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Cross-modal tactile–taste interactions in food evaluations

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ABSTRACT

Detecting the taste components within a flavoured substance relies on exposing chemoreceptors within the mouth to the chemical components of ingested food. In our paper, we show that the evaluation of taste components can also be influenced by the tactile quality of the food. We first discuss how multisensory factors might influence taste, flavour and smell for both typical and atypical (synaesthetic) populations and we then present two empirical studies showing tactile–taste interactions in the general population. We asked a group of non-synaesthetic adults to evaluate the taste components of flavoured food substances, whilst we presented simultaneous cross-sensory visuo-tactile cues within the eating environment. Specifically, we presented foodstuffs between subjects that were otherwise identical but had a rough versus smooth surface, or were served on a rough versus smooth serving-plate. We found no effect of the serving-plate, but we found the rough/smoothness of the foodstuff itself significantly influenced perception: food was rated as significantly more sour if it had a rough (versus smooth) surface. In modifying taste perception via ostensibly unrelated dimensions, we demonstrate that the detection of tastes within flavours may be influenced by higher level cross-sensory cues. Finally, we suggest that the direction of our cross-sensory associations may speak to the types of hedonic mapping found both in normal multisensory integration, and in the unusual condition of synaesthesia.

1. Introduction

The chemical sense of gustation (taste) involves the detection of five basic taste categories of sweet, sour, bitter, salty and umami or savoury (e.g., see Chaudhari and Roper (2010)). Tastant molecules bind (either directly or indirectly) to ion channels in the membranes of taste receptor cells in the mouth, which are organised into taste buds (Chandrashekar et al., 2006). From there, the signal is converted and sent to the brain in a process known as transduction (e.g., see Frank and Hettinger (1992)). However, substances are very rarely delivered into the mouth in the form of pure tastes. Most consumption is of foodstuffs that have complex flavours involving not only taste but also texture (Philipsen Clydesdale et al., 1995), temperature (Talavera et al., 2007), other tactile sensations (Cardello, 1996) and trigeminal nerve irritation (such as the burning sensation of capsicum pepper or cooling of menthol; Lawless and Stevens, 1984). For these reasons flavour perception is multi-sensory, and it also shows influences from other senses such as olfaction (Small et al., 2004), and vision (DuBose et al., 1980; see below, and Auvray and Spence (2008) for a review). The integration of multiple senses when eating appears to be supported anatomically via the orbitalfrontal cortex (OFC) which is implicated as the site of integration for the components of flavour, and this serves as a “higher-order gustatory cortex” (Small et al., 2007, p. 136).

That flavour is comprised of more than just taste means flavour can of course be influenced by changes in modalities unrelated to taste. Hence the flavour of a food that is soft and heated would be different to one that is cold and crispy. Our interest here however, is to test how multisensory manipulations can effect taste evaluations themselves. We look at how participants rate taste qualities within flavoured food, if we alter modalities *other than* chemical tastants. Specifically we ask whether the taste quality of food becomes more sour, or sweet or bitter even if we modulate only texture.

Why consider the texture of food, and what predictions might we make? To preface our study we briefly review previous work that has used multisensory manipulations to evaluate changes in taste (as well as flavour and smell – since all three involve the chemical senses). We also look at what might be learned from studies of people with synaesthesia – an extreme type of multisensory integration – which could perhaps give insights into how evaluations of the taste components within food are made by the average person. In both cases we look especially at how multisensory integration sometimes involves hedonic qualities (i.e., the matching of two sensory qualities according to their pleasantness).

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2. Cross-modal associations affecting smell, taste and flavour

A wide range of cross-modal associations relating to the perception of food have been reported. These studies tend to have one of two methods: either they manipulate one modality while measuring another (e.g., varying the colour of food while eliciting taste/flavour judgements from participants) or they ask participants to make intuitive matches across the senses (e.g., What shape seems to "best fit" this taste?). Studies such as these have revealed a variety of cross-modal influences on taste, flavour and smell. For example, both the smell and the taste/flavour of food are affected by its colour. Wan et al. (2014) reported a broad range of cross-modal associations between different visual features (namely colour, shape and texture) and tastes (for example, 'bitter' was associated with 'black', 'salty' with 'white' and 'sour' with 'green'). More specifically, Zhou et al. (2015), found that the colour of noodles influenced expectations participants had regarding their taste and flavour (e.g., participants expected red noodles to have a spicy flavour). Darker versions of the same cherry flavoured drink were rated as more intensely flavoured (Philipsen et al., 1995; see also Chan and Kane-Martinelli (1997)). Colour can also affect evaluations of specific taste components within foods. Johnson and Clydesdale (1982) found participants rated darker red-coloured sucrose solutions as 2–10% sweeter (as a function of the amount of dye added) than a lighter solution, which in fact had a slightly stronger sucrose concentration. Smell too, can be modified by visual changes in food substances. When white wine was artificially coloured red, researchers found its smell was ascribed red wine qualities, leading to the conclusion that colour can act as a primer for smell (Morrot et al., 2001).

