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Experience dependent changes in odour–viscosity perception

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ABSTRACT

One consequence of experiencing flavour — the combination of taste, smell and somatosensation that occurs during ingestion — is that it can result in perceptual changes for the odour component, when this is later smelled alone. One such change is the acquisition of taste-like properties, but whether odours can also acquire somatosensory-like qualities is largely unknown. Participants here were exposed to one odour sampled in a viscous solution, another sampled in a sweet/viscous solution, and a further odour sampled in water. The odour sampled in the sweet/viscous solution was, when later sniffed alone, judged to smell thicker and sweeter, than the other two odours. Similarly, when the sweet/viscous paired odour was added to a viscous solution, the combination was judged as more viscous, than the other two odours — and sweeter when added to a sweet solution. This experiment suggests that odours can acquire tactile-like somatosensory qualities and this may best occur when a taste is present during learning. Recent work indicates that tastes may be superior to somatosensory stimuli alone in promoting flavour binding, a seeming precondition for this type of learning.

1. Introduction

The senses of taste, smell and somatosensation, combine during eating and drinking, to generate a flavour percept (e.g. Delwiche, 2004; Verhagen & Engelen, 2006; Small, 2008). One consequence of this multisensory flavour experience is that it may modify the perception of the olfactory component, when this is later smelled alone (e.g. Yeomans & Mobini, 2006). The most well studied modification concerns the acquisition of taste-like properties following flavour experiences that are composed of a taste and an odour. Here, participants experience a range of stimuli, amongst which are included pairings of an odourant dissolved in a particular taste solution. After this exposure phase, participants who sniff the target odour judge it to smell sweeter (or more sour — dependent upon the taste) than a control odour that was presented in water (e.g. Stevenson, Boakes, & Prescott, 1998). These acquired taste-like properties have been observed in both humans and rats (e.g. Verhagen & Gautam, 2010), and in the former case, appear to be acquired with minimal conscious awareness (see Stevenson & Tomiczek, 2007, for review). Odour–taste learning is robust and resistant to interference, and the taste-like experience that the odour comes to generate has many psychological, physiological and neural properties in common with that generated by an actual tastant (see Prescott & Wilkie, 2007; Stevenson, Miller, & Thayer, 2008; Veldhuizen, Nachtigal, & Small, 2009).

While taste and smell are clearly central attributes of flavour, the somatosensory component is also of great significance (Munoz & Civille, 1987; Szczesniak, 2002; Weel et al., 2002). Oral somatosensory receptors are responsible for detecting temperature, chemical irritants (e.g. chilli pepper and menthol) and pain, as well as most of the sensation relating to food texture (Christensen, 1984). Texture may be divided (approximately at least) into three major classes: (1) mechanical, including attributes such as hardness and viscosity; (2) geometrical (e.g. grittiness); and (3) chemical (e.g. fattiness). In addition, there are some emergent properties such as creaminess (i.e. a combination of mechanical [viscosity] and chemical [fattiness]: see Kokini, 1985; Szczesniak, 2002). Whether any of these textural somatosensory properties can be acquired by odours in the manner that taste-like ones can, has not been well investigated. Part of the reason for this is that textural variables can be difficult to manipulate in the laboratory (Christensen, 1984).

In principal odours should be able to acquire a somatosensory quality. This is because the conditions under which such experiences occur are clearly similar to those that result in odour–taste learning. For effective odour–taste learning, it has been argued that the elements have to be experienced in the same perceived location (the mouth) and at the same time (simultaneous presentation; Stevenson, 2009). Indeed, evidence from several indirect sources suggests that odour–somatosensory learning may occur. Many odour profile studies — where participants identify the various qualities that are perceived to characterise an odour — report somatosensory-like qualities, including those relating to irritation, temperature and certain textural qualities, especially fattiness (e.g. Boelens, 1974; Dravnieks, 1985; Harper, Land, Griffiths, & Bate-Smith, 1968). Although mention of fatty-like attributes

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is quite common, the problem here is that one cannot be certain that the sensory modalities that *actually* generate fat perception are completely driven by somatosensation. Recent evidence suggests that fat perception may involve receptors, which fall under the taste system (Mattes, 2009a,b).

A similar interpretive problem surrounds the only study to have tested whether odours can acquire somatosensory qualities (Sundqvist, Stevenson, & Bishop, 2006). In this study participants were exposed to combinations of odours, fats and sugars in a milk base. While evidence was obtained showing that certain odours smelled more fatty after pairings with fatty milk, this study could not rule out the possibility that it was taste (i.e. fatty acid perception via gustatory receptors) that was driving this association. An additional and related concern was that the cream used as the fattening agent in this study, probably included volatiles that may smell fatty. In this case, participants may have been associating the target odour with the cream odours, resulting in changes in fattiness perception for the targets. Unfortunately neither possibility — odour–taste or odour–odour learning — can be excluded as an account of Sundqvist et al.'s (2006) data. Thus it remains to be seen whether an odour can acquire an oral tactile quality.

