Literary study

Age and Changes in the Chemical Senses Related to Food Perception

Annika Bengtzon

October 2002
CONTENTS

Preface .................................................................................................................. 1
Summary ................................................................................................................. 2
Introduction: Chemical senses .............................................................. 3
Ageing .................................................................................................................. 4
Chronological and physiological ageing ............................................... 5
Chemoreception and ageing .................................................................. 6
Study of ageing ......................................................................................... 7
Flavour versus taste and odour .............................................................. 8
Important sensations ............................................................................. 8
Taste .................................................................................................................. 9
Physiology ................................................................................................. 10
Receptor cells .......................................................................................... 10
Taste buds ............................................................................................... 11
Papillae ........................................................................................................ 11
Olfaction ....................................................................................................... 12
Physiology ................................................................................................. 13
Trigeminus ................................................................................................. 14
Physiology ................................................................................................. 16
Psychophysics .......................................................................................... 16
Psychophysical test procedures ......................................................... 17
Detection tests .......................................................................................... 17
Capacity and tolerance ......................................................................... 17
Signal detection tests ........................................................................... 18
Discrimination or difference tests ...................................................... 18
Suprathreshold scaling procedure ...................................................... 19
Hybrid techniques ................................................................................. 19
Quality discrimination tests ............................................................... 20
Quality recognition tests .................................................................. 20
Quality identification tests ................................................................. 20
Test validity and reliability ................................................................. 21
Stimulus presentation ............................................................................. 21
Gustatory measurements ........................................................................ 21
Olfactory measurements ...................................................................... 21
Context Effects and Biases .................................................................. 23
Adaptation ................................................................................................. 23
Contrast effects ...................................................................................... 23
Ageing and changes in taste thresholds ........................................ 24
Ageing and changes in odour thresholds ........................................ 29
Ageing and changes in suprathreshold intensity perception .......... 31
Taste ............................................................................................................ 31
Odour ......................................................................................................... 32
Ageing and changes in ability to identify tastes and odours .......... 35
Taste ............................................................................................................ 35
Odour ......................................................................................................... 36
Problems with measurements ............................................................. 38
Memory ....................................................................................................... 38
Preferences .............................................................................................. 40
Food choice ............................................................................................. 45
Olfaction .................................................................................................... 47
Appetite and food intake ....................................................................... 48
Sensory-specific satiety ........................................................................ 49
Energy intake .......................................................................................... 50
Oral health ............................................................................................... 50
Preface

This literature review is part of a Ph.D. work in sensory evaluation performed at the department of Flavour and Sensory Evaluation, SIK - The Swedish Institute of Food and Biotechnology, Göteborg, Sweden. The Ph.D. work is financially supported by Arla Foods and the KK-foundation. Special thanks to Drs G. Hall and H. Lingnert for reading and commenting this review, and to Dr B. Fjelkestam-Nilsson for reviewing the language.
Summary

In the daily language the word “taste” refers to the sensations that professionals carefully distinguish as taste and odour, or flavour. The sense of taste is notably robust with age, whereas declines in the sense of olfaction are dramatic. Age-related changes in taste functioning do not affect all individuals, and some elderly individuals are essentially unimpaired. Age has a more significant effect on olfaction ability than either gender or smoking. Many chemosensory deficits in the elderly can be attributed to pathologic conditions and medication rather than ageing. In addition to deficits, individuals may experience taste or smell phantoms.

A variety of quantitative psychophysical tests can be used in clinical settings to evaluate chemosensory functioning in the elderly. These include detection, recognition and suprathreshold tests as well as preference tests. Age-related changes in psychophysical functions seem to be quality-specific; the differences are not necessarily equal for various flavours. The greatest age-related losses in suprathreshold taste appear to be associated with the perception of bitterness and the least with the perception of sweetness. Losses are not uniform across compounds but tend to vary with the structure of the molecule. Reduced taste sensitivity e.g., for sweeteners and salt might be a disadvantage for elderly persons. Compensation for reduced sensitivity can lead the elderly to ingest excessive amounts of sugars, artificial sweeteners, or salt which may be detrimental to health.

