a sound sample the subjects had to choose one of three pictures that matched best the selected sound sample. The pictures were designed to show some visual analogies to the three sound samples. For instance, the subjects could choose between a straight, a jagged and a wavy line or a pattern in three different degrees of contrast. After every selection they could optionally mark a field indicating that they found it very difficult to make a selection ("Die Auswahl ist mir sehr schwer gefallen"). After finishing all tasks, the subjects had the possibility to give feedback on how they managed the tasks, and if they had particular difficulties. Finally, they were asked if they were practicing music themselves.

Only 6% of all cases, the participants marked a field indicating that they found it very difficult to make a selection. It took the participants between 12 and 20 minutes to complete the tasks. The written feedback of the participants evidenced good overall comprehension und usability of the test procedure.

B. Results of the First Experiment

1) Association task. A multiple analysis of variance (MANOVA) was carried out for the adjective ratings with flavour type, tasting/imagination, gender and age category as factors. Since gender and age showed no significant influence except for some marginal interactions, both factors were discarded for a second MANOVA on which we report here.

Highly significant differences could be found for the tasting/imagination condition (F(9,69)= 3.16, p=0.003**) and for flavour type (F(9,69)=6.872, p=0.000***). There was also a highly significant interactions of lab and flavour (F(9,69)=4.187, p=0.000***). Investigating those results further, it showed that flavour type produced highly significant differences on *all* adjective pairs except for *light–heavy* (p=0.50) and *angular–round* (p=0.09), as well as only a moderate significance for *dark–bright* (p=0.033*). Ratings of the orange and vanilla flavoured drinks on the bipolar scales showed highest contrast on the adjective pairs *acute–dull* (p=0.000***), *quiet–loud* (p=0.000***) *smooth–rough* (p=0.000***) and *high–low* (p=0.002**). In terms of generic attributes, the *high–low* continuum can be assigned to the inter-modal dimension of “brightness”, *acute–dull*, *smooth–coarse* to the inter-modal dimension of “roughness”, and *quiet–loud* belongs to “intensity”. In these terms, the orange flavour was generally rated as brighter, rougher and more intense than the vanilla taste.

The factor tasting/imagination showed significance only for *acute–dull* (p=0.002**), *cold–warm* (p=0.000***), and *angular-round* (p=0.000***). For *acute–dull* and *angular–round* there were also significant interactions. A comparison of the results from the group which actually tasted orange flavour with the group that imagined the flavour of orange, showed considerable differences on the scales *round–angular*, *acute–dull*. The group that had to imagine the flavour rated it much more *round* (mean=4.24 as compared to 3.42 in the taste group) and much more *dull* (mean=3.31 as compared to 2.65 in the taste group). The reason for these differences might be due the fact that the mere imagination of the orange flavour evokes also the visual imagination of the round shape of an orange and hence influences ratings on the scales *round–angular* and *acute–dull*. In contrast, the subjects that rated the drink were not told that it was orange flavoured. The feedback of some participants and the results of the free association tasks are underpinning this assumption. The subjects who had to imagine the orange flavour mentioned terms like “round” (“rund”), “round fruit” (“runde Frucht”) and “ball” (“Kugel”), whereas the group with the orange flavoured drink did not mentioned such terms. Evaluation and ratings of the orange stimuli (real taste und imagined taste) showed a more ambiguous tendency compared with results of the vanilla stimuli, which were much more homogenous. This might be caused by the fact that orange combines the tastes “sweet” and “sour” whereas vanilla is only “sweet”.

