CHAPTER 1

INTRODUCTION

TEXTURE

Sensation and perception

Sensation is the receptor response to bodily stimulation, whereas perception, as defined in the Oxford dictionary, is the awareness through the senses interpreted in the light of experience. The senses are touch, including temperature, in addition to taste, smell, hearing and sight. Perception can be the awareness arising through one single sense or through a combination of many. Perception of food is the result of food characteristics interacting with the processes in the mouth, as interpreted by the brain.

We eat several times a day and most of the time we are actively aware of what we eat. The food undergoes many events on its way from the plate to the stomach: e.g. spooning, stirring, ingestion, mastication and swallowing. In the oral cavity, the food is subjected to several mechanical and chemical processes: It is chewed and otherwise manipulated mechanically, e.g. by the tongue. Furthermore it is diluted and broken down by saliva, heated or cooled by the ambient temperature of the mouth, formed into a bolus and finally swallowed. The numerous receptors in the oral cavity and nose respond to the initially ingested food and monitor the changes during processing. This leads to central perceptions of taste, odour, irritation and texture of the food.

What is texture?

In literature, a number of definitions of texture can be found. One of the most used definitions was stated by Szczesniak (1), who defined texture as “the sensory manifestation of the structure of the food and the manner in which this structure reacts to the applied forces, the specific senses involved being vision, kinesthesis, and hearing”. Jowitt (2) extended the definition of texture: “Texture is the attribute of a substance resulting from a combination of physical properties and perceived by the senses of touch (including kinesthesis and mouthfeel), sight, and hearing. Physical properties may include size, shape, number, nature and conformation of constituent structural elements”. Jowitt also stated that the appreciation of texture involves the subtle interaction between both motor and sensory components of the masticatory and the central nervous system. In the study presented in this thesis, I have chosen to use Jowitt’s definition as the working definition.

When asking lay people to describe food, taste and flavour are most often mentioned. However, subconsciously, texture of food is of great importance for the appreciation of food. Just think of soggy cornflakes, water thin chocolate mousse or wilted lettuce. Conversely, very good texture, such as a soft and airy hollandaise sauce, is associated with excellent cooks. Texture is not only important for the appreciation, but also for the recognition of food. After blending food products, the lack of texture cues resulted in only 40% of the products being correctly identified from their flavour only (3).

Food texture and its importance to the consumer are considerably less well understood than factors such as odour and taste (4). In contrast to odour or taste, there are no specific receptors for texture *per se*. Texture perception has in the past received relatively little research attention compared with odour and taste. However, this is a changing trend as reported by Szczesniak (5).

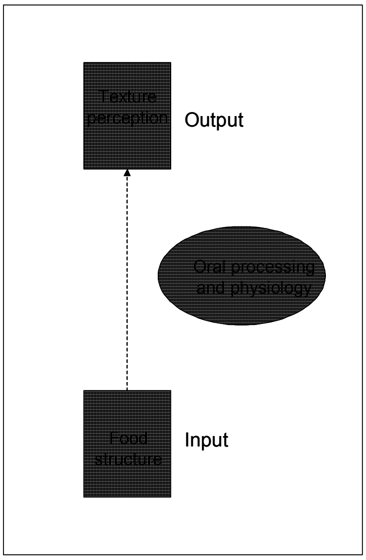


Fig 1. Oral physiology as the missing link in the relation-ship between food structure (input) and texture perception (output).

Missing link in understanding texture

Previous research on food texture has focused mainly on rheological measurements, frequently correlated with sensory data of the same product (Fig 1). Conventional rheological measurements, such as viscosity and puncture tests, are not based on oral systems, but have their origin in process technique and product control (6). As a result, rheological measurements have often turned out to be unsatisfactory in explaining the relationship between food structure and texture perception. This could be explained by the notion that this approach disregards the oral processing and physiology of the mouth (7). Moreover, most sensations associated with food texture occur only when the food is manipulated, deformed, or moved across the oral receptors. During the time in the mouth, the stimulus undergoes constant changes: it is heated or cooled; diluted and broken down by saliva; and manipulated mechanically. This makes the mouth a very challenging system to mimic *in vitro*.

Another indication to that oral processes are important, is that human volunteers (subjects) assessing the same stimulus do not only differ largely in their ratings of that stimulus, the oral physiological parameters also exhibit large inter-individual variations. In this light, oral physiology, e.g. oral processes (manipulation, mixing and dilution of food in the mouth) and oral sensitivity and receptors, possibly is the “missing link” in understanding the relationship between food structure and texture perception (Fig 1).

