Appetite 125 (2018) 244–252

Contents lists available at ScienceDirect

Appetite

journal homepage: www.elsevier.com/locate/appet

Multisensory flavor perception: The relationship between congruency, pleasantness, and odor referral to the mouth

Robin Fondberg [a, *], Johan N. Lundström [a, b, c], Maria Blöchl [d], Mats J. Olsson [a], Janina Seubert [a, e]

[a] Department of Clinical Neuroscience, Karolinska Institutet, Stockholm, Sweden
[b] Monell Chemical Senses Center, Philadelphia, United States
[c] Department of Psychology, University of Pennsylvania, Philadelphia, United States
[d] Department of Psychology, Leipzig University, Leipzig, Germany
[e] Aging Research Center, Karolinska Institutet and Stockholm University, Stockholm, Sweden

ARTICLE INFO

Article history:
Received 4 October 2017
Received in revised form
1 February 2018
Accepted 9 February 2018
Available online 13 February 2018

Keywords:
Flavor
Flavor binding
Congruency
Odor referral
Retronasal odor
Taste

ABSTRACT

Our hedonic response to a food is determined by its flavor, an inherently multisensory experience that extends beyond the mere addition of its odor and taste. While congruency is known to be important for multisensory processes in general, little is known about its specific role in flavor processing. The aim of the present study was to delineate the effects of odor-taste congruency on two central aspects of flavor: odor referral (or mislocalization) to the mouth, and pleasantness. We further aimed to test whether an eventual effect on pleasantness was mediated by odor referral. Aqueous solutions containing odors and tastes were prepared to create food-like stimuli with varying degrees of congruency, ranging from maximally incongruent to maximally congruent in nine steps. Thirty participants reported where they perceived the odors, and how much they liked the solutions. Congruency had a positive linear effect both on odor referral to the oral cavity and on pleasantness. However, the effect of congruency on pleasantness was not mediated by odor referral. These results indicate that as an odor-taste mixture approximates a mental representation of a familiar food, its components are increasingly merged into one perceptual object sensed in the mouth. In parallel, the mixture is evaluated as increasingly pleasant, which promotes consumption of familiar foods that have been determined through experience to be non-toxic. While the modulatory role of congruency on pleasantness and odor referral was confirmed, our results also indicate that these effects arise through distinct perceptual mechanisms.

1. Introduction

Flavors are multisensory phenomena (Small et al., 2004). With every bite, odorous molecules reach the olfactory receptors through the retronasal passage, while dissolved tastants connect to taste receptors in the mouth (Lundström, Boesveldt, & Albrecht, 2011; Seubert, Ohla, Yokomukai, Kellermann, & Lundström, 2015). The concurrent activation of the olfactory and gustatory modalities then gives rise to unitary flavor percepts, which determine the hedonic response to the food we consume (Stevenson, 2014; Verhagen & Engelen, 2006). These flavors have one defining feature that clearly distinguishes them from other sensory experiences: every time we eat, perceptual content belonging to the sense of smell is erroneously attributed to the sense of taste (Hollingworth & Poffenberger, 1917; Rozin, 1982). Coffee is said to *taste* like coffee, which demonstrates that humans are aware of its olfactory component (coffee), but without recognizing the sensory system (olfaction) that created it. While other senses certainly interact, no equivalent to this illusion has been found outside the olfactory-gustatory domain. A sound, for example, can influence how a visual cue is perceived, but is never mistaken for an image. The (mis)localization of olfactory content to the mouth, or *odor referral*, is central to this confusion (Spence, 2016). Yet, its underlying mechanisms and potential relevance for our hedonic responses to food remain poorly understood.

Our knowledge of multisensory binding, the process where signals from distinct modalities are integrated to form unitary

* Corresponding author. Division of Psychology, Department of Clinical Neuroscience, Karolinska Institutet, Nobels väg 9, 171 77, Stockholm, Sweden.
E-mail address: robin.fondberg@ki.se (R. Fondberg).

https://doi.org/10.1016/j.appet.2018.02.012
0195-6663/

percepts, has mainly been obtained by studying audition and vision. It has repeatedly been demonstrated that binding is promoted if the signals appear at the same point in time and space (Slutsky & Recanzone, 2001; Stein & Meredith, 1993). Temporal and spatial concordance hence aid grouping of sensory input, which facilitates the formation of unitary percepts that correspond to real world objects. This cortical mechanism provides salience to relevant events around us to elicit appropriate behavioral responses. While the impact of spatial and temporal characteristics of multisensory stimuli has been well documented, more recent work has suggested that other features acting on later stages of neural processing also aid the formation of unitary percepts (Chen & Spence, 2010; Hein et al., 2007; Laurienti, Kraft, Maldjian, Burdette, & Wallace, 2004). By comparing responses to congruent (e.g. picture of a dog and a barking sound) and incongruent (e.g. picture of a car and a barking sound) stimulus pairs, these studies have revealed that binding is further facilitated when the incoming signals would be expected to arise together during exposure to a specific object. Hence, the term *congruency* will be used throughout this paper to represent the extent to which signals for distinct modalities could be considered attributes to the same object.

