Food Oral Processing
fundamentals of eating and sensory perception
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Fundamentals of Eating and Sensory Perception

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Preface

‘It is critically important not only what we eat but also how we eat!’

Eating, or food oral consumption, is an essential part of our daily life. It is a routine process of obtaining the energy and nutrients essentially required for living and well-being and also the appreciation of sensory pleasure and enjoyment. The eating process can be seen as the ultimate stage of the food supply chain and is the starting point of food disintegration and the digestion process. Therefore, the eating quality and sensory experience of a food always remains a top concern to food researchers, food manufacturers and retailers, as well as consumers. How a food is broken down inside the mouth could also have important implications for our well-being and health, as indicated by Horace Fletcher (1849–1919) almost a century ago. Even though the practice of eating is well-known to most, the fundamental principles involved in eating and sensory perception of food are not as obvious as they are normally perceived. This book endeavours to review the latest research findings on food oral processing and sensory perception. The main objective of the book is to provide readers with up-to-date knowledge and understanding of the underpinning principles of food physics, oral physiology and sensory psychology of an eating process.

Studies of food texture, taste, flavour, aroma and colour as independent scientific disciplines began only around the middle of the last century, shortly after food science and technology became the subject of degree courses. Knowledge of food sensory properties was in urgent demand due to largely industrialised food manufacturing and supply, which led to huge expansions of research activities in these areas during the second half of last century. Approaches during the early stages of eating and food sensory studies were mostly either through an objective instrumental characterisation or a human subject sensory description method. For example, for food texture studies, rheology and mechanical investigations were most commonly used, where food was essentially treated as a material, that is mechanical and rheological properties (e.g. hardness, springiness, viscosity, cohesiveness, etc.) were characterised using instrumental devices, and results were interpreted in relation to sensory perception. On the other hand, food taste and aroma studies focused mainly on small molecules, their release, characterisation and detection. It is only during the last one or two decades that cross-disciplinary approaches were introduced into eating and food sensory studies. During the last decade, increased use of physiological methodologies and techniques has been reported by food scientists. Food texture studies have been conducted in combination with the observation of orofacial muscle activities and the analysis of saliva interactions. Very recently, fNMI (functional Nuclear Magnetic Imaging) observation by neuroscientists revealed positive correlations between increased brain activities and the eating and sensory pleasure perception. Eating is no longer seen as a simple
process of food break down, but is recognised as a highly sophisticated process of human responses (physiological, psychological and neurological) to the changing physicochemical properties of the food.

Based on this background, we feel that there is a need for a book that elucidates the multi-disciplinary nature of eating and sensory perception and that reviews the latest progress in related areas, from fundamental studies to industrial applications. This book endeavours to be a multi-disciplinary source of stimulation and reference, and we hope it will encourage further researches in these areas. The book is divided into five sections: 1 Oral anatomy and physiology; 2 Food oral management; 3 Oral processing and sensory perception; 4 Principles and practices of instrumental characterisation for eating and sensory perception studies; and 5 Applications and new product development.

The first section covers the oral cavity, where Luciano Pereira describes the anatomy and function of the different parts of the oral cavity; oral receptors, where Lina Engelen reviews the oral tactile and chemosensory receptors; and saliva, where Guy Carpenter discusses the origins and composition of saliva as well as its role in the oral processing of food. In Section 2 Andries van der Bilt starts by discussing the strategies of food oral management, from ingestion to swallow; followed by a chapter on the oral break down and mastication of solid foods and the determining physical principles (Carolyn Ross and Clifford Hoye Jr.). Anwesha Sarkar and Harjinder Singh introduce food emulsions and their behaviour in the mouth. This chapter explains the possible mechanisms of oral destabilisation of food emulsions and their implications on sensation. The section ends with a review by Jianshe Chen on the mechanisms of food bolus formation and the critical criteria in triggering a swallowing action.

The third section of the book covers the interactions between oral processing and sensory perception, regarding texture by Lina Engelen and Rene de Wijk, and flavour by Sara Adams and Andrew Taylor, followed by an account of sensory integration and psychophysics by Charles Spence.

Section 4 begins with two chapters by Jason Stokes on ‘oral’ rheology and ‘oral’ tribology, in which he discusses the underlying physical principles of food oral break down and food oral movement and their roles in sensory perception. This is followed by a chapter on the EMG (electromyography) technique (by Yadira Gonzalez and Jianshe Chen), covering the theories and practices of the technique and its application to eating studies. Micha Peleg and Maria Corradini conclude Section 4 with a chapter on food–body interactions, where, by treating the human mouth as a soft machine, soft machine mechanics are discussed in relation to instrumental characterisation of textural properties of a food.