THE PRESENT STUDY

Factors influencing texture

There are numerous factors, both product and subject related, that can influence texture perception (Fig 2.). These factors can affect texture perception directly or indirectly. Many of the factors influence each other, which makes the whole concept rather complex. Since there are many possible interactions, no lines have been added in the diagram, indicating that all interactions are possible. This diagram is not exhaustive, but includes a collection of factors for food types ranging from solid to liquid.

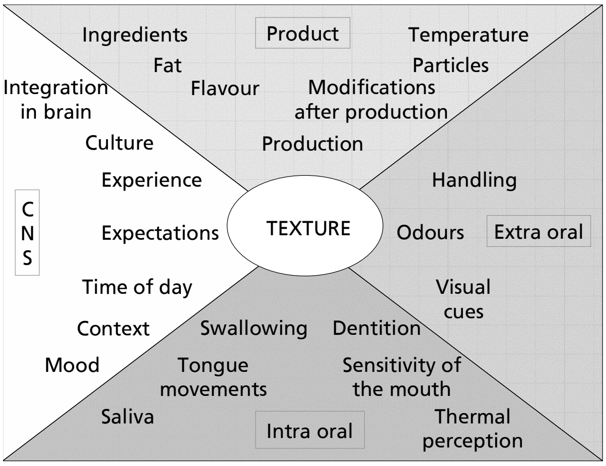


Fig 2. Diagram of factors that can influence food texture

Starting at 11 o'clock product ingredients (top left in Fig 2) are major determinants of the product structure. The ingredients include thickeners, type of starch, oil, water etc. Moving clockwise, the level of fat is thought to influence flavour release, mouth feel, and thermal perception. In addition, the ingredients can affect the flavours e.g. by having off-flavours. Product structure is of importance for how the product will be handled in the mouth. Production techniques, e.g. homogenization, baking and freezing affect the final structure strongly. Various matters, such as particles, can be added after production, to modify the product. Temperature of the product does not only affect the structure, it can also influence the perception of food texture, flavour and irritation.

Texture is also perceived outside the mouth (extra oral). Before the food enters the mouth, visual cues such as colour, shine, grains, and heterogeneity (lumps), provide information on the texture of the food. Additional information can be obtained by handling the food, e.g. stirring, spooning and cutting.

Intra-oral factors that are subject-related can affect the food itself and how it is perceived. These are: thermal perception; sensitivity of the mouth to touch and size; dentition; swallowing; movements of the tongue in relation to the palate; and saliva amount and composition.

Finally, the central nervous system is an important determinant in texture perception. Memory and emotional state of the person eating the food, social background, time of day and expectations could be of importance. During exposure to different foods, the perception and appreciation of food will change due to experience. In different cultures, different textures are favourable, such as stickiness and pliability in Japan (8).

A selection of factors, potentially influencing texture, was made to study further. Since the research was aimed at investigating the role of oral physiology on texture perception, mainly factors that are subject-related and applicable to semi-solids were selected: Saliva, sensitivity, added particles, tongue movements and temperature.

This selection is in accordance with Szczesniak's ideas (9). She stressed that tactile perception, perception related to size and position of particles in the mouth and temperature are very important.

Multi-disciplinary project

The research presented in this thesis is part of a multi-disciplinary project with the scope of investigating the fundamentals of texture of semi-solids. The relation between food structure and texture perception was investigated by the combined efforts of three disciplines; sensory science, oral physiology and physical science (rheology).

Semi-solids were chosen as stimuli, as they can be easily and reproducibly modified. The independent variation in starch content, starch type, fat etc. resulted in a large variation of stimuli. In addition, the choice of semi-solids largely excluded the effects of the chewing process and teeth, which enabled the research to focus on other oral mechanisms. Oral texture attributes of semi-solids can be divided into functional sub-groups: lip-tooth feel, mouth feel and after feel (10).

Subjects and individual differences

Human perception of texture is a physical and psychological response to a stimulus, thus a full description of texture can be achieved only by the employment of human volunteers. Previous research has shown that there are large differences in reported sensations among subjects, even though they are assessing the same product. In part these differences could be a result of physiological differences between individuals, in part they reflect differences in the use of the measurement scale and terminology. In this research we have focused on investigating the physiological differences among subjects.