Age-related changes in the chemical senses are affecting the perception of foods and food flavour, and impairments give a reduced ability to identify foods on the basis of taste and smell. Loss of taste and smell can also reduce the motivation to eat. Commercial or natural flavours may be added to foods to improve intake and compensate for losses in the chemical senses. Chemosensory losses in the elderly could also be compensated in part by adding texture to food. This could be crunchiness or chewiness, or for elderly with dentition problems, addition of functional fibre and flavours to soften textured foods.
**Introduction: Chemical senses**

The chemical senses are taste, smell and trigeminal sensitivity. Trigeminal sensitivity is also called the common chemical sense. Together but independently, the chemical senses contribute to the perception of a food flavour (Weiffenbach 1991). They are called “chemical” because they are stimulated either by molecules that contact receptors in the mouth, throat and the nasal cavity, or respond to direct contact with chemicals. They normally act in concert with one another as a functional unit, but differ from each other in a variety of important ways. The anatomic distribution and the size of the chemoreceptive surfaces differ. Also in the neural pathways supporting them the chemical senses differ in their anatomical route, their complexity and their vulnerability to damage from trauma, toxic chemicals, or viral attack (Oakley 1986; Schiffman 1994; Weiffenbach 1991).

When the various chemosensory senses are functioning properly, they respond sensitively and accurately to stimulation and return to perceptual silence thereafter. When they are not functioning properly, they may demonstrate abnormally diminished or increased sensitivity. They may also demonstrate other dysfunctions. Perception may be discordant with the stimuli or take place in absence of stimulation (Weiffenbach 1991). Changes in the chemical senses can be measured by psychophysical evaluation which is a study of the relationship between physical stimulation and the sensory experience it triggers (Lawless and Heyman 1998a). There are a variety of psychophysical test methods that can be used in a clinical setting to evaluate chemosensory functioning (Schiffman 1997). The usual classification of chemosensory loss includes *aguesia* (no taste sensation), *hypogeusia* (decreased taste sensation), *dysgeusia* (distorted taste sensation), *anosmia* (no sensation of smell), *hyposmia* (decreased sensation of smell), and *dysosmia* (distorted smell sensation) (Schiffman 1993, 2000).

Sensations of taste and odour are important, not only by giving enjoyment when eating, but also because these chemosensory systems prepare the body for digesting food by triggering salivary, gastric, pancreatic, and intestinal secretions, which are termed “cephalic phase responses”. There is a learned association of food’s taste and smell sensation with its postingestive effects (Schiffman 1997).
**Ageing**

It is a well known fact that we have an ageing population (Lilley 1996). Throughout the world, there are demographic trends towards an ageing population which increases in both absolute number and proportion of elderly persons. World population of the age of 60 and more is expected to increase from 376 million (8.5%) in 1980 to 1.121 billion (13.6%) in 2025 (Schiffman 1998).

The population is not only ageing. The very elderly are becoming a larger proportion of the total number of elderly. Despite these important trends, elderly people are not often studied in lifestyle studies. Relatively little is known about the food choice of elderly people, their attitudes and beliefs, which inform about the choices they make (Lilley 1996).

Definitions of ageing include many structural and functional changes which occur across the lifespan. The sequence of age-related changes is predicted within a species, but the rate at which these changes occur differs between individuals. Studies of ageing focus on the psychological and behavioural features of the ageing process as well as underlying biological, socio-cultural, economic and psychological factors influencing this process. The study of age-related vulnerability to disease is called geriatrics, and the study of normal ageing is called gerontology (Hetherington 1998).

Gerontology as defined by The Nordic Society of Gerontology (Den Nordiska Gerontologiska Föreningen) is in a free translation: “Gerontology is the science of ageing and the study of age-related changes in life-processes of an individual from attained maturity until death. Gerontology includes basal-biological and clinical-medical, humanistic and social science disciplines”. The term Gerontology was first used around the year 1900 by the Russian zoolog, microbiologist and Nobel-prize winner Ilja Metinikov (1845-1916) (Berg 1996).

The age of retirement has often been used as the defining age of the elderly. But recently retired adults are likely to be more prosperous, active and healthy than elderly people already in their 80s. Thus in order to examine physical, physiological and economic changes with ageing, there is a general agreement to see this group in three different categories (**Table 1**).
These categories are meaningful in appreciating differences within the elderly population (Hetherington 1998). There is also an individual variability in level, rate, and direction of change, as ageing is a very individual and differential process with regard to mental, behaviour, and social outcome variables. There are 70-year-olds that look and think like 50-year-olds and vice versa (Baltes and Baltes 1990).

**Chronological and physiological ageing**

Chronological ageing is not necessarily the same as biological ageing. Description of ageing can be done by classification of health status as is described in a thesis by Mathey, (2000). She used three categories (Table 2).