The final section is dedicated to possible applications of recent research findings for new product developments. Paula Varela and Susana Fiszman focus mainly on crispy and crunchy foods and the principles and practices applied in industry in designing and providing such products. Adam Burbidge finishes off the book by reviewing the biomechanics of oral stress and strain, which (micro-)structures elicit these effects, and considers potential routes for creating these structures in a food context.

Integrated studies of eating and sensory perception have been adopted only fairly recently and this book is probably the first of its kind. We anticipate that this book will be of interest to scientists, technologists and engineers in food-related areas, as well as to those from other disciplines such as oral physiology, oral biology, dentistry and sensory science. This book could also be used as a useful reference for undergraduate and postgraduate students studying in above disciplines and for R&D researchers in food manufacturing and food service industries.
We would like to take this opportunity to thank all the contributors; their expert knowledge, enthusiasm and hard work have enabled us to put a book together of high scientific quality; the editorial staff at Wiley-Blackwell for their support and advices; and our families and friends for bearing with us through the long nights and weekend hours.

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Part One
Oral Anatomy and Physiology
1 Oral Cavity
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1.1 INTRODUCTION

The oral cavity is the first part of the digestive tract. However, the mouth is not only responsible for digestive functions. It also plays a role in breathing, behavioural and social activities (talking, smiling, yawning, sucking) and taste perception. The oral cavity consists of two parts: the vestibule, which is limited externally by the lips and cheeks and internally by the gums and teeth; and the oral cavity itself (1.1), which is limited laterally and ventrally by the alveolar process and teeth and dorsally communicates with the pharynx through the isthmus faucium (Gray, 2000).

Mastication is the most important function of the mouth. Teeth, muscles of mastication and salivary glands all work together to shred and break down food for swallowing. The teeth are the hardest tissues in the jaw and are involved in different activities, such as food ingestion and pronunciation of words, and also play an important role in facial aesthetics (Honda et al., 2008; Koussoulakou et al., 2009). The muscles of mastication promote the force needed to elevate the jaw so that food can be shredded between the teeth as the upper and lower arches come into contact (Fontijn-Tekamp et al., 2000). Simultaneously, saliva is produced by major and minor salivary glands. The water in saliva moistens food particles and salivary mucins bind masticated food into a coherent, moist bolus that can be easily swallowed (Pedersen et al., 2002).

This chapter reviews the main anatomical and physiological aspects of the oral cavity – teeth, tongue, salivary glands and major orofacial muscles. The review focuses on the physiological behaviour of the mouth and fundamental knowledge of oral operations covered in four main sections: the oral cavity (including teeth and periodontal tissue); saliva (saliva glands, saliva secretion, composition, physical and chemical properties); orofacial muscles (location, function, activity) and tongue (tongue muscles, function).

1.2 THE ORAL CAVITY

The oral cavity is delimited anteriorly by the upper and lower lips (vermilion surface, mucosal lip, labial mucosa), laterally by the cheeks, superiorly by the hard palate and
inferiorly by the tongue and muscles attached to the internal side of the mandible, including the geniohyoid, mylohyoid and digastric muscles. The upper and lower dentition, salivary glands, mucosal glands, tongue and the mucosal tissue covering the hard palate are found in this cavity (German and Palmer, 2006) (Figure 1.1).

The oral cavity is continuous with the pharyngeal cavity. The region where the pharynx connects to the oral cavity is called the oropharynx, and it embraces the base of the tongue, vallecula, soft palate, uvula, lateral pharyngeal walls (including the palatine tonsils and tonsillar pillars) and the posterior pharyngeal wall extending from the plane of the soft
palate/hard palate junction to the level of the pharyngoepiglottic folds at the hyoid bone. The base of the tongue is the part posterior to the circumvallate papillae (Yousem and Chalian, 1998).

The mucous membrane that covers the mouth connects to the integument at the free margin of the lips and with the mucous covering the pharynx. It has a rose-pink colour and it becomes thicker on hard parts limiting the cavity. The mucous membrane is covered by stratified squamous epithelium (Gray, 2000).

The bones adjacent to the oral cavity are the maxilla and mandible. These bones support the dentition and form the hard palate, which is made up of the palatine process of the maxilla and the maxillary process of the palatine bones. The final portion of the oral cavity is formed by muscle, with the hyoid bone and cartilages of the larynx functioning as the pharyngeal arch structures (German and Palmer, 2006).