Healthy adult volunteers were screened for well functioning smell and taste. The selected subjects were trained in QDA (Quantitative Descriptive Analysis) and formed a weekly panel.

Aim of the research

The previous sections discussed the complexity of understanding texture and the involved factors. This includes the difficulties of relating conventional rheology with texture perception and of oral physiology as possibly being the missing link. Further, it has been suggested that the differences in perception among subjects might partly be explained by differences in their oral physiology.

The aim of this research was to examine the role of oral physiological processes on oral texture perception of semi-solids and to investigate whether individual differences in perception could be attributed to and explained by differences in oral physiology among subjects.

The next two sections offer a general overview of a few aspects of physiology that are referred to in subsequent chapters of this thesis.

SALIVA

Secretion of saliva

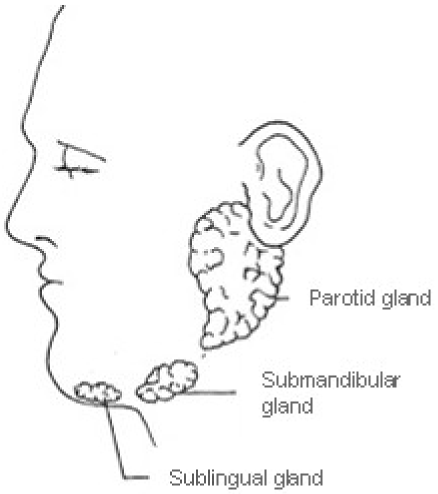


Fig 3. The location of the three major salivary glands.

Human whole saliva consists of the combined secretions from the salivary glands, and its characteristics are dependant on the origin of the secretion. Whole saliva is derived mainly from the three paired major salivary glands – the parotid, submandibular, and the sublingual glands (Fig 3). They are characterized by the presence of a large number of secretory cells. In addition to these, minor salivary glands are dispersed throughout the mouth, including the palate, lips, cheeks and tongue. The parotid gland, the largest of the salivary glands, is a purely serous gland that produces watery, enzyme-rich saliva upon stimulation which is rheologically speaking comparable to water (11). Parotid saliva is virtually absent during sleep, but can easily be stimulated to be the major constituent of whole saliva. The parotid gland contributes up to 50% or more of the stimulated saliva in the mouth. During sleep and rest whole saliva consists for 70% of submandibular saliva, whereas during stimulation this decreases to 30-45 % (12). The submandibular glands are mixed glands, containing both serous and mucous cells, which secrete a more viscous mucus-containing saliva. The sublingual glands consist mainly of mucous cells. As a result, sublingual saliva is very viscous, which can be attributed to the high levels of mucins present. The minor salivary glands contribute to saliva volume with 7-14% (13) and the secretion contains high levels of protein, such as immunoglobulins (12).

The mean total amount of saliva secreted per day is estimated to be between 500 and 1500 ml. Watanabe and Dawes estimate was about 570ml (14). This calculation implies 54 minutes of eating (4 ml/min), 16 hours of awake activities (0.3 ml/min), and 7 hours of sleep (0.1 ml/min) (15). Hence, the flow rates exhibit circadian fluctuations (16;17), and depend largely on the activity and type of stimulation. Normally, mean saliva flow at rest is around 0.3ml/min, whereas during stimulation, the flow can increase to a maximum of 7ml/min (18). Despite the large variation in normal salivary flow rates, it is generally agreed that salivary flow rates of 0.1ml/min or less (unstimulated) and 0.5ml/min or less (stimulated) are abnormally low (19).

Salivation can be stimulated in various ways: mechanical input mediated by oral mechanoreceptors (20) and taste, where acids are the most, and sugars the least potent stimulators, represent the major input. Olfaction, the sight of food and thermal stimulation are other inputs that contribute to salivation (20;21). Factors such as mood, disease, medication, body hydration and exercise (22) also affect salivary flow and composition. The salivary glands are innervated by both parasympathetic and sympathetic nerve fibres (23). Parasympathetic stimulation increases the synthesis and secretion of amylase, mucins and saliva. Sympathetic stimulation on the other hand causes constriction of blood vessels, with consequent reductions in salivary flow from the gland (23).

