Identification of seminal works that built the foundation for functional magnetic resonance imaging studies of taste and food

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The evaluation of human brain processing of food and taste has been conducted for decades. The large number of articles published has advanced our understanding towards the neurobiology behind gustatory perception. By the approach of reference publication year spectroscopy, the present study identifies the publication years and the respective seminal works that received much more citations compared to other studies published in the same period. Results reveal that seminal works were written by multiple authors and focused on animal studies, psychophysical studies and development of questionnaire tools.

It is important to understand how the brain processes taste and food information, as excessive intake of calories may lead to overweight and eventually obesity. Functional magnetic resonance imaging (fMRI) studies have utilized the latest technology to evaluate the human brain and have provided vast amount of data that were converted into insightful information for a better understanding of the neurobiological mechanism of taste and food perception, such as taste intensity[1] and quality[2].

Bibliometric studies have identified highly cited neuroscience articles in general[3–5]. However, the seminal works that contributed to modern fMRI taste studies have yet to be identified and appreciated by the scientific community. Therefore, the aim of this study was to identify the publication years and the respective seminal works that received much more citations compared to other papers published in the same period.

Source of data

The study was based on data provided by the Web of Science Core Collection hosted by Clarivate Analytics. The search string was: TS = (food OR taste OR gustatory OR gustation OR sweet OR sweetness OR salty OR saltiness OR sour OR sourness OR bitter OR bitterness OT umami OR savory OR savoury) AND TS = (fMRI OR 'functional magnetic resonance imaging' OR 'functional MRI'). Only articles published in English were considered. The search yielded 933 articles. Reference lists of these articles served as the basis of analyses in the present study.

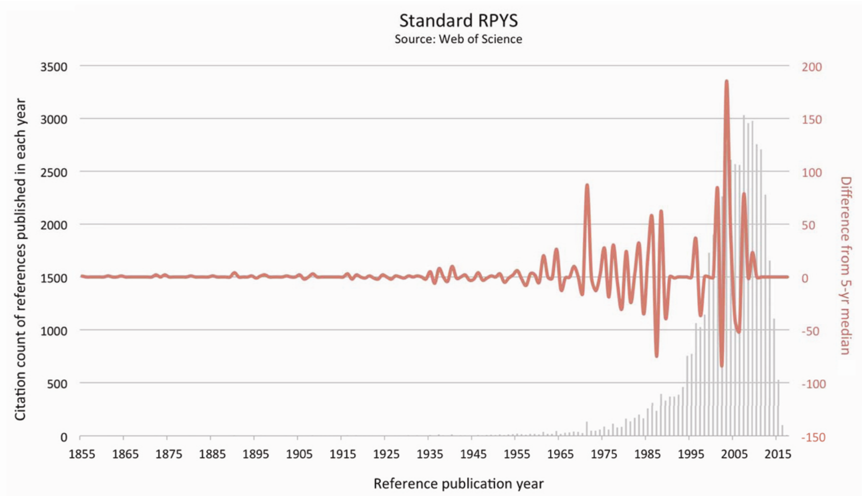

Figure 1. Results from reference publication year spectroscopy. The reference lists of 933 selected articles were analysed by CRExplorer. References were sorted by publication year (*x*-axis), and citation counts received by each publication in the same year were summated (left *y*-axis). The spectrogram was generated by plotting the difference in annual citation count from its 5-yr median.

Reference publication year spectroscopy

Full records and cited references from all 933 articles were imported into CRExplorer, a software developed based on the concept of plotting references in documents along a timeline, and thus the plot resembled a spectrogram[6,7]. The plot consisted of two parts: a bar chart displaying the raw frequency of cited references published in each year, and a spectrogram showing positive and negative peaks that indicated years when the citation count deviated from the 5-yr median. Positive peaks indicated higher-than-average citation count received by articles published in those years. Details of the ten largest positive peaks were examined to identify the articles that had the largest contributions.

Distribution of positive peaks

The ten largest positive peaks in terms of difference from 5-yr median were located between 1971 and 2007 (Figure 1). There were two peaks in the 1970s, three in the 1980s, one in the 1990s and four in the 2000s.

Types of seminal works

The largest peak was in 2003: the fMRI studies of taste and food have been cited 2753 times on the works published in that year, which was more than the median citation count during 2001–2005 by 183. In that year, Killgore *et al*. published an fMRI paper reporting differential brain activation by photographs of high- and low-calorie foods (Table 1). Among the ten articles most cited from their respective publication year, four

Table 1. Details of the ten largest positive peaks from the reference publication year spectrogram. The most cited article from each of these peaks has been listed