The dentition is placed in the maxilla and mandible and consists of 32 teeth. Children are born edentulous; the first deciduous (primary) teeth erupt approximately six months after birth. There are five types of deciduous teeth: medial incisor, lateral incisor, canine, first molar and second molar. These teeth are replaced by permanent teeth. However, the permanent dentition is composed of two additional premolars and a third molar. The permanent dentition is usually complete (except for the third molar) at 12 years of age. The third molar erupts at around 16 to 20 years of age and frequently fails to erupt at all (German and Palmer, 2006). Some individuals do not even present those teeth (agenesia).

The main component of a tooth is dentine, which is calcified tissue produced by odontoblasts (Koussoulakou et al., 2009). The dentine surrounds the pulp, which is rich in fibroblast-like cells, blood vessels and nerves. The dentine that forms the tooth crown (the visible part of the tooth in the oral cavity) is covered by a layer of enamel, which is produced by ameloblasts. The enamel is the hardest tissue in the human body and is collagen free. Its main proteins are amelogenin (90%), ameloblastin, enamelin and tuftelin. The teeth are firmly attached to the jaw by their roots, which support the teeth within an alveolar socket by means of the periodontal ligament. The periosteum is connected to the fibrous structure of the gums (Gray, 2000).

The teeth are important to the masticatory system, as they break down food particles during occlusal contact (Pereira et al., 2006). A significant reduction in masticatory function occurs following the loss of post-canine teeth. Moreover, individuals with natural dentition present better masticatory function than those who wear removable dentures or have an implant-supported prosthesis (van der Bilt, 1994; Wilding, 1993; Julien et al., 1996; Fontijn-Tekamp et al., 2000; Hatch et al., 2001; van Kampen et al., 2004). A linear relationship has been found between masticatory performance and the number of occluding teeth (van der Bilt et al., 1993). However, individuals who have lost posterior teeth do not necessarily chew longer before swallowing than individuals with all teeth. This indicates that, on average, people with a bad masticatory performance swallow larger food particles (Fontijn-Tekamp et al., 2004).

Tooth loss is related not only to a reduced occlusal area, but also to the disappearance of the periodontal ligament. Mechanoreceptors located in the periodontal ligament obtain detailed information on the spatial relationship and load modulation in the process of food fragmentation (Johanson et al., 2006). Thus, chronic periodontal disease can cause the destruction of the support tissue, with consequent loss of periodontal mechanoreceptors, resulting in tooth mobility and masticatory impairment (Alkan et al., 2006). The subjective perception of the impact of oral health on mastication diminished after periodontal treatment (Pereira et al., 2011).
1.3 **SALIVARY GLANDS AND SALIVA SECRETION**

The major salivary glands are characterized by three pairs of organs: parotid, submandibular (Figure 1.2) and sublingual glands that work simultaneously to produce saliva for the oral cavity (Denny et al. 1997). The major salivary glands secrete more than 90% of the total volume of saliva and the remaining amount is secreted by the minor glands. These glands are located all over the mouth except the gums and anterior portion of the hard palate (Tenovuo, 1997). Salivary glands are made up of acinar and ductal cells. The formation of saliva inside the salivary glands occurs in a similar manner to the action of the tubular filtration in the kidneys. A plasma-like filtrate is formed by the acinar cells. Initially, this fluid is isotonic with respect to blood plasma. During its way through the gland ducts the filtrate becomes hypotonic due to resorption and secretion of ions and other components. (Turner et al., 2002; Dodds et al., 2005). Secretion is controlled by the autonomic nervous system. Parasympathetic stimulation induces the output of a large volume of saliva with a low protein concentration, whereas sympathetic stimulation has the opposite effect, causing the release of a relatively small volume of saliva, with a high protein concentration (Anderson et al., 1984). Even though both parasympathetic and sympathetic stimulation can evoke salivary flow, stress situations can cause dry mouth symptoms due to vasoconstriction.

The parotid gland (Figure 1.2) is located in the retromandibular fossa anterior to the ear and sternocleidomastoid muscle. Parts of the superficial lobe cover the ramus of the mandible and the posterior part of the masseter muscle (Bialek et al., 2006). The acinar cells of the parotid gland produce a largely serous secretion and synthesise most of the $\alpha$-amylase (Llena-Puy, 2006).

The submandibular gland (Figure 1.2) is located in the posterior portion of the submandibular triangle. The submandibular triangle is limited by the anterior and posterior bellies of the digastric muscle as well as the body of the mandible. (Bialek et al., 2006).