Constituents and actions of saliva

Saliva consists for more than 99% of water and the remaining 1 % contains a large number of organic and inorganic constituents (24;25). Saliva contains minerals, enzymes e.g. α-amylase, a large number of proteins, such as proline rich proteins (PRPs), and mucins, glycoproteins with a number of functions, e.g. lubrication and antibacterial actions. A number of these constituents of saliva, including water affect the structure and perhaps also the perception of food.

Saliva is indeed expected to be involved in our perception of the taste, flavour and texture of foods. The effects of saliva on food leading to changes in perception are plentiful. Mixing of saliva with food can have a diluting effect (26;27) and play a role by initial breakdown of food (28;29;29), by affecting flavour release (26;30-33), transport of taste compounds to the taste buds (30-33), precipitation of proteins by tannins e.g. resulting in a sensation of astringency (34;35), and acting as a buffering system (36-38), affecting the degree to which we perceive sourness (39). In addition, the large salivary proteins can influence the lubrication (12) and hence perhaps the perception of attributes such as smoothness and astringency (35;40) and facilitating manipulation of food in the oral cavity and swallowing. These examples indicate the value of saliva for the appreciation and acceptance of food.

Amylases are enzymes that catalyze the hydrolysis of starch into smaller carbohydrate molecules such as maltose and glucose. There are two types of amylases, denoted alpha and beta, that differ in the location they attack the bonds of the starch molecules. By hydrolyzing the starch of semi-solids, such as custard desserts, into sugar molecules, the starch loses its ability to bind water, resulting in a decrease in product viscosity.

Since saliva is always present in the mouth, with increasing amounts during eating or otherwise stimulated, we hypothesized that saliva would be important for the sensation and perception of semi-solids. We therefore investigated both the amount and composition of saliva in the subjects and related these to their perception of the foods in order to establish the importance of saliva on perception of semi-solids.

RECEPTORS AND SENSATIONS

The studies included in this thesis, have only paid little attention to the receptors and processing of the signals in the central nervous system. Yet, sensation and perception are a result of receptor signals and central processing. Therefore, the following section gives an overview of the oral receptors and how the signals are conveyed and processed to give the resulting perception.

Humans have four classes of receptors, each of which is sensitive primarily to one type of physical energy – chemical, mechanical, thermal and electromagnetic. In the mouth all types, except the photoreceptors sensitive to electromagnetic energy, are present. The chemical receptors include taste and smell; the mechanoreceptors mediate sensations of touch and proprioception; the thermoreceptors sense the temperature of the body and objects that we come in contact with and nociceptors signal sensations of pain. All these types of receptors contribute to the total sensation and perception of food that we ingest.

Taste and smell

The senses of taste and smell have been studied extensively and much is known on how tastes, odours and flavours are sensed and how the sensations are processed in the central nervous system. Food is often classified on the basis of their taste and smell.

Taste

Chemical constituents of food interact with receptors on taste cells, which are found in taste buds distributed throughout the oral cavity, pharynx and upper part of the oesophagus. Most taste stimuli are hydrophilic molecules that are soluble in saliva. The gustatory system distinguishes four basic stimulus qualities: salt, sweet, sour, and bitter. Monosodium glutamate may represent a fifth stimulus category, called umami. Recent evidence indicates that fat may represent an additional taste quality (41). These tastes can interact, to enhance or suppress the perception.

Smell

The olfactory system reacts to airborne stimuli, called odorants. These interact with olfactory receptor neurons in the nasal mucosa located in the roof of the nasal cavity (42). From the olfactory receptors neurons, numerous olfactory cilia, which are in fact the structures in contact with the odorants, protrude into the layer of mucous is the nasal lumen. The odorants can reach the nasal cavity through the nose (orthonasal) or through the mouth (retronasal), which is the case when eating a product. In the nasal lumen the odorants bind to specific receptors on the cilia and a signal is transduced to the olfactory bulb and then further on to the olfactory cortex.