2) Matching tasks. In order to assess possible differences in the following 14 matching tasks, we used only the data from the taste group, in which the subjects were actually tasting the flavours. 14 Kruskal-Wallis-tests were carried out with flavour as factor. We applied a Bonferoni-correction for multiple testing. Only three significant differences survived:

a) *Matching flavours to sound samples*. In this task one and the same melody was presented in three different timbres. The timbres were designed with respect to the results of the preliminary study and differed strongly in the musical parameter brightness/sharpness. The internal labels for the three sound samples were “vanilla”, “orange”, “lemon”. The “lemon” sound had a very sharp and bright timbre, the “orange” sound a less sharp timbre, and the “vanilla” sound a soft and dull timbre. From the subjects that tasted the vanilla flavour, 86% selected the “vanilla” sound sample and 14% the “orange” sound sample as the best match. In the group that had to assign the orange flavoured drink, 50% chose “orange”, 30% “lemon” and 20% “vanilla”.

b) *Matching flavours to melodies with different ambitus*. Subjects were also asked to choose one of three short melodies that differed in the tone ambitus, i.e., the range between the lowest and the highest tone. In the vanilla group 85% selected the sample with the smallest ambitus, 15% the middle range and no one the sample with the largest ambitus. In the orange group, 21% selected the smallest ambitus, 53% the middle range ambitus and 26% the largest one.

c) *Matching flavours to picture*. In another task, subjects had to assign pictures showing different kind of horizontal lines to the selected sound. In the vanilla group, 86% chose the wavy line, and 7% each the straight or the jagged one. In the orange group, 55% selected the jagged, 40% the wavy, and 5% the straight line.

By taking the clearest tendencies for each matching task, a list of suggestions (see Tab. 1) for musical parameters could be compiled which seem the most suitable for representing the tested flavours.

Table 1. Best fitting musical parameters for orange and vanilla flavour

Parameter	Orange	Vanilla
Timbre	Bright, fairly sharp and rough	Soft, dull, not sharp or rough
Articulation	Staccato, accentuated, dynamic	Legato, even, little dynamics
Rhythm	Syncopated	Even
Melody	Medium to large intervals	Small intervals, consonant
Ambitus	Mid to large range	Small range
Tempo	Lively and fast	Rather slow