![Figure 1.2 Parotid and submandibular salivary glands.](image-url)
The sublingual gland lies between the muscles of the oral cavity floor – geniohyoid muscle, hyoglossal muscle (medially), mylohyoid muscle and intrinsic muscles of the tongue. Its lateral side is adjacent to the mandible (Bialek et al., 2006). Mucins are glycosylated proteins, mainly produced by the submandibular and sublingual glands, whereas proline-rich and histatin-rich proteins are produced by the parotid and submandibular glands. The minor salivary glands are basically mucus (Llena-Puy, 2006) and they play an important role in lubricating the mucosa, thereby accounting for a large fraction of the total secretion of salivary proteins. The minor glands, which are distributed throughout the oral mucosa (labial, buccal, lingual, palatinal mucosa), are mixed glands largely comprising mucous acinar cells (Pedersen et al., 2002).

During non-stimulated salivary flow, about 20% of the volume is secreted by the parotid glands; about 65 to 70% by the submandibular glands, around 7 to 8% by the sublingual glands and less than 10% by the minor salivary glands. When salivary flow is stimulated, the parotids contribute more than 50% of total salivary secretion (Edgar et al., 1992).

Saliva is basically composed of water. However, it also contains several diluted electrolytes (sodium, potassium, calcium, chloride, magnesium, bicarbonate, phosphate); proteins (albumin) and enzymes; immunoglobulins and mucosal glycoproteins, among other peptides. There is also glucose, urea and ammonia (Edgar, 1992; Humphrey and Williamson, 2001).

Saliva is involved in taste perception, as its high water content provides the capacity to dissolve substances and allows the gustatory buds to perceive different flavours (de Almeida et al., 2008). Additionally, saliva mucins lubricate the food bolus and protect oral tissues from irritating agents (Nagler et al., 2004). The water in the saliva moistens food particles, allowing salivary amylase to access available starch. The salivary mucins bind masticated food into a coherent, moist bolus that can easily be swallowed (Pedersen et al., 2002). The dilution effect seems to be the most important factor related to digestive properties, since the act of adding fluids to the food significantly reduces the number of chewing cycles and total muscle effort. The type of fluid (water, artificial saliva containing mucins or a solution of \( \alpha \)-amylase) has been found to have no significant effect on the chewing process (van der Bilt et al., 2007) and salivary flow does not seem to have a significant influence on masticatory performance (de Matos et al., 2010). In addition to diluting substances, saliva provides the mechanical removal of residues, non-adherent bacteria and food debris (Almeida et al., 2008).

The most known enzyme of saliva is \( \alpha \)-amylase, which breaks carbohydrates down to maltooses by cleaving the \( \alpha \)-1-4 glycosidic bindings. Salivary \( \alpha \)-amylase is considered to be of small significance in digestion because of its rapid inactivation in stomach (Pedersen et al., 2002). Salivary \( \alpha \)-amylase is secreted mainly from the serous acinar cells of the parotid and submandibular gland. An additional salivary digestive enzyme is lingual lipase, which is secreted from acinar cells of the serous von Ebner’s glands located on the posterior region of the tongue and beneath the circumvallate papillae. Lingual lipase is, however, considered to be of limited significance (Pedersen et al., 2002).

1.4 OROFACIAL MUSCLES

The anterior limit of the oral cavity is formed by the orbicularis oris muscle, which surrounds the opening of the mouth. The labial muscles also control the lips and therefore the movements of the mouth: levator labii superioris, depressor anguli oris and risorius. The
buccinator is the cheek muscle. These are superficial facial muscles and receive motor supply from branches of the facial nerve (VII) (German and Palmer, 2006).

Although they do not form the boundaries of the oral cavity or pharynx, the muscles of mastication are critical to moving the jaws and therefore oral function. The muscles of mastication are the masseter, temporalis, internal pterygoid (raisers of the mandible) and external pterygoid muscle (mandible protruder) (Figure 1.3). These muscles act in a group more than individually. They move the mandible in different directions, with the temporomandibular joint acting as a fulcrum. They are innervated by the motor root of the trigeminal nerve (Madeira, 2003).

The masseter consists of two portions, superficial and deep. The superficial portion, which is larger, arises from a thick, tendinous aponeurosis of the zygomatic process of the maxilla and from the anterior two thirds of the lower border of the zygomatic arch (zygomatic-temporal suture); its fibres pass downward and backward (Gray, 2000). The smaller deep portion arises from the posterior third of the lower border and from the whole of the medial surface of the zygomatic arch; its fibres are more vertical and pass downward and forward. Both portions are inserted into the angle and lower half of the lateral surface of the ramus of the mandible (Gray, 2000). The masseter is the most powerful jaw elevator muscle.