<table>
<thead>
<tr>
<th>Definition by Mathey 2000</th>
<th>Definition by Baltes &amp; Baltes 1990</th>
</tr>
</thead>
<tbody>
<tr>
<td>Successful agers</td>
<td>Optimal ageing</td>
</tr>
<tr>
<td>Usual agers</td>
<td>Normal ageing</td>
</tr>
<tr>
<td>Accelerated agers</td>
<td>Sick or pathological ageing</td>
</tr>
</tbody>
</table>

Table 2. Classification of the elderly population (Mathey, 2000)
This classification highlights the heterogeneity of the elderly population (Mathey 2000a). This has also been demonstrated by Baltus & Baltus, (1990). Here the sick ageing is characterised by medical etiology and syndrome of illness. A classical example is dementia of Alzheimer’s type (Baltes and Baltes 1990). In studies of sensitivity to different qualities, the focus on the distinction between pathological ageing and normal ageing may well be supplemented by interest in the distinction between normal ageing and successful ageing (Weiffenbach 1991).

Age differs between individuals and functions. Berg (1996) described three types of age. Biological age is a measure of the individual physiological capacity that is the capacity of different organs and organ systems e.g. kidney or brain. Psychological age is the individual capacity to cope and adjust to his/her environment. Important aspects are intelligence, memory and personality. Social age is personal contacts, position groups and society (Berg 1996).

**Chemoreception and ageing**

Both clinical and laboratory studies have found a progressive decline in taste and smell functioning with age. A gradual loss in taste and smell perception seems to be an inevitable part of the ageing process. Although some losses may occur earlier, most individuals begin to suffer chemosensory decrements by the age of 60 and more significant losses when over the age of 70 (Schiffman 1993, 2000). Chemosensory losses can reduce the quality of life, increase the risk for food poisoning, and lead to inadequate nutrition, especially in the elderly sick. Chemosensory losses result from normal ageing, certain disease states (especially Alzheimer’s disease), pharmacological and surgical interventions, radiation, and environmental exposure (Schiffman 1993). These chemosensory deficits can alter food choices and food intake and subsequently provoke medical conditions, impair nutritional status and immunity, and produce weight loss (Schiffman 2000).

There is a strong association between life-style and health. Commonly recognised risk factors include cigarette smoking, excessive alcohol consumption, inadequate exercise, increased dietary saturated fat, excessive salt intake inadequate fibre etc. (Fries 1990). Genetics and environmental factors could be influencing physiological ageing (e.g., pollution, pharmacy, alcoholism, nutrition status) (Finkelstein and Schiffman 1999).
third most important factor for good health that a person can control is, after cigarette and alcohol consumption, what you eat (Sandberg 2001). This is supported by acceleration of secondary or false ageing by environmental factors (Berg 1996). Sensory changes with advancing age may arise from alternations that are part of the normal physiological ageing, or may be acquired in response to influences that are not part of normal or physiological ageing (Weiffenbach 1991). A variety of factors may influence and produce changes in the responses of older and younger individuals to chemical stimuli. Age differences may arise from changes affecting one or another of the chemical senses or from alternations in one or another of the co-operating senses with which they interact. Alternatively, there are age-related variations in attention, memorial and cognitive functions which have no sensory basis at all (Weiffenbach 1991).

Concerning ageing and chemoreception, studies should distinguish between chronological and physiological ageing (Finkelstein and Schiffman 1999).

**Study of Ageing**
An important part in the study of ageing is to describe and explain what makes a person develop or function in a certain way at a certain age. There are in principal two ways to study ageing, cross-section study and longitudinal study. Neither of the methods is perfect, and when both have been used they have often given different results. A particular problem is that they mix three different types of influence on the individual development: age effect, time effect and cohort effect (Table 3).

<table>
<thead>
<tr>
<th>Influence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age effect</td>
<td>Fundamental changes within an individual, including things that are not explained by time or cohort effects.</td>
</tr>
<tr>
<td>Time effect</td>
<td>Different age groups are exposed at the same time. This could be environmental exposure like times of war.</td>
</tr>
<tr>
<td>Cohort effect</td>
<td>Differences depending on environmental or cultural factors specific for a certain generation or age group. E.g. length of education is different for different generations.</td>
</tr>
</tbody>
</table>

Table 3. Influence of individual development (Berg 1996).
The traditionally most frequently used method is cross-section studies where different age groups are compared at the same time. This method does not take into consideration effects of the environment and of true (biological or physiological) ageing.