While the discussion above does not preclude the possibility of odour–somatosensory learning, there may be a complicating factor. Recent data suggests that gustatory stimulation — taste — may play a role in localising olfactory sensation to the mouth (Stevenson, Oaten, & Mahmut, in press). Humans have only one set of olfactory receptors, but two different means of stimulating them — one by sniffing (orthonasal perception) and the other via the nasopharynx (retronasal perception), which is used during eating and drinking (Rozin, 1982). During routine sniffing, the odour is perceived as coming from the environment, but during retronasal perception it is perceived as part of an orally located flavour. How this location binding occurs is poorly understood, but it now seems that one contributory factor is the presence of an oral tastant, as tasteless somatosensory stimulation alone (e.g. vigorous oral movement of water or viscous oral solutions) is less effective at localising an odour to the mouth (Stevenson, Mahmut, & Oaten, in press; Stevenson, Oaten, et al., in press). This may occur because taste is often a more salient cue (i.e. affective, intense) relative to somatosensory stimulation alone, thus gustation may better capture attention — at olfaction's expense (Stevenson, Mahmut, et al., in press). One potential consequence of this observation — which has not been tested before — is that odour–somatosensory learning may be more successful if a tastant is present, relative to somatosensory learning without a tastant. This is because with a taste, the odour is more likely to be localised to the mouth and hence bound together to produce a flavour.

The experiment reported here investigated two related issues. First, is it possible for an odourless and tasteless somatosensory stimulus to become associated with an odour? Second, is this more likely to occur when a taste is present, as the discussion above might suggest? To address these questions, participants' ability to acquire one particular tactile attribute — viscosity — was tested. Viscosity can be reliably manipulated in the laboratory, and the thickening agent used here, carboxy methylcellulose, is both odourless and tasteless (e.g. de Araujo & Rolls, 2004). Participants were exposed to three stimulus conditions. One involved sampling an odour presented in a viscous solution. A second involved sampling a further odour presented in a sweetened viscous solution. Sucrose was used as the sweetener here as it is known to have a negligible effect on physical measures of viscosity (van Ruth, De Witte, & Uriarte, 2004; Theunissen & Kroeze, 1995). However, its effects on *perceived* viscosity are uncertain, with conflicting findings across studies — as with other sweeteners and viscous agents (see Christensen, 1980; Theunissen & Kroeze, 1995). Third, a control pairing condition was also employed in which another odour was paired with water. Although one report suggests that a single pairing may be sufficient to support conditioning, most previous studies include multiple presentations of each pairing type and so this approach was also adopted here (e.g. see Stevenson et al., 1998).

To assess any changes in odour quality, two types of test were used that have been employed before in odour–taste learning paradigms (e.g. Stevenson et al., 1998). The first asked participants to evaluate all three odours on a range of attributes, including some relating to texture, prior to being exposed to the conditions described above. After the exposure phase was complete, participants were again asked to sniff these three odours and judge their attributes, to see if there was any change for those relating to sweetness and texture (thickness and creaminess). The second type of test examined whether adding the odourants to a weak viscous solution increased perceived viscosity (thickness), and whether adding them to a weak sweet solution increased perceived sweetness. Together these tests should determine whether an odour can acquire a somatosensory quality (thickness/creaminess) and whether this process is more effective in the presence of a tastant — sucrose.

2. Method

2.1. Participants

Thirty-seven participants (M age = 20.0, SD = 2.6; 13 males/24 females), with reportedly normal olfaction (i.e. no colds or allergies), took part for course credit. No participant had taken part in any related experiment and all were naïve to the study aims.

2.2. Materials

Three odourants were prepared by dissolving them directly into their respective solution (water, viscous fluid, etc.) at the following concentrations; Oolong tea (Quest; 0.60 g/L), Lychee (Quest; 0.55 g/L) and Water chestnut (Quest; 0.22 g/L). For orthonasal smelling, 40 mL of each odourant in water was presented in a 200 mL opaque plastic squeeze bottle. Sucrose solutions were prepared at two concentrations, 100 g/L (10%w/v) for use during the conditioning phase and at 50 g/L (5%w/v) for the enhancement test phase. Carboxy methylcellulose (CMC; Sigma) was dissolved directly into warmed and rapidly stirred water to generate the viscous solutions. For the conditioning phase of the experiment, CMC was presented at 20 g/L (50–200 cP) and for the viscous enhancement test at 10 g/L. For the combinations of stimuli used during the conditioning and test phases, odourants were added to sucrose solutions and to the viscous solutions (with or without sucrose). In addition, saline solution (0.25%w/v) was used for a proportion of filler trials during the conditioning phase of the experiment. Stimuli to be sampled by mouth were presented as 10 mL samples in transparent 30 mL plastic sample cups.

2.3. Procedure

2.3.1. Overview

Participants completed a six-phase within-subject procedure after providing consent to take part in a 'flavour judgment' experiment (the study was approved by Macquarie University Human Research Ethics Committee). The first phase — the odour pretest — consisted of smelling the three odourants oolong tea, lychee and water chestnut and evaluating each on 9 rating scales. Following a 4-min break the conditioning phase commenced, in which participants were asked to successively sample sets of three stimuli, picking the odd one out in each set. This 'discrimination' procedure was used to disguise what in fact were a series of exposures to one odour consistently presented in water (6 presentations), another presented in a viscous solution (6 presentations) and a third presented in a sweet viscous solution (6 presentations). On completion of this conditioning phase, a further 4-min break occurred before participants undertook the odour posttest, again smelling and evaluating all three odours. After a further 4-min