Flavour evaluations can also be influenced by sound (see Spence and Shankar (2010) for a review). For example, the sound of frying bacon leads participants to rate food as having more of a bacon flavour (Spence et al., 2010) and participants eating crisps rated them as fresher and 'crispier' when listening to the sound of eating crisps played at higher volumes or with higher frequency sounds amplified (Zampini and Spence, 2004). Similar results were found with the expected 'fizziness' of carbonated drinks (Zampini and Spence, 2005) and even seemingly arbitrary sounds can exert influence over the perception of flavour. Participants rated beer as more enjoyable and flavoursome if accompanied by high versus low pitch sounds (Holt-Hansen, 1968, 1976). High pitch sounds were also associated with the names of sour- or sweet-tasting foods (Crisinel and Spence, 2009; Crisinel and Spence, 2010a) while low pitch sounds were more associated with the names of foods that have either a bitter (Crisinel and Spence, 2009) or umami taste (Crisinel and Spence, 2010b). Similarly, Simner et al. (2010) found that participants making systematic associations between sounds and pure tastants preferred sweet tastes associated with smooth continuous phonetic sounds and sour tastes associated with staccato sounds. Furthermore, haptic information can also influence the perceived characteristics of food. For example, the texture of the packaging has been found to influence the perceived texture of consumed food (Piqueras-Fiszman and Spence, 2012), and the texture of the food itself has been shown to play a role in whether it is perceived as fresh or stale (Barnett-Cowan, 2010).

Of particular interest to the current study are associations relating taste/flavour to touch and texture. Of course, even before food enters the mouth, there is an interaction between touch and vision, so judgements can be made regarding the shape of foods and of their surface texture (Verhagen and Engelen, 2006). Indeed, when interacting physically with food, the somatosensory system is important for multi-sensory integration (Verhagen and Engelen, 2006). The proprioceptive system is also an important source of information about the shape, size and texture of foods in the mouth, for example during oral exploration by the tongue (Cardello, 1996). But texture/touch can also influence flavour perception in more surprising ways. Bult et al. (2007) found interactions between viscosity and flavour, with less viscous milk receiving higher flavour ratings. Mosca et al. (2012) reported that food texture can influence the perception of taste, with softer textures leading to higher ratings of sweetness intensity. Aside from texture, other touch related qualities (specifically, visuo-tactile qualities of shape) also influence judgements about foods, and even food names. Several recent studies, for example, have demonstrated shape-taste or shape-flavour associations. Ngo et al. (2011) found that people associate more angular shapes with chocolate samples higher in cocoa content – which is a likely proxy for increasing bitterness. In a similar way, Spence and Gallace (2011) found angular shapes pairing with carbonated (versus still) water, and with other food products with a range of more complex flavours (e.g., cranberry juice but not brie). Obrist et al. (2014) asked participants to match taste experiences to a selection of shaped objects (by feel only, objects were not visible), and found sweet taste was perceived to be smooth and rounded, while sour was described as sharp and matched to more angular shapes. Finally, Deroy and Valentin (2011) produced analogous findings linking bitterness and carbonation to more angular shapes – this time in beers. These authors (Spence and Gallace, 2011; Ngo et al., 2011) also show that this type of angular (versus rounded) mapping can also manifests in preferred names for food products, given the particularly well-established linguistic link between angular shapes and certain types of words (e.g., nonwords containing plosives such as *kiki* and *takete*; Köhler, 1929; Ramachandran and Hubbard, 2001) Together, these studies provide evidence for cross-modal interactions of texture, shape and flavour in everyday food consumption and even in the naming of foods.

In our study we manipulated the texture of food substances, but we also chose to consider the texture of the serving plate because studies have shown that eating receptacles, too, can influence food judgements. For example, the colour of a plate has been shown to exert an influence over how food is perceived: participants rated a strawberry mousse as more intense, sweet and likeable when it was presented on a white versus black plate (Piqueras-Fiszman et al., 2012). Similarly, participants rated the taste of popcorn differently when eaten from coloured bowls as opposed to white ones: sweet popcorn was perceived as saltier when eaten out of a coloured (versus white) bowl, and vice versa for salty popcorn (Harrar et al., 2011). Plate shape and food presentation can also influence the perception of taste. For example, Fairhurst et al. (2015) found that round shaped food served on round plates led to participants perceiving that food as sweeter relative to the same food served in an angular shape on a square plate. Stewart and Goss (2013) reported that both plate colour and shape may interact to influence the perception of food, but that any relationship between these two variables is likely to be complex. Even the choice of cutlery can influence the flavour and enjoyment of foods if these cutlery carry their own taste-enhancing properties (e.g., zinc- and copper-coated spoons were rated as less pleasant-tasting, and in turn they enhanced the perception of certain hedonically negative tastes such as bitterness; Laughlin et al. 2011; Piqueras-Fiszman et al., 2012). These studies show that the qualities of even cutlery and plates can influence taste and flavour. Since our focus in the current paper is on texture, we will manipulate the texture of plates to see whether this influences the perception of the taste components within flavoured foods.

Finally we point out that cross-modal associations may form on the basis of a hedonic association, i.e. associations may form because sensations regarded as equally pleasant or unpleasant can be grouped together. Evidence suggests this is indeed the case, at least in some areas of flavour, taste and smell. For example, Simner

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