The temporal muscle arises from the whole of the temporal fossa and from the deep surface of the temporal fascia. Its fibres converge as they descend and end in a tendon, which passes into the zygomatic arch and is inserted into the medial surface, apex and
anterior border of the coronoid process as well as the anterior border of the ramus of the mandible (Gray, 2000). It is divided into three portions based on fibre position: anterior, mid and posterior. The fibres are more vertical in the anterior portion and gradually become horizontal in the posterior region. Thus, the fibres of the anterior portion are more active during mouth closing and the posterior fibres are basically jaw retruders.

The external pterygoid muscle extends almost horizontally between the infratemporal fossa and the condyle of the mandible. It arises from two heads: an upper head from the lower part of the lateral surface of the great wing of the sphenoid and from the infratemporal crest; and a lower head from the lateral surface of the lateral pterygoid plate. Its fibres pass horizontally backward and laterally and are inserted into a depression in front of the neck of the condyle of the mandible as well as into the front margin of the articular disk of the temporomandibular articulation (Gray, 2000). The simultaneous contraction of both right and left external pterygoid muscles causes the jaw to move forward. When associated to contraction of the suprahyoid muscles (especially the digastric muscle), the mandible rotates and the mouth opens. If only one external pterygoid acts at a time, it moves the jaw to the opposite side (lateral movement) (Madeira, 2003).

The internal pterygoid muscle arises from the medial surface of the lateral pterygoid plate and the grooved surface of the pyramidal process of the palatine bone; it has a second slip of origin from the lateral surfaces of the pyramidal process of the palatine and tuberosity of the maxilla. Its fibres pass downward, laterally and backward and are inserted by a strong tendinous lamina into the lower and back part of the medial surface of the ramus and angle of the mandible at the height of the mandibular foramen (Gray, 2000).

The supra-hyoid muscles comprise the muscles of the oral floor. These are sheets of parallel fibrous tissue running from the hyoid bone to the mandible and include the digastric (V3 and VII), mylohyoid (V3) and geniohyoid (XII and C1) muscles (Figure 1.4). The digastric muscle is believed to be the principal muscle of jaw opening, whereas the geniohyoid is the most important muscle for elevation of the hyoid bone. The supra-hyoid muscles are in a group designated jaw retruders and mouth-opening muscles (Gray, 2000).

Masticatory muscle activation and coordination determine the direction of jaw movement and control occlusal force (Herring, 2007). The thickness of the muscles of mastication affects facial dimensions and bite force (Pereira et al., 2007; Castelo et al., 2010). The functioning of the jaw muscles is highly dependent on the physiological properties of their motor units. These properties (force output, fatigability and contraction speed) vary considerably (Van Eijden and Turkawski, 2001). The jaw-closing muscles seem more adapted to performing slow, tonic movements and producing a smooth, gradable force. In contrast, the jaw-opening muscles seem more adapted to producing faster, phasic movements (Korfage et al., 2005).

The soft palate is the upper limit of the oropharynx and consists of several muscles joining in an aponeurosis: tensor veli palatini, levator veli palatini, palatopharyngeus, uvulus and palatoglossus. The principal elevator of the soft palate is the levator veli palatini, but all of these muscles play an important role in opening or closing the airway during swallowing (German and Palmer, 2006).

1.5 THE TONGUE

The tongue plays a major role in food ingestion. When the tongue moves during the mastication process the food progresses distally through the oral cavity, from the anterior region
to the pharynx, for bolus formation and swallowing. Chemoreceptors and mechanoreceptors on the tongue surface sense the nature and mechanical properties of food (Hiimae and Palmer, 2003). In addition, tongue position is also important for breathing and talking.

The dorsum of the tongue is convex and marked by a median sulcus, which divides it into two symmetrical halves. This sulcus ends in a depression called foramen cecum, from which a shallow groove denominated the sulcus terminalis runs laterally and forward on both sides of the tongue. The anterior surface of the tongue is covered with papillae; the posterior region is smoother and contains numerous muciparous glands and lymph follicles (lingual tonsil) (Gray, 2000). There are different kinds of papillae. Circumvallate papillae are located on the dorsum of the tongue right in front of the foramen cecum and sulcus terminalis, forming a row on both sides; these papillae run backward and medially and meet at the mid line, forming an inverted V shape. Foliate papillae are clustered into two groups positioned on each side of the tongue just in front of the ‘V’ of the vallate papillae; these papillae are involved in taste sensation and have taste buds on their surfaces. Fungiform papillae are found both at the sides and apex, but are also scattered irregularly and sparsely.