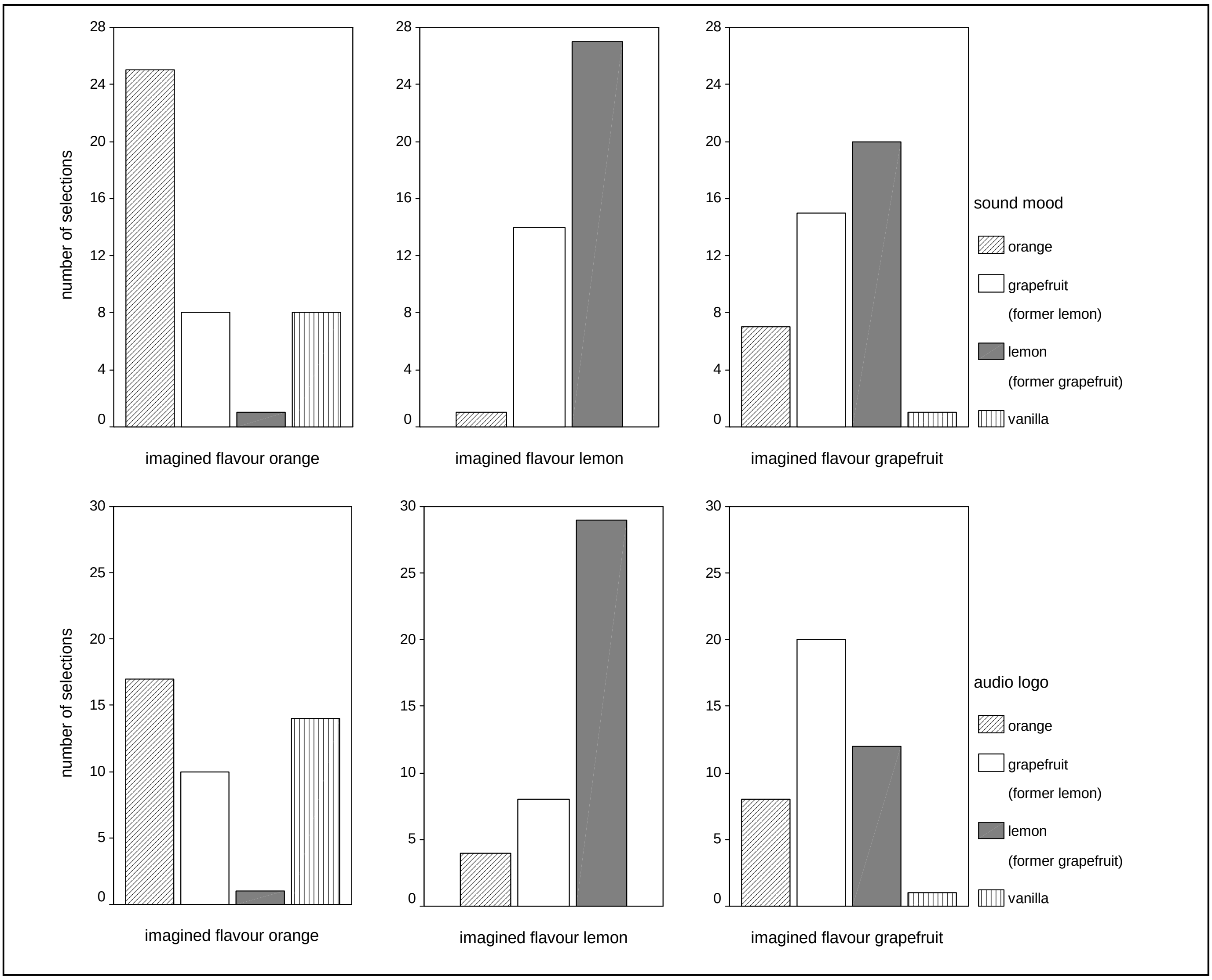

Figure 2. Selection of sound moods and audio logos for the imagined flavours "vanilla", "orange", "grapefruit", "lemon"

C. Second Experiment

1) Participants. 43 subjects participated in the second experiment: 27 males, 16 females, age range: 3 subjects between 14-29 years, 21 between 20-29, 8 between 30-39, 4 between 40-49, 4 between 50-65, 3 subjects over 65 years. High level of education: 56% university graduates. With respect to age and gender, the participants were spread as equally as possible over four groups.

2) Procedure. The overall test procedure was the same as in the first experiment. Based on the findings of the first experiment with respect to the best fitting musical parameters for vanilla and orange flavours, sound elements with duration of 4 seconds (called audio logos) and 16 seconds (called sound moods) were created. The orange sound elements were also varied in their degree of intensity and sharpness, supposed to match three different kind of citrus flavours in respect to their degree of sourness, namely orange, lemon and grapefruit, resulting in 4 different audio logos and sound moods each (orange, lemon, grapefruit, vanilla).

It took the participants between 10 and 16 minutes to complete the tasks. The written feedback of the participants evidenced good overall comprehension und usability of the test procedure.

D. Results from the Second Experiment

Most of the results from the second experiment basically replicated the results of the first experiment. A detailed analysis will be given elsewhere. Instead we will focus on the results of the matching tasks.

All participants had to imagine the flavours of orange, lemon and grapefruit and to select one of the 4 audio logos (orange, lemon, grapefruit, vanilla) that matched best the respective flavour. The same task had to be performed with the sound moods in lieu of the audio logos. Fig. 2 shows the selections of the subjects. χ^{2-}tests indicated significant results for all 6 tasks.

The orange sound mood was detected correctly by 60% of the subjects ($\chi^2(3) = 29.8$, $p < .001$), the orange audio logo by 41% ($\chi^2(3) = 13.8$, $p < .01$). Lemon sound mood was correctly detected by 65% ($\chi^2(2) = 24.1$, $p < .001$), the lemon audio logo by 69% ($\chi^2(2) = 26.3$, $p < .001$). Grapefruit sound mood was detected by 35% ($\chi^2(3) = 19.7$, $p < .001$) and the grapefruit audio logo by 49% ($\chi^2(2) = 18.4$, $p < .001$).

