Physiology & Behavior xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Physiology & Behavior

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

Oral processing and texture perception influences satiation

Bryony James[*]

University of Auckland, New Zealand

ARTICLE INFO

Keywords:
Oral processing food texture satiation

ABSTRACT

This article offers a brief review of the state of understanding of the role of oral processing and food texture on satiation. Food texture is a sensory property that contributes to the manner in which food transits the oral cavity. Several studies have shown the impact of oral transit time on satiation, with longer times relating to enhanced satiation response. Recent studies have also begun to show an impact of texture on satiation independent of oral processing time. There are still many questions to answer before the underlying mechanisms of these impacts are understood.

1. Introduction

There are many factors contributing to the current "obesity epidemic", ranging from an energy imbalance in people's food consumption to environmental and genetic factors, and the role played by the gut microbiome, with much debate about potential causes and solutions [1]. One small part of the puzzle is that people are simply eating too much [2]. Stopping eating when you are full (satiation), and feeling full between meals (satiety) would appear to be simple parts of the equation managing food intake. However, the roles of satiation and satiety are fraught with contradictory opinions [3–6], fascinating but outside the scope of this brief review.

Given that satiation could be a part of the puzzle it is worth considering what aspects of food, and of eating, contribute to this feature of an eating episode. These aspects will include factors related to the biology and physiology of the consumer including genetics [7] and metabolism [8,9]. They will also, naturally, include factors related to the composition and nutritional make-up of the food [10,11], and flavour and liking [12,13]. Further to these obvious aspects consideration must also be given to the situation in which the food is eaten (including social and environmental [14,15] factors) and prior experience and expectation [16,17]. These factors combine with the physical form of the food (solid, semi-solid, liquid etc) to affect how the food is chewed and swallowed during oral processing.

Oral processing encompasses all the physical and physiological aspects of taking food into the mouth and preparing it for swallowing [18–20]. It combines the breakdown and restructuring of a food material in a feedback loop of sensory signals and motor control, and each step can reveal (or conceal) specific flavour or textural attributes [21,22].

2. What is food texture?

Food texture, a vital part of food quality and acceptability, may be defined in a number of ways. A standard definition is "all of the rheological and structural attributes of a product perceptible by mechanical, tactile, visual and auditory receptors" [23]. Bourne [24] summarised numerous other definitions of texture and simplified an overall definition to: "the textural properties of a food are that group of physical characteristics that arise from the structural elements of the food, are sensed primarily by the feeling of touch, are related to the deformation, disintegration, and flow of the food under a force, and are measured objectively by functions of mass, time, and distance". This approach emphasises that "texture" is a multi-parameter attribute.

Textural properties are, first and foremost, sensory attributes [25] and are frequently assessed using sensory panels and tools such as Quantitative Descriptive Analysis [26] or, for dynamic changes in texture, Temporal Dominance of Sensation [27]. These measurements are necessarily subjective and work has been going on for many years to make and link objective instrumental measurements of food properties to texture [28]. Assessing and, ultimately, quantifying the physical properties of food that contribute to textural properties combines techniques more common in materials engineering [29,30] (fracture mechanics, rheology) with those of cognitive neuroscience (such as psychophysics, and neuroimaging) [31].

Relating instrumental measurements of a material property (such as Young's modulus or fracture toughness) to a textural perception (such as crunchiness or crispness) requires correlations of subjective and objective measurements in the presence of the response biases of a human judge. This is where the tools of psychophysics are used [32], treating the human observer as an instrument transducing physical

---

[*] Corresponding author.
E-mail address: b.james@auckland.ac.nz.

https://doi.org/10.1016/j.physbeh.2018.03.015
Received 18 December 2017; Received in revised form 12 March 2018; Accepted 13 March 2018

Please cite this article as: James, B., Physiology & Behavior (2018), https://doi.org/10.1016/j.physbeh.2018.03.015

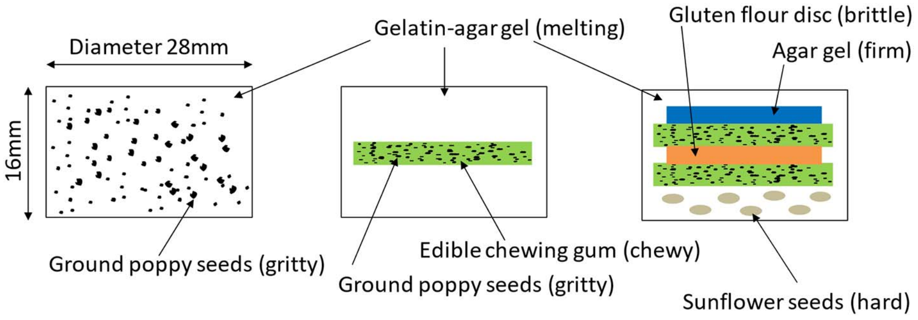

Fig. 1. Model foods used in [66]. Each is a bite-sized disc, isocaloric, with matched oral processing time. Foods are not macro-nutrient matched.

information into sensory perception. In this context sensory scales of texture need to be derived that may be used as a transfer function to determine quantitative relationships. More recently functional magnetic resonance imaging (fMRI) has been used to provide insight into the reward-related pathways in the brain and their response to chewing and food texture [33–35]. Early results related to texture are sparse, and concentrate on the motor-control needed for hard or less hard food [36,37].