As odor referral is central for perceiving unitary flavors, it is not surprising that this phenomenon also has been shown to be influenced by congruency (Lim, Fujimaru, & Linscott, 2014; Lim & Johnson, 2011, 2012). In three consecutive studies, Lim and colleagues used food odorants that were either presented alone, or together with a congruent (chicken odor and salty taste) or incongruent (chicken odor and sweet taste) tastant. These results consistently showed that odors are referred to the mouth most frequently when presented with a congruent taste, demonstrating that the formation of unitary perceived flavors is facilitated when the odor and taste are associated with the same type of food.

In addition, two studies have provided evidence that congruency also influences our hedonic responses to foods (Schifferstein & Verlegh, 1996; Small et al., 2004). In both studies, participants rated congruent olfactory-gustatory mixtures as more palatable than incongruent mixtures. Combinations such as strawberry odor and sugar were, for example, more pleasant than would be expected based on individual evaluations of their sensory components. This highlights that, in order to fully understand the mechanisms that regulate food preferences, one must not only assess the hedonic value of the odor and taste components (for a full discussion of flavor hedonics based on unisensory evaluations, see Prescott, 2012, 2015), but also the perceptual context those signals are processed in during consumption.

Taken together, evidence indicates that congruency exerts an effect on both the formation of unitary flavors perceived in the mouth, and on the hedonic responses those flavors evoke. However, all studies to date have used olfactory-gustatory mixtures restricted to the endpoints of the congruency spectrum (maximally congruent e.g. strawberry odor and sweet taste, or minimally congruency e.g. strawberry odor and salty taste), which poorly reflects the complexity of foods encountered in our daily life. Also, the relationship between congruency and pleasantness has only been demonstrated using flavors with a sweet taste component, which does not correspond to the wide variety of dietary products needed to assure adequate intake of nutrients. These restrictions limit the ability to estimate the relevance of congruency in real-life settings, where encountered deviations from mental representations of foods are the rule, rather than the exception. The tomato in your salad might have a sweeter taste than you are used to but still be safe to consume; hence, the slight mismatch between the tomato odor and the sweet taste ought not to result in rejection. While certain flavor qualities within each food category (e.g. tomato) might differ substantially from one another, not all deviations are biologically meaningful (Wilson, 2009). We must thus constantly determine the biological relevance of small deviations of encountered sensations from mental representations of familiar foods. A perceptual mechanism that regulates the hedonic response in a way that favors congruent combinations across different tastants, but without making all incongruencies result in immediate rejection, would therefore have clear survival value.

Interestingly, results from a recent study by Amsellem and Ohla (2016) have demonstrated that, in the case of *orthonasal olfaction* and gustation, congruency and pleasantness are indeed linearly related. In their study, food odors were sniffed, while tastants were administered to the mouth. The olfactory-gustatory pairs were divided into five successive congruency levels ranging across the full congruency spectrum. As expected, the odor-taste pairs were rated as more pleasant with increasing levels of congruency. This shows that humans can differentiate between different levels of congruency when the odor is delivered to the nose, and that this evaluation affects the hedonic value of the sensation. However, many studies have shown that retronasal and orthonasal odors are perceived and processed differently (Goldberg, Wang, Goldberg, & Aliani, 2017). Also, the distinct congruency levels might be harder to differentiate when the odor is presented in a more complex perceptual environment that better reflects the conditions during actual food consumption. It therefore remains an open question whether the same principle applies when the odor is presented retronasally, and in perfect synchronization with taste and somatosensory signals.

The aim of the present study was to assess the effect of linear congruency modulations on odor referral to the mouth, as well as on hedonic responses, to combined olfactory-gustatory mixtures presented to the mouth. We also aimed to determine the interrelationship of these judgements, based on the speculation that the enhanced pleasure attributed to congruent mixtures is a direct effect of increased odor referral. Specifically, we tested three hypotheses: First, that congruency has a positive, linear effect on odor referral to the mouth. Second, that congruency has a positive, linear effect on pleasantness ratings for both sweet and salty mixtures. Finally, that the effect of congruency on pleasantness is mediated by odor referral.

2. Methods

2.1. Participants

Thirty-one individuals between 18 and 45 years of age were initially recruited to participate in the study. All were instructed not to eat or drink 1 h prior to the testing session and received a small compensatory payment. Exclusion criteria were taste or smell dysfunctions, pregnancy, regular tobacco use, vegetarian or vegan diet, and current respiratory tract infection. To assess taste and smell functions, a 4-item forced choice taste identification test (Hummel, Hummel, & Welge-Lüssen, 2013) was administered followed by a 16-item forced choice odor identification test (Sniffin' Sticks, Hummel, Sekinger, Wolf, Pauli, & Kobal, 1997). Each individual correctly labeled all four taste qualities, while one individual failed to reach the cut-off point of 11 correctly identified odors. Of the final sample of 30 (age $M \pm SD = 26.90 \pm 5.35$), 21 were female and 9 male. All aspects of the study were approved by the Regional Ethics Review Board in Stockholm and all participants provided written informed consent.

2.2. Stimuli and delivery

Citrus and chicken were chosen as target flavors to represent clearly distinguishable familiar foods. Their odor and taste