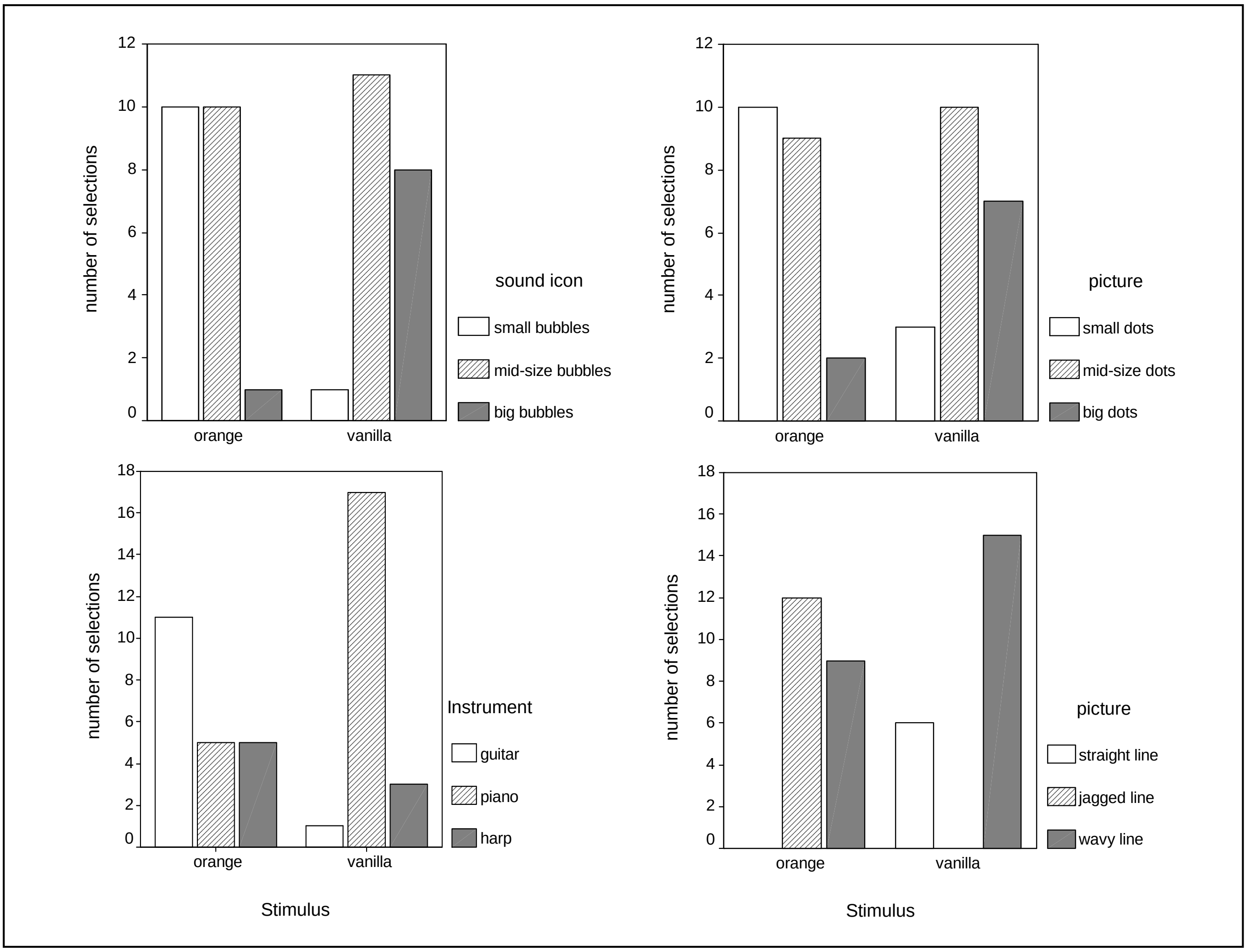

Figure 3. Participants' selections of sound icons, dot sizes, instrument sounds and lines

During the design of the citrus sounds (orange, lemon, grapefruit) which should differ from each other in the degree of intensity and sharpness in order to match different levels of sourness, orange was thought to be the least sour one, grapefruit the most sour one and lemon in between. But the results of matching sound pieces to flavours as well as the feedback of the subjects made us change the labels of the sounds afterwards. The sound pieces initially called "grapefruit" were more frequently detected as "lemon" and vice versa.