The somatic sensory system

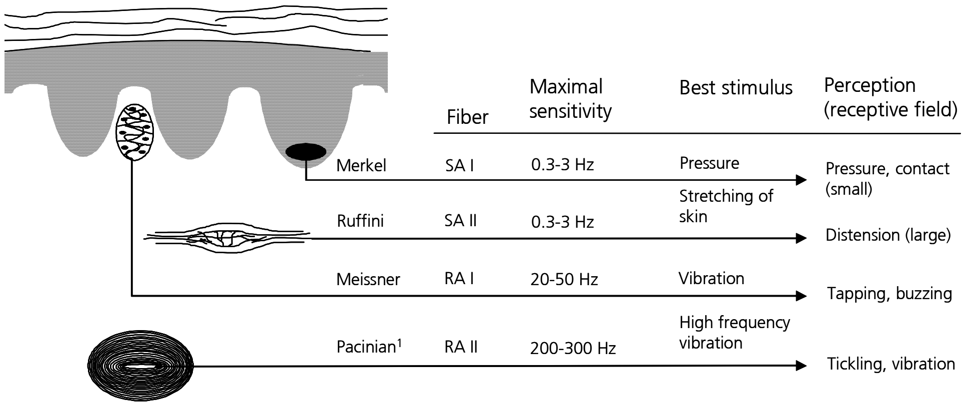
The mouth is a very sensitive organ. The oral cavity is one of the regions of the body most densely innervated with nerve fibres and receptors (43) and is exquisitely sensitive to tactile stimulation (44;45). This means that thresholds for somethetic stimuli are lower and discrimination is better than on most other skin areas of the body. Thresholds for detection of light touch are lowest on the tip of the tongue and hard palate (44;46). Somethetic receptors are found in all regions of the oral cavity, including the lips, tongue, teeth and mucosa.

The somatic sensory system transmits information about four modalities: touch, temperature, pain and proprioception. The receptors for each modality are specialized structures, allowing them to sense specific types of stimuli. Cutaneous receptors can be subdivided according to the type of stimulus to which they respond. The major types of receptors include mechanoreceptors responding to tactile stimuli, thermoreceptors and nociceptors, responding to pain.

Mechanoreceptors in the mouth

Mechanoreceptors respond to tactile stimuli, such as pressure or tapping. There are a number of different types of receptors present in the skin of humans. Four major types of histological nerve endings (Merkel disks, Ruffini endings, Meissner corpuscles and Pacinian corpuscles) are associated with a particular type of tactile perception: pressure, stretch of skin, taps on skin, and high frequency vibration. However, in the mouth and specifically on the tongue, there is as yet only little information on the morphology of the nerve endings (personal communication, Mats Trulsson).

However, functionally, the receptors behave similarly in all areas and the ones present in the mouth and lip closely resemble the mechanoreceptors previously described for the skin of the hand. These are slowly adapting type I and II (SA I and SA II) and rapidly adapting type I (RA I). No RA II afferents have been found in face/mouth, i.e. no receptors showing response properties similar to Pacininan-corpuscle afferents were observed. Barlow (47) concludes that pacinian-type frequency sensitivity characteristics of the finger, was absent in the face. The various receptors are sensitive to different frequencies of vibration, ranging from 0.4 Hz to over 500 Hz. A summary is presented in Fig 4.



	Fiber	Maximal sensitivity	Best stimulus	Perception (receptive field)
Merkel	SA I	0.3-3 Hz	Pressure	Pressure, contact (small)
Ruffini	SA II	0.3-3 Hz	Stretching of skin	Distension (large)
Meissner	RA I	20-50 Hz	Vibration	Tapping, buzzing
Pacinian[1]	RA II	200-300 Hz	High frequency vibration	Tickling, vibration

Fig 4. Summary of nerve endings, fibers and perception of skin.
[1] not present in the oral cavity

The majority of the mechanoreceptive afferent units in the skin of the human face are slowly adapting with small and well defined receptive fields (48). This makes these receptors very well suited for resolving fine details (49). Johansson *et al.* (48) found primarily slowly adapting units in the oral mucosa and the transitional zone of the lip. In contrast, the tongue has primarily rapidly adapting receptors (50). Receptors associated with rapidly adapting fibres notice changes, they respond only to the application and removal of a stimulus. In contrast, slowly adapting receptors respond to prolonged and constant stimulation, and, hence are well suited for signalling the location of stimulation and fine details. The receptors respond best to frequencies within a certain range. However, if the stimulus is well above threshold, a number of receptors can be activated at once (49).

Mechanoreceptors in the mouth are not yet fully understood. In the sensation and perception of oral texture, the tactile stimuli are probably the most prominent clues to texture. Hence, a deeper insight into the mechanoreceptors and their exact function in food sensation would be of great importance in this area of research. This could be one way to proceed to gain more fundamental knowledge of the origins of oral texture sensations.

