

possible because these standardized mullite crucibles were available to yield reliable and reproducible results.

Although unaware of the presence of this aluminium silicate in their Hessian crucibles, the producers evidently coined a very successful recipe — which explains why it was not modified, or publicized, for centuries.

**Marcos Martínón-Torres\***, **Thilo Rehren\***,  
**Ian C. Freestone†**

\*Institute of Archaeology, University College London, London WC1H 0PY, UK  
e-mail: m.martinon-torres@ucl.ac.uk

†School of History and Archaeology, Cardiff University, Cardiff CF10 3EU, UK

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## SYNAESTHESIA

# The taste of words on the tip of the tongue

Synaesthesia is a rare familial condition involving a 'crossing' of the senses — for example, ordinary activities such as reading or listening to music may be perceived with different colours or tastes<sup>1</sup>. Here we show that individuals who experience synaesthetic tastes that are elicited by words (who are known as lexical-gustatory synaesthetes) begin to taste an upcoming word before they can actually say it (that is, while it is still 'on the tip of the tongue'). Taste sensations in these synaesthetes are therefore triggered by thinking of the word's meaning, rather than by its sound or spelling. It is possible that conceptual thought may even be linked to perceptual experience in all of us.

Brain imaging<sup>2</sup> and inheritance patterns<sup>3</sup> have established that synaesthesia is a genuine neurological phenomenon, but the psychological mechanisms that drive each manifestation are not yet fully understood. In the word-taste variant, pictures do not usually elicit a taste sensation without retrieval of the associated word<sup>4</sup>, and tastes are triggered by the corresponding food name (for example, mince taste by the word *mince*) as well as by words that share phonemes with that food name (such as *prince*)<sup>4,5</sup>.

Given this phonological influence, it might be assumed that explicit processing of phonological word-forms (from auditory input, for example) is a necessary stage for stimulating synaesthetic tastes. Alternatively, taste could be experienced directly from the word's meaning (that is, from abstract semantic information encoded in long-term memory, or its lemma<sup>6</sup>). In this case, the role of phonology would be restricted to the stages in development when word-taste associations are being established (that is, determining which words become associated with which tastes), rather than serving to trigger the taste itself.

We investigated this second hypothesis by testing whether synaesthetic tastes could be induced in 'tip-of-tongue' (TOT) states<sup>7</sup>, when only word meaning, but not the phonological word-form, is available for processing. Six cases

with this rare type of synaesthesia were studied (for methods, see supplementary information). Each demonstrated the behavioural hallmark of synaesthesia<sup>8</sup> by showing a significantly higher test-retest consistency over more than one year, compared with a control group tested after only two weeks (for details, see supplementary information).

In a TOT picture-naming task, the participants were shown images of unusual objects (a platypus, for example) to induce the TOT state, in which the word required was known but there was a temporary inability to recall it; they were then questioned about the 'taste' of the target word. Out of 550 trials, 89 induced a TOT state in which the synaesthete was striving to name the experimenter's intended target word. Seventeen of these were accompanied by anticipatory tastes, 15 of which occurred in a complete TOT state — where neither the word itself nor any constituent letters could be recalled.

In all instances, the anticipated taste corresponded to the correct taste of the target word, as verified afterwards by the participant (confirmation stage) and then again more than one year later in a surprise retest (see supplementary information). For example, one participant tasted tuna fish when the word *castanets* was on the tip of her tongue: she then named tuna as the taste associated with the spoken item *castanets* in the confirmation stage, and reproduced this same association in the surprise retest 1.1 years later.

The anticipated taste associations named in the TOT state are unlikely to have been spuriously generated, because the synaesthetes experienced their correct anticipatory tastes significantly more often than would be predicted by chance (all *P* values less than 0.02), as estimated from the baseline frequencies with which each taste occurred for each synaesthete (for details, see supplementary information).

We conclude that perceptual experience, for these synaesthetes, is one component of the representation of the meaning of words.

As synaesthetic taste can be induced in TOT states in the absence of phonological information, we propose a model in which pathways exist between word lemmas and taste centres. (Phonological factors may nevertheless developmentally determine the nature of a taste — that is, the tastes associated with food names and their phonological neighbours.)

These pathways may operate in everyone, but be exceptionally active in synaesthetes: other variants of synaesthesia (tone-colour, for example) are known to rely on universal cognitive mechanisms<sup>9</sup>, and functional magnetic resonance imaging indicates that merely imagining a taste can activate the area of the normal brain associated with taste<sup>10</sup>. Lexical-gustatory synaesthesia may therefore represent an exaggeration of normal mechanisms that link linguistic thought and sensory perception.

**Julia Simner\***, **Jamie Ward†**

\*Department of Psychology, University of Edinburgh, Edinburgh EH8 9JZ, UK  
e-mail: j.simner@ed.ac.uk

†Department of Psychology, University College London, London WC1E 6BT, UK

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