Another observation was that the imagined flavour "lemon" has not been assigned to the "vanilla" sounds at least once, and only in 6% of all cases to the "orange" sounds. On the other hand, the imagined flavour "grapefruit" was assigned to the "vanilla" sounds in 2% of all cases and to the "orange" sounds in 18% of all cases.

This was also an indication to change the labels of the lemon and grapefruit sound pieces afterwards. Yet worth noting is that the imagined flavour "orange" was most frequently assigned to the "vanilla" sounds (in 22% of all cases). With regard to the real flavours of the citrus fruits, lemon being definitely sour, orange sour and sweet, and grapefruit not as sour as lemon but rather bitter, the selections of the subjects seem plausible. Besides it suggests that the subjects based their decisions on different levels of sourness and sweetness which could be perceived in the presented sound stimuli.

In the free association task of the first experiment for the vanilla stimuli, terms such as "ice cream", "pudding", "milk" were mentioned. For the orange stimuli terms like "juice", "juicy", "fizzy", "fresh", "fizzy drink" were recorded. The reason for associating these terms is obvious: dairy products, ice cream and pudding are often flavoured with vanilla. Orange juice is the prototypical juice, and refreshing, carbonated drinks are frequently flavoured with orange.

Following these considerations, the participants had to choose between three "bubbling" sound icons in the second experiment. The first sound icon represented fizzy, carbonated beverages with the sound of many, small, fast bursting bubbles (higher frequencies), the second represented dairy products and pudding with few, bigger, slowly bursting bubbles (lower frequencies), and the third sound icon was located somewhere between in the two others with respect to number, rate and frequency range of bursting bubbles. After selecting one of the sound icons, the participants had to choose one of three pictures that matched best the selected sound. The pictures showed either many, small dots, several mid-size dots, or few big dots.

In the group with the orange stimulus 10 of 21 subjects (48%) selected the sound icon with small bubbles, 10 subjects (48%) the sound icon with mid-size bubbles and 1 subject (4%) selected the sound icon with big bubbles. In the vanilla group 1 of 20 subjects (5%) chose the sound icon with small bubbles, 11 subjects (55%) the sound icon with mid-size bubbles and 8 subjects (40%) selected the sound icon with big bubbles. A χ^2-test ($\chi^{2(}2$) = 12.8, p<.01) indicated that the ratings are dependent on the stimuli and not made at random. Assigning pictures to the selected sound icon, in the group with the orange stimulus 10 of 21 subjects (48%) selected the picture with small dots, 9 subjects (43%) the picture with mid-size dots and 2 subjects (9%) selected the big dots. In the vanilla group 3 of 20 subjects (15 %) selected the small dots, 10 subjects (50 %) the mid-size dots and 7 subjects (35 %) the picture with the big dots. A chi square test $\chi^2(2) = 6.6$, p<.05 indicated significant results for this task as well.

The participants had also to assign one of three sound samples that were composed of short tone sequences played by either a guitar or a piano or a harp. After selecting one of the sound samples the participants had to choose one of three pictures that matched best the selected sound sample. The pictures showed either a straight line or a jagged line or a wavy line. In the group with the orange stimulus 11 of 21 subjects (52%) selected the guitar sample, 5 subjects (24%) the piano sample and 5 subjects (24%) the harp sample. In the vanilla group 1 of 21 subjects (5%) selected the guitar sample, 17 subjects (81%) the piano sample and 3 subjects (14%) the harp sample.