Thermoreceptors

Thermal sensations result from differences between temperature of the air or of objects contacting the body and the normal skin temperature. There are two types of thermoreceptors in the skin, responding to specific temperatures and changes in temperature: cold and warm receptors. Both classes are slowly adapting, although they also discharge phasically when skin temperature is changing rapidly. The receptors are active over a broad range of temperatures – cold: 20°C - 40°C; warm: 30°C - 48°C (49). At moderate skin temperatures, such as 35°C, both types of receptors may be active. However, as the skin is warmed, the cold receptors stop firing and conversely, as the skin is cooled, the warm receptors become inactive. Cold and warm receptors also stop firing altogether as the temperature extends into the noxious (damaging) range (below 5°C and above 50°C) (51). At these stimuli temperatures, humans perceive freeze and heat pain rather than sensations of cold and warmth. The fact that the face and particularly the lips contain more temperature-sensitive spots than any other region of the body, suggests that the temperature of the food entering the mouth is well sensed. This could have an effect on the way the food is perceived. Oral parts can be heated and cooled down depending on the temperature of the food, which in turn also physically affects the food.

Nociceptors

The sensation of pain serves an important protective function: It warns of injury that should be avoided or treated. Pain is mediated by specialized free nerve endings, called nociceptors. They respond to stimuli that may produce tissue damage, such as intense pressure, extreme temperature, or burning chemicals. This response can be direct to some noxious stimuli and indirect to others by means of chemicals released from cells in the traumatized tissue (51). There are three major classes of cutaneous nociceptors that often work together: the Aδ mechanical and thermal nociceptors, and the C-polymodal nociceptors, that respond to noxious stimulation of varying origin. The fast sharp pain is transmitted by the Aδ fibres and the slow dull pain by the C fibres (52). Unlike the specialized somatosensory receptors for touch and pressure, most nociceptors are free nerve endings.

Proprioceptors

Proprioception is the sense of static position and movement of the limbs and body. There are two sub-modalities of proprioception: the sense of stationary position of the limbs and the sense of limb movement. Cutaneous proprioception in the face is especially important for control of lip movement in speech and face expressions (51). Three types of receptors in muscle and joints transmit proprioceptive information: Muscle spindles are situated in the muscles and signal changes in the length of muscles, Golgi tendon organs signal changes in tension, and receptors located in joint capsules sense flexion or extension of the joint(51;53;54).

Periodontal receptors

Human teeth are sensitive to very small forces applied to them (55). Teeth are attached to the alveolar bone by the periodontal ligament. This ligament is invaded by nerve fibres terminating in periodontal mechanoreceptors, which respond to loading of the teeth and which are dependent on the direction in which the forces are applied (56). The periodontal receptors probably especially play a role for solid and hard foods (57).

From sensation to perception

The oral regions are innervated by afferent nerve fibres in the trigeminal nerve (cranial nerve V). Hence, tactile information from the receptors in the mouth is conveyed to the central nervous system by the trigeminal somatic sensory system (Fig 5). The oral receptors initiate action potentials upon stimulation. This activity is conveyed via first-order neurons in the trigeminal ganglia, entering the brain stem at the level of the pons, further on to second-order neurons in the trigeminal brainstem complex. This complex has two major components: the principal nucleus (responsible for processing mechanosensory stimuli) and the spinal nucleus (responsible for painful and thermal stimuli). The second-order neurons of the trigeminal brainstem nuclei give off axons that cross the midline and ascend to third-order neurons in the [1]VPM nucleus of the thalamus. The axons arising from neurons in the [2]VP complex of the thalamus project mainly to cortical neurons located in the primary somatosensory cortex (SI, also known as Brodmann's area. Somatic sensory information is distributed from the SI to "higher-order" cortical fields, such as the adjacent secondary somatosensory cortex, which sends projections to limbic structures, e.g. the amygdala and hippocampus. On all levels neurons also receive parallel information. The representations from each modality (taste, vision, olfaction and touch) are brought together in multimodal regions, such as the orbitofrontal cortex (58). The signals are integrated to a complete picture, the perception.

