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The Dictionary for Multidisciplinary Music Integration (DiMMI) is a proceedings series about the event organized by the University of Trento and the Conservatory "F. A. Bonporti" of Trento and Riva del Garda, in which musicians and representatives of the academic world are called to reflect together on a word of common interest, each from the perspective of their own discipline.

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Crossmodal Correspondence between Pitch Height and Olfactory Categories

Michelle Caldana and Elena Rusconi

Department of Psychology and Cognitive Science, University of Trento, Rovereto, Italy

Abstract

To date, not all crossmodal correspondences can be fully explained by statistical, semantic, linguistic or hedonic accounts. It has been hypothesised that the crossmodal correspondence between odours and auditory pitch may subtend a structural basis and originate in neural mechanisms intrinsic to the general organisation of sensory experience. Here we show that the same olfactory categories that have been shown to give rise to a vertical stimulus-response compatibility effect (SRC) are systematically associated with high and low tones, suggesting access to a common vertical spatial representation. The investigation of this type of crossmodal correspondence could help further our understanding of how we experience music and more generally of the architecture of our cognitive system, by identifying possible structural determinants underlying crossmodal correspondences.

1 Introduction

Crossmodal correspondences are consistent associations between certain attributes and dimensions in different sensory modalities [Spence, 2011]. Verbalizing olfactory perceptions is notoriously challenging and descriptors are frequently borrowed from other sensory modalities, which makes olfaction of particular interest in the field of crossmodal correspondences. This also suggests that the unisensory experience as we know it may in fact be the result of simultaneous contamination by other senses. To date, numerous correspondences between olfaction and other senses have been documented (e.g. [Gilbert et al., 1996, Belkin et al., 1997, Dematte et al., 2006, Hanson-Vaux et al., 2013]). Certain correspondences are easily ascribable to a specific mechanism. For example, those between odours and colours can be explained in terms of semantic mediation, and those between odours and thermal attributes through internalisation of environmental statistics. However, some peculiar correspondences between odours and contingent features, such as auditory pitch, are more difficult to explain. For example, odours and tones hardly co-occur in the environment, which may rule out a statistical account. The use of a lexicon referring to a common semantic field (high and low in the case of pitch; top and base in the case of olfactory notes) is unlikely to be the primary cause of this association since for the olfactory domain it occurs almost exclusively within the perfume industry. Finally, pitch choice for a given odour is not guided by hedonic values [Stevenson et al., 2012, Crisinel & Spence, 2012, Crisinel et al., 2013, Ward et al., 2022]. Deroy et al. [Deroy et al., 2013] proposed that this could be a case of structural correspondence, that is mediated by a common neural substrate or mechanism involving a structural feature. For instance, access to a common spatial representation. In support of this hypothesis, Caldana and Rusconi [Caldana & Rusconi, 2023] reported that, similarly to the auditory domain, where pitch evokes a subjective experience of spatial elevation and can also influence spatial response selection (e.g., [Pratt, 1930, Rusconi et al., 2006]), olfactory notes that across the literature have been individually associated with high tones (lemon, bergamot, orange) and low tones (coffee, caramel, vanilla), and that can be grouped into categories referred to as examples of top and base notes by professionals (e.g. fruity and gourmand), can also give rise to a vertical SRC effect. This effect does not correlate with the degree of perceived pleasantness, intensity, perceived lightness/heaviness, or correct odour recognition. However, in Caldana and Rusconi's study [Caldana & Rusconi, 2023], the rela-

tionship between such olfactory categories and tonal pitch was not explicitly investigated. It is therefore unknown whether such categories of stimuli would indeed give rise to crossmodal correspondences with auditory pitch. In this study, we investigate the presence of crossmodal associations between auditory pitch and the olfactory categories that in Caldana and Rusconi have originated a spatial SRC effect, by testing participants with an explicit association task, as part of a larger study. More precisely, we predict that odours in the fruity category will be associated with tones that are significantly higher in frequency than those with which odours in the gourmand category will be associated.

2 Methods

2.1 Stimuli and Procedure

We used the same six odorants as used by Caldana and Rusconi [Caldana & Rusconi, 2023]: bergamot, lemon and orange for the fruity category, caramel, coffee and vanilla for the gourmand category. Each odorant was delivered for 1,200 ms, with an inter-stimulus-interval of at least 11s, via a nosepiece connected to an olfactometer. During the task, an odorant could be reassessed for a maximum of two times by pressing an ad hoc key. Crossmodal correspondences were probed with pure tones having a range of frequencies from 65 Hz to 1,046 Hz; participants could play and evaluate as many tones as desired by moving the cursor on a slider, where pitch gradually changed in a horizontal direction, and pressing the "listen" button with a mouse click. Each tone lasted 1,500 ms and was presented over closed-ear headphones (HP, gaming OMEN blast) at a loudness of 70 dB [Crisinel & Spence, 2012, Crisinel et al., 2013, Ward et al., 2022]. The slider, subtending 26° degrees of visual angle in width, was centered on a PC screen positioned in front of the participant. The direction of pitch increase was counterbalanced (for half of the participants it was from right to left, for the rest from left to right) and responses were given by pressing with a mouse click the on-screen "confirm" button. Participants were then asked to score the degree of perceived heaviness/lightness of each of the 6 odorants, presented in random order, by selecting a number from 1 (extremely heavy) to 7 (extremely light) on a keyboard attached to the computer. The same procedure was used to assess the degree of perceived pleasantness (1 for extremely unpleasant; 7 for extremely pleasant), and intensity (1 for extremely weak; 7 for extremely strong). Finally, the 6 odorants were presented individually in random order and participants were required to locate in a list of 12 (lemon, pine, orange, cherry, green apple, bergamot, caramel, musk, coffee, lavender, banana, vanilla) the odour just delivered.