In longitudinal studies a group of persons are studied during a long period of time, the study may continue over many years. These are time-consuming and therefore also expensive. Longitudinal studies are influenced by the time effect.

Another method that is also used is time-shift- or cohort analysis where groups of the same age but born different years are being compared (Berg 1996).

**Flavour versus taste and odour**

Although individuals speak about “tasting” foods, foods are actually tasted, smelled, and felt (Weiffenbach and Bartoshuk 1992). In daily life language the term taste often refers to the sensations that professionals carefully distinguish as taste and odour, or flavour. Taste in the everyday meaning makes use of many separate senses, including taste, smell, trigeminus, temperature, touch, vision and hearing (“they taste as good as they crunch”). All of these contribute to flavour. Taste, as used by the chemoreception scientists, refers specially to those sensations mediated by the taste buds, which lie throughout the mouth, but especially on the taste papillae of the tongue. Odour is mediated by the olfactory mucosa. In addition many olfactory stimuli affect the trigeminal nerve, which contributes to the odour of many compounds (McBurney 1986). The senses of taste and odour both respond to chemical stimuli, and they co-operate closely with one another in the generation of a sensation. They are, however, separated in important ways (Weiffenbach and Bartoshuk 1992).

**Important sensations**

Sensations of taste and odour are important as they:

- Enhance feelings of pleasure and satiety from a meal
- Prepare the body to digest food by triggering “cephalic phase responses” salivary, gastric, pancreatic, and intestinal secretions; and
• Provide cues for learned associations of food with its postingestive effects.

Overall, persons with chemosensory losses do not derive full gratification from food and may have impairments in the ability to absorb nutrients or adjust food choices/meal size based on anticipations of postingestive effects (Schiffman 1997, 1998).

**Taste**

Taste is also called gustation. When a person says that a food “has lost its taste”, she/he generally means that it has lost its flavour. In the classical view taste in humans is made up of the sweet, salt sour and bitter qualities of flavour. (Oakley 1986) While most textbooks still suggest that there are only four tastes (sweet, sour, salty and bitter), recent data reveal that there are many other taste qualities, including those associated with glutamate (a taste quality called “umami” in Japanese) and calcium salts (Oakley 1986; Schiffman 1994). It appears that each taste quality has a separate and unique receptor/transductive system (Bartoshuk 1994). All four taste qualities can be perceived on all the locations that contain gustatory tissue (Bartoshuk 1989b).

Experimental data in a variety of species including humans, monkeys, and rodents, support that the full range of taste qualities is broader than the four prototypical or basic tastes. Taste qualities such as metallic (iron salts), umami (monosodium glutamate/5’nucleotides), and chalky (calcium salts) are also mediated by taste nerves. Other amino acids than monosodium glutamate have unique taste qualities. Fat sensation can be detected without movement of the tongue, suggesting that some components in fat also may activate taste nerves (Schiffman 1997). Perception of every taste sensation begins with the receptors in the mouth being stimulated. This event is transmitted to the brain as a change in firing rate of sensory nerve fibres (Yamaguchi and Ninomiya 1998).

The new taste quality, called umami, is produced by certain substances, monosodium glutamate (MSG) and disodium 5’-inositate (IMP). There are several fibres within the glossopharyngeal nerve which respond to MSG, but not to the four basic tastes. Glutamic acid is the most abundant of all amino acids present in food protein. Free glutamic acid is more abundant in foods of vegetable origin than in foods of animal origin. Foods of animal origin are rich in inosinic acid or adenylic acid, which enhances the umami effect of
glutamic ion synergetically. When vegetable and animal foods are cooked together, or eaten at the same time, umami is greatly enhanced and this makes the combination of foods more palatable. Comparable to sugar as a signal for energy, and bitter as a signal for poison, umami could be a signal for proteins, as protein is a source of essential nutrients (Yamaguchi and Ninomiya 1998).

Elderly people often complain that ageing dulls the sense of taste. Investigations have been made and some show a decline in taste function with age and some do not. The apparent disagreement may have several causes. Methodological differences may give rise to differences in the results. All studies do not measure the same aspects; some are clear threshold studies while others are studies of suprathreshold functions. The health status of subjects in some studies may have interacted with age (Murphy 1986).

**Physiology**

The “peripheral taste system“ includes taste buds, the lingual papillae, their distribution and innervation. Taste buds are microscopic. The pink elevations that can be seen on the tongue are lingual papillae (Miller 1995).

Perception of taste begins with an interaction between a taste stimulus and the membranes of receptor cells. These receptor cells form globular clusters (taste buds) that are embedded in taste papillae visible on the tongue (Weiffenbach and Bartoshuk 1992).