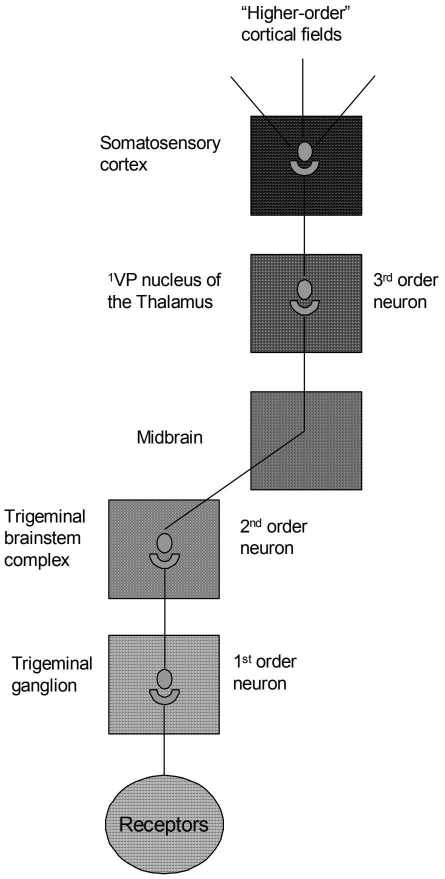


Fig 5. Trigeminal pathway from receptor to higher brain centres.

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[1] Ventral Posterior Medial Nucleus of thalamus

[2] Ventral Posterior complex of thalamus

OUTLINE OF THE THESIS

This thesis presents eleven studies on four aspects of oral physiology in relation to texture perception (Fig 6):

- Oral sensitivity and particles (chapter 2-5)
- Manipulations of tongue movements (chapter 6)
- Oral and product temperature (chapter 7-8)
- Amount and composition of saliva (chapter 9-12)

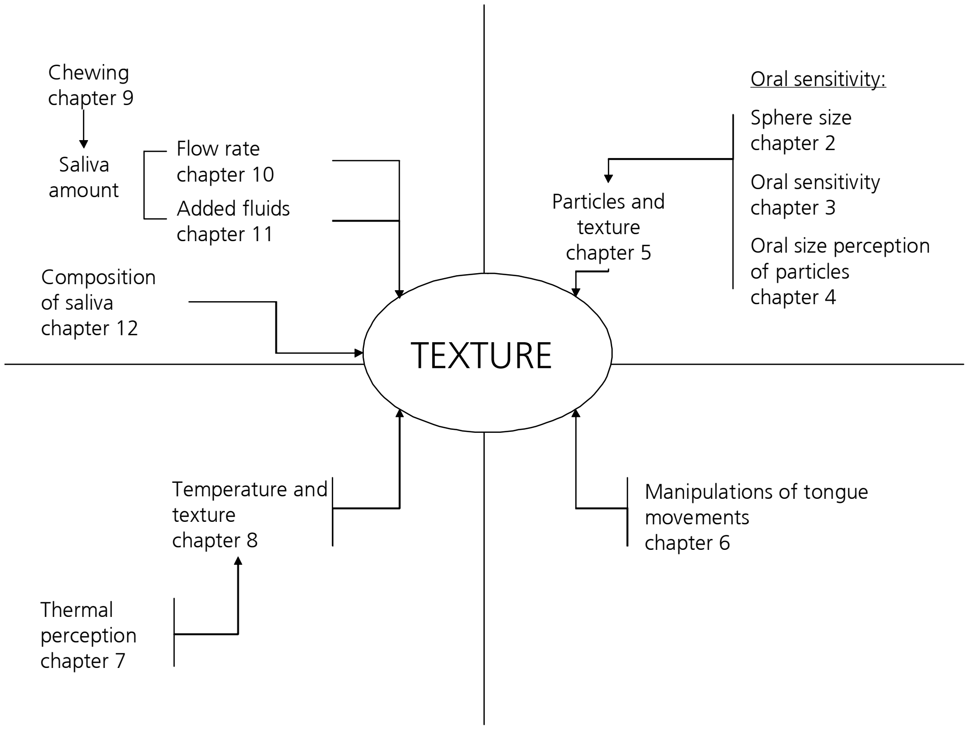

Fig 6. Schematic representation of the thesis outline. The research topics are depicted in relation to texture

Oral sensitivity and particles

Sensitivity of the mouth includes the ability to assess shape, size, and surface texture. Information on the significance of the various oral parts in oral size perception and sensitivity is required to understand their role in the control of bite size and swallowing, and perception of food. Practically all food contains particles. It has been suggested that the presence of particles in food may affect the perception of sensory attributes. While some are obviously present such as pits in berries, others are small, or soft and hardly noticeable, such as oil droplets in mayonnaise. Large particles in low concentrations are likely to be perceived as separate entities, e.g. seeds in a watermelon. Conversely, small particles of high concentrations are more likely not to be noticed separately, but instead to have an effect on the texture of the product, e.g. graininess.