Year	Difference from 5-yr median	Total citation count (TC)	Most cited article of the respective year	Article citation count (AC)	Share (AC/TC, %)
2003	183	2753	Killgore, W. D., Young, A. D., Femia, L. A., Bogorodzki, P., Rogowska, J. and Yurgelun-Todd, D. A., Cortical and limbic activation during viewing of high-versus low-calorie foods. *Neuroimage*, 2003, **19**, 1381–1394.	124	4.5
1971	87	135	Oldfield, R. C., The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia*, 1971, **9**, 97–113.	60	44.4
2001	83	2346	Small, D. M., Zatorre, R. J., Dagher, A., Evans, A. C. and Jones-Gotman, M., Changes in brain activity related to eating chocolate. *Brain*, 2001, **124**, 1720–1733.	154	6.6
2007	78	3032	Rothemund, Y., Preuschhof, C., Bohner, G., Bauknecht, H.-C., Klingebiel, R., Flor, H. and Klapp, B. F., Differential activation of the dorsal striatum by high-calorie visual food stimuli in obese individuals. *Neuroimage*, 2007, **37**, 410–421.	149	4.9
1988	62	393	Talaraich, J. and Tournoux, P., *Co-planar Stereotaxic Atlas of the Human Brain*, George Thieme, Stuggart, 1988.	98	24.9
1986	54	310	Scott, T. R., Yaxley, S., Sienkiewicz, Z. J. and Rolls, E. T., Gustatory responses in the frontal opercular cortex of the alert cynomolgus monkey. *J. Neurophysiol.*, 1986, **56**, 876–890.	32	10.3
2004	41	2611	Pelchat, M. L., Johnson, A., Chan, R., Valdez, J. and Ragland, J. D., Images of desire: food-craving activation during fMRI. *Neuroimage*, 2004, **23**, 1486–1493.	76	2.9
1996	36	1063	Cox, R. W., AFNI: software for analysis and visualization of functional magnetic resonance neuroimages. *Comput. Biomed. Res.*, 1996, **29**, 162–173.	77	7.2
1983	31	199	Rolls, E. T., Rolls, B. J. and Rowe, E. A., Sensory-specific and motivation-specific satiety for the sight and taste of food and water in man. *Physiol. Behav.*, 1983, **30**, 185–192.	14	7.0
1977	30	114	Murphy, C., Cain, W. S. and Bartoshuk, L. M., Mutual action of taste and olfaction. *Sens. Process.*, 1977, **1**, 204–211.	15	13.2

were related to human brain mapping, three were development of methods for data collection or analysis, two were psychophysical studies and one was an animal study. In terms of accounting for the largest share of citations received by works published in the respective year, Oldfield's seminal paper in 1971 that described an inventory to assess the handedness of a subject accounted for 44.4% of citations.

Discussion

Citation analyses have traditionally focused on the citation counts of selected publications[4]. However, recent bibliometric works have taken a new perspective by evaluating the cited references of selected publications[6,7]. Marx and Bornmann[8] have published a comprehensive overview on this approach, and explained that one of the greatest advantages of this is its ability to identify the historical roots of the selected body of literature that might be of decisive importance, but conceptually heterogeneous. For instance, Oldfield's[9] seminal work on the Edinburgh inventory could be considered as one of the most important tools to be administered to subjects before they underwent taste fMRI experiments, as handedness was considered to influence the hemispheric dominance of brain activations by taste[10]. However, the inventory was not designed for taste or brain studies and hence would not be included into the body of literature to be analysed by traditional search strategy aimed at identifying taste and food fMRI studies by relevant keywords. Another crucial work related to methods is the book by Talaraich and Tournoux[11] depicting the classical brain atlas derived from dissecting a single human brain. It was digitized and developed into a gold standard stereotactic coordinate system for analysing neuroimaging data, which was later superseded by the more precise Montreal Neurological Institute system[12]. The last method identified was by Cox in 1996 that introduced the renowned neuroimaging data processing software called Analysis of Functional NeuroImages (AFNI)[13].

There were two psychophysical studies by Rolls *et al.*[14] and Murphy *et al.*[15] published in 1983 and 1977 respectively. The former studied how satiety modulated the pleasantness brought by the sight and taste of food, whereas the latter assessed the interactions between taste and smell during sensory evaluation. They established the scientific theories for designing relevant fMRI studies. Similarly, the animal study conducted by Scott *et al.*[16] reported a chemotopic organization of neurons (i.e. clustering of neurons according to their sensitivity to different tastes) in the frontal operculum of two monkeys. This seminal work revealed the organization of taste-responsive neurons in the taste cortex, and eventually inspired a human fMRI study that attempted to replicate a similar chemotopic organization[17].

The four neuroimaging studies listed in Table 1 are related to eating behaviour and food choice. Killgore *et al.*[18] and Rothemund *et al.*[19] studied the differential response of subject to viewing photographs of high- and low-calorie foods and differential response to viewing photographs of high-calorie food between obese and healthy subjects respectively. Pelchat *et al.*[20] studied how the brain activated during food craving, and Small *et al.*[21] assessed the differential brain response to eating chocolate during hungry and satiated states. These studies probed into the mechanisms of how the human brain dictates eating behaviour. It should be noted that Small *et al.*[21] used positron emission tomography (PET) for functional imaging, which was largely superseded by fMRI due to the necessity of radioactive tracers and the inherent lower spatio-temporal resolution using PET[22].

The present study highlighted seminal works from tools development, psychophysical studies, animal studies and earlier human neuroimaging studies that have driven the evolution of the contemporary fMRI studies on taste and food.

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