2.1. Texture, satiation and satiety

A recent, comprehensive review [38] of studies relating the role of food structure and oral processing to satiation and satiety indicates that, whilst oral processing time is clearly relevant, the mechanisms underpinning this relationship of chewing and satiation remain to be elucidated. Linking oral processing and texture perception to satiation and satiety is challenging because chewing, salivation and somatosensory stimulation interact in complex ways [39].

Strong evidence has come from studies relating food-form and bite-size/volume to satiation and satiety that suggests one important part of the mechanism is the extent of oro-sensory exposure [40,41]. This has been shown for beverages [42,43] and semi-solids [44,45] where increasing viscosity, and longer oral transit time, correlated positively with subjective satiation signals [46] and bio-markers [47]. Researchers have also compared solid and fluid forms of the same foods eg watermelon/watermelon juice, cheese/milk and coconut meat/coconut milk [48], meat [49], and complete meals [50] and found that solid food forms elicit enhanced satiation responses. Similarly researchers have shown an acceleration of the satiation response of the perceived texture of solid foods ranging from soft solids such as luncheon meat [51], to harder solids such as rye based products [52]. Specific textural sensations have been linked *via* liking and expectation to expected satiation of solid foods [53].

One mechanism suggested for the acceleration in satiation response with increased oral processing time is that some foods demand greater oral processing effort. Few studies have controlled for the work required for mastication but de Wijk et al [43], in studying the effect of viscosity on “bite size” for liquids and semisolids found that differences in amount consumed were eliminated when controlling for bite effort. However, Pentikäinen et al. [52] found that solid products demanding the most masticatory effort were not the most satiating samples in their study of rye products suggesting that there are still many other factors to be determined.

Several authors have suggested that increased oral transit time increases the intensity of the Cephalic Phase Responses (CPRs) [39,54] CPRs include salivation and production of hormones such as cholecystokinin (CCK) and glucagon-like peptide 1 (GLP-1), often cited as biomarkers of satiation [55,56]. However, in all the studies mentioned a longer time in the mouth was frequently created by modifying food texture, for example changing the viscosity of a liquid [57], or the form of a solid product [58,59]. The ecological validity of an approach that varies texture in order to vary oral transit time is self-evident inasmuch as real foods, eaten in real situations, would have many factors varying together. However this approach has the unfortunate effect of confounding the impact on satiation of both texture and oral transit time. As such a fundamental question remains as to whether texture itself, independent of oral processing time or chewing effort, contributes to satiation. Teasing out whether there is a direct impact of texture on satiety is a further question that has received less attention to date but could be tackled using similar approaches to those described in the final section of this review.

2.2. Textural complexity and satiation

Isolating textural parameters from other variables, in order to answer this question, is difficult and raises a further issue inasmuch as textures are rarely present in isolation from other textures. Even a simple yoghurt might be perceived as smooth, creamy, gritty etc. and, arguably, solid foods are likely to be represented by an even larger number of textures evolving throughout the period of oral processing.

Complexity has previously been considered in the context of food products, and is universally acknowledged as being difficult to quantify [60–62]. Some researchers, studying complexity in flavours, have acknowledged the interaction of *intensity* and *number* of sensations [63,64]. Complexity has also been quantified using appearance [65] and in that study Mielby et al. also suggested that it is a concept that falls into the “I know it when I see it” category. We have proposed the idea of “textural complexity” as a food property, defined in its most simple form as “a succession of perceived textures from first bite to the point of swallow” [66].

We have recently shown that there is an independent role played by texture itself in the satiation response that is *independent* of oral processing time [67,68]. These studies used gel-based model foods with differing inclusions to create different levels of textural complexity. The lowest complexity food had 15 unique textural descriptors and the highest had 27. Critically these small bite-sized food models (Fig. 1) had no significant difference in chewing time, chewing rate or number of chews. The food models were used as a preload in single-blind, randomised cross-over satiation trials with participants eating the preload and then eating *ad libitum* a two course meal of pasta followed by chocolate cake. In two separate trials panellists ($n_1 = 26$, $n_2 = 36$) ate significantly less of the *ad libitum* meal following the high complexity preload.

2.3. Exploring texture's impact on satiation

The trials reported to date linking texture to satiation have built a broad and solid foundation [69] but currently miss some parts of the puzzle. The separate contributions of texture, oral processing time, and masticatory effort need more work to be teased apart. So too do the contributions of liking or hedonics. Satiation, considered as the opposite of “appetite” or “desire to eat” might be a different sensation than “fullness” with the latter's implication of stomach distension and an aversive component related to digestive well-being. In addition to this it