Imai et al. have studied grittiness in the mouth (59-61). Also other types of texture were studied, e.g. digital roughness when moving the fingers over an embossed surface (62;63). For oral perception of grittiness, it has been reported that concentration, size and shape of the particle are of importance, as well as the medium in which they are dispersed (59;61;64). This thesis presents four studies that address these aspects of oral sensitivity and the effect of particles on texture perception.

In **chapter two**, the perception of sphere sizes (4-9 mm), and the relative importance of tongue and palate in size perception were addressed. To investigate the mechanisms of particles sensed separately, it was chosen to take things to extremes and an experimental set-up was chosen, in which spheres were used which could be handled separately and safely. Subjects are to some degree able to detect and measure the size of objects in the mouth. This study questioned whether this is done by assessing the weight or the volume of the object in the mouth and what the most important oral parts included in this assessment are.

Chapter three: Oral sensitivity has often been measured to track damage and rehabilitation after occasions of stroke (65), prosthodontic treatment (66;67), and speech disorders (68). Various methods to measure oral sensitivity have been employed, including oral form recognition (66;69-72), interdental size and weight discrimination (73), intra-oral size judgements of small holes (74-77), cylinders (78), liquid volume during swallowing (79), and 2-point discrimination (44). The study presented in chapter 3 investigates the relation between three different measures of oral sensitivity to size, i.e. chewing thresholds, two-point discrimination and size perception of spheres. In addition, the importance of the tongue and palate in oral sensitivity and size perception was investigated by applying local anaesthesia.

Chapter four addresses how oral size perception is affected by different types of particles in sizes varying from 2-230 μm and media of different viscosities. Two different methods of assessing size (direct scaling and forced ranking) were compared.

Chapter five. Following the results of the previous studies (chapter 2-4), the next step was to investigate the effect of added particles, including the effect of particle size on texture perception. In addition, the relation between subjects' assessment of particle size, and their perception of texture in custard dessert was studied.

Manipulations of tongue movements

In **chapter six**, a new approach to gathering data on the relation between oral movements and attributes was explored. Oral movements were experimentally modified and their effects on flavour, mouth- and after-feel sensations evaluated. To gain insight into the effect of oral processes on perception, we defined a set of 5 specific oral manipulations and investigated their effects on the perception of semi-solid foodstuffs. Modifications of tongue movements ranged from simply placing the stimulus on the tip of the tongue to vigorously moving it around in the mouth.

Oral and product temperature

Thermal effects on texture perception can be mediated by physico/chemical changes in the product, or by differences at the level of the mucosa. Product temperature could influence the viscosity of the product and the ratio of solid and melted fat and thereby influence the quality and the thickness of the oral coating formed. Foods, initially at temperatures higher or lower than body temperature, undergo physical changes when eaten as thermal equilibrium occurs. The differences in oral temperature could affect receptor response, blood flow and have a secondary effect by altering the product on contact, all of which may change the response to the stimuli. If oral temperature is important, it can be hypothesized that heating or cooling the mouth can modify sensory ratings.

Chapter seven reports on the effect of oral and stimulus temperature on thermal perception.

In **chapter eight**, the effects of oral and product temperature on sensory perception are studied.

Amount and composition of saliva

Saliva is always present in the mouth and the amounts increase during eating. The food is mixed and diluted and break down is initiated by saliva. It seems likely that the amount of saliva present in the mouth during mastication could affect the perception of the food. In addition, the composition of saliva varies largely between subjects and depends on the type of stimulation. Hence the composition of saliva might have an effect on the actual physical structure of food and on the interaction between the food and the mucosa.

Chapter nine reports on a study in which the individual salivary flow rates at rest and after different stimulations are correlated with the subjects' sensory ratings.

Chapter ten: The effect of an artificial increase in amount of saliva and fluid in the mouth during eating were studied and an attempt to separate the action of the different liquid components of saliva was made.
The subjects' individual composition of saliva was analyzed in **chapter eleven** and the correlations between the salivary components and sensory perception determined.

In **chapter twelve**, the salivary flow was measured during chewing on parafilm and a number of different foods. We also determined the duration of a chewing cycle, the number of chewing cycles until swallowing, and the time until swallowing for these foods. The relations among these parameters were examined.

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