A chi-squared test χ^2 (2) = 15.4, p< .001 indicated a relationship between stimuli and ratings. Assigning pictures to the selected sound sample, in the group with the orange stimulus no subject selected the straight line, 12 of 21 subjects (57 %) selected the jagged line and 9 subjects (43 %) the wavy line. In the vanilla group 6 of 21 subjects (29 %) selected the straight line, no one the jagged line and 15 subjects (71 %) the wavy one. The results of a chi square test test χ^2 (2) = 19.5, p < .001 indicated that the differences between the orange and the vanilla group are also significant. All the ratings of sound icons, instruments and pictures are shown in Fig. 3.

III. SUMMARY AND DISCUSSION

Both experiments showed that it is possible for subjects to differentiate acoustically between the flavours of orange and vanilla. Combinations of musical parameters have been identified that are suitable to represent the flavours of orange and vanilla. Moreover, the results of the second experiment indicate that the subjects were able to map the citrus flavours orange, grapefruit and lemon to different sound samples by basing their decisions on different levels of sourness and sweetness they could perceive in the presented sound samples. The degree of intensity and sharpness of the sound samples seems to correspond to the flavours in relation to their degree of sourness. The more intense and sharp the sound samples are, the higher is the perceived sourness: orange least sour, lemon most sour, grapefruit between orange and lemon.

In terms of generic attributes, manipulations along the *weak–strong* and *acute–dull* axes of the inter-modal dimensions intensity and roughness/brightness caused corresponding perceptions of the stimuli across the gustatory and the auditory modality. This suggests that a cross-modality matching as described by Stevens (1966) can also work between a gustatory (flavour) and an auditory (sound) stimulus. The findings are also in line with more recent studies about the correspondences between flavour and music/sound (Spence & Crisinel 2010; Mesz, Marcos, Trevisan & Sigman, 2011).

The most notable differences between the evaluations of the orange and vanilla flavoured drinks on the bipolar adjective pairs were found on the scales *high–low*, *acute–dull*, *angular–round*, *quiet–loud*, and *smooth–rough*. Consequently these scales were most suitable to convey a certain taste into sound. It turned out that the scale *bright–dim*, representing the inter-modal dimension of brightness, was not well suited for the assessment of the presented flavours. Instead the scale *high–low*, which shares an affinity to *dark–bright* and can be assigned to the inter-modal dimension of brightness, proved to be more suitable.

The verbalization of sensory perception requires higher levels of cognitive processing in the brain whereas the formation of analogies mainly happens in lower levels. This “detour” of information processing can bias the outcome. Therefore the verbalization of sensory perception contains some difficulties (cf. Haverkamp 2002). Considering these possible difficulties and to test visual and tactile correspondences the subjects had to match different pictures showing some visual analogies and in one case they had to match one of three sandpapers differing in their degree of coarseness. The matching of pictures and sandpapers showed corresponding parallels to the selection of sound stimuli with regard to generic attributes/inter-modal analogies. The use of sound icons (bursting bubbles) in the second experiment was based on the associations that were given by the subjects with regard to the flavours in the first experiment. This strategy of establishing cross-sensory connections called iconic coupling refers to objects in memory and is based on learning and experience of the subject (Haverkamp 2009). The mappings of orange and vanilla stimuli to the sound icons showed significant differences in the predicted way. As iconic coupling depends on living environment and cultural background of an individual, the same test conducted with subjects from another cultural background, however, could give different results.

The results indicate that the subjects used the basic tastes sweet and sour respectively their acoustic correspondents via intermodal analogies as main criteria for evaluating flavour and sound stimuli and matching flavours and sounds. Though the tests show good evidence that it is possible to describe different levels of sourness/taste intensity by means of diverse combinations of musical parameters. However, it seems more difficult to differentiate acoustically between two sweet and mild flavours like vanilla and coco or between a bitter and a salty flavour, e.g. coffee and bacon. For the future we plan to validate our findings with a larger number of participants and to refine the used methodology. To proof the applicability of the methods and to test if they also work with olfaction, the other flavour related sense, different tastes and scents shall be used as stimuli.

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