3 Results

3.1 Participants

One hundred and fourteen participants were tested. Four (3M, 1F; all right-handed; age: M = 25.5, SD = 8.5) were excluded due to failure to reach the cut-off (10 correct identifications out of 12) at the Sniffin' Sticks Screening Test (ODOFINTM). The rest (N = 110; 25M, 85F; Age: M = 24, SD = 7) reached or exceeded the cutoff and did not report any professional experience related to perfumes.

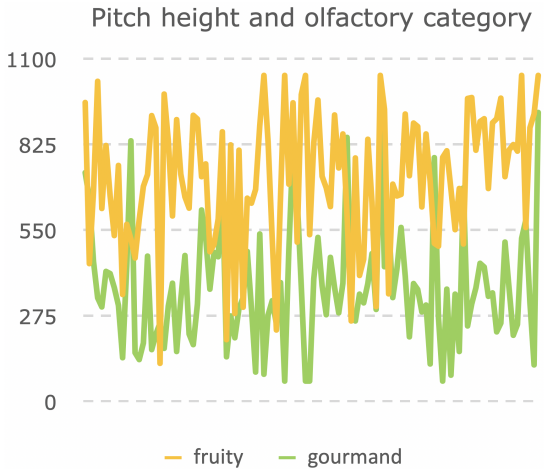

Figure 1: *The plot shows the median frequency of tones associated to fruity odours (in orange) and to gourmand odours (in green) for each of the 110 participants in the study (each corresponding to a point on the x-axis).*

3.2 Crossmodal Correspondence between Pitch Height and Olfactory Categories

Participants associated tones of higher frequency to fruity odors (M of medians = 717, SD = 212) than to gourmand odours (M of medians = 364, SD = 188; Figure 1). Because the distribution of frequencies associated to fruity odours did not significantly deviate from normality ($p = .055$) but the distribution of frequencies associated to gourmand odours did ($p < .001$), a Wilcoxon Signed-Rank test was performed. The test detected a significant difference between fruity and gourmand odours ($z = 8.277$, $p < .001$, matched rank biserial $r = .91$, SE = .11). A Bayesian version of the test, with data augmented using 5 chains of 5000 iterations, returned a BF10 superior to 5, indicating very strong evidence in favour of the alternative hypothesis ($BF10 = 9.095 \times 109$, $W = 5828$, $Rhat = 1.786$). For only 12 out of 110 participants the difference between the median frequency associated with fruity odours and the median frequency associated with gourmand odours was a negative number. A series of Spearman correlations did not detect any significant associations between

such difference and the difference between fruity and gourmand odours in their median scores of pleasantness, heaviness/lightness, intensity or in their percentage of correct recognition (all ps > .127), even though fruity odours were perceived as significantly more pleasant, lighter and less intense than gourmand odours (all ps < .009) and were better recognized than gourmand odours (p = .013).

4 Discussion

The association between odorants and tones appears to be one of the most intuitive crossmodal correspondences. In the middle of the 19th century, Septimus Piesse created the "Gamut of odors", one of the first and most notorious examples of spontaneous association between olfactory and auditory notes. He suggested that scent creation has analogies with music composition, as they both entail a harmonious combination of notes [Di Stefano et al., 2021, Spence, 2021]. In fact, to date, numerous examples of contamination between olfaction and music in the arts and entertainment scene have been proposed, to enhance multisensory processing without additional cognitive load, improve the quality of the experience and user enjoyment [Spence, 2021, Murray et al., 2016]. This study demonstrates that olfactory notes (fruity and gourmand), which are mapped by professionals onto higher and lower positions of the olfactory pyramid and can give rise to a vertical SRC effect [Caldana & Rusconi, 2023], are spontaneously associated to high- and low-pitch sounds in a consistent way across participants. This differential association is not correlated with differences in perceived pleasantness, intensity and lightness/heaviness of the two odour categories, or in the accuracy of their recognition. This rules out explanations in terms of statistical, language/semantic or hedonic accounts but is consistent with the hypothesis of a common (or analogous) spatial representation elicited by olfactory and auditory stimuli [Deroy et al., 2013]. To localize stimuli in physical space, both the olfactory and the auditory systems employ receptors with a fixed position. Localization of olfactory and auditory stimuli on the horizontal axis reflects a birhinal or binaural comparison of onset/duration and intensities, that are subsequently analysed and integrated centrally to construct a representation of auditory and olfactory spaces [Bao et al., 2019]. Localization on the vertical axis is generally poor in physical space (e.g. [Yost & Nielsen, 2000, Porter et al., 2007]) and it appears that certain stimulus characteristics are spontaneously mapped on a vertical direction instead. In the auditory domain, pitch height can evoke an experience of spatial elevation and consistently influence spatial response selection [Pratt, 1930, Rusconi et al., 2006]. In the olfactory domain, preliminary evidence suggests that certain categories of olfactory stimuli (which happen to be crossmodally associated high and low tones) may also influence spatial response selection [Caldana & Rusconi, 2023]. This line of investigation looks promising and may lead to a better understanding of the mechanism subtending this peculiar type of crossmodal correspondence, In addition to fostering contaminations in music, sound and art.

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