Three nerves carry taste information to the brain: facial (VIIth), glossopharyngeal (IXth), and the vagus (Xth). Two branches of the facial nerve are particularly important for taste of which the corda thympani innervates the fungiform papillae on the anterior two thirds of the tongue and the greater superficial petrosal taste buds on the palate (at the point of the roof of the mouth where the hard and the soft palate meet). The glossopharyngeal innervates the foliate and the circumvallate papillae and the vagus receptors on the laryngeal surface of the epiglottis and the throat (Weiffenbach and Bartoshuk 1992).

**Receptor cells**

Two facts about taste receptor cells are of special importance. First, there is a synapse between the taste receptor cell and the sensory axon that carries taste information to the brain. This is very different from olfaction, in which there is no synapse and the receptor cell is actually the dendrite of an olfaction neuron. Secondly, the taste receptor cells live
only days before they are replaced by new cells (Weiffenbach and Bartoshuk 1992). Taste receptor cells originate from basal cells whose progeny elongate and differentiate into the taste bud where they function as receptor cells for several days. The constant renewal of cells ensures that viable cells are present in spite of repeated mechanical, thermal or chemical damage to the tongue (Oakley 1986).

*Taste buds*

The mammalian taste buds are elongated clusters of around 50 epithelial cells that are embedded in the skin of the tongue and the soft palate in epiglottis, pharynx and the larynx. This cluster is called a taste bud. It is shaped like and named for the calyx of an unopened flower. Humans have a few thousand taste buds, and how they are distributed in the mouth varies from person to person. These variations are associated with individual differences in taste perception. Taste buds are microscopic, with a size of about 20-40μm in diameter and about 40 to 60μm in length. Taste buds, like other epithelial cells, have a half-life of about 10 days. There are different types of cells identified within a taste bud: a light cell (type II) and a dark cell (type I) (Miller 1989, 1995; Oakley 1986).

*Papillae*

The gustatory papillae include circumvallate, foliate, and fungiform papillae. Filiform papillae and conical papillae do not usually contain taste buds (Figure 1) (Miller 1995). Fungiform papillae can be seen as small red dots on the tip and on the front edges of the tongue. Along the edges at the back of the tongue, there is a series of parallel ridges. On the top of the ridges there are additional fungiform papillae. At the extreme back edges of the tongue, the ridges form clear folds and appear bumpy and reddened. The foliate papillae are located inside these folds. On the extreme back of the tongue across the centre, there are raised, circular structures forming an inverted V shape; these are the circumvallate papillae (Weiffenbach and Bartoshuk 1992). The fungiform papillae have a small hole or holes, called taste pores, on the surface through which fluid on the tongue makes contact with the cells in the taste bud. Taste buds are also found, closely packed in the trenches of 8-12 circumvallate papillae lying in a curved row at the back of the tongue, and also 4 slit-like foliate papillae on the sides of the tongue. These taste buds are buried in troughs (Miller 1995).
Figure 1. Drawing of the human tongue showing the regional locations of lingual papillae (Miller 1995)

**Olfaction**

The odour is perceived by the olfactory epithelium, either through the nostrils (orthonasal) or via the mouth (retronasal) (Duffy, Cain and Ferris 1999; Wendin 1999).

It is commonly known that odours contribute to many of the subtleties that determine the flavour of foods (Murphy 1986). The contribution of the olfactory component to food flavour can be dramatically illustrated by blocking the nostrils before ingestion (Murphy 1993).

Olfactory experiences are perceived as a totality rather than as many different sensory characteristics together. Testing usually involves naming its characteristic source rather than describing the sensory experience it elicits. Odours are often described as something familiar, like grandmother’s kitchen stove or kerosene, rather than one principal odour “quality” with lesser amount of two other smells. In this respect, odour perception differs from taste perception where basic taste quality names provide convenient descriptions of sensation. For taste stimuli, it is often possible to name the sensory components and even rate the relative contribution of each (Weiffenbach 1984). Effects of ageing on the olfactory sense and the trigeminal sense are indeed important to investigate, in an attempt to uncover the factors responsible for changes in what we in daily life call taste reported by older people (Murphy 1986).
**Physiology**

The nasal cavity (Figure 2) can be thought of as a modified box that is open at opposite ends, with a roof, a floor, and two sides wall (Lanza and Clerico 1995). The olfactory epithelium covers an area of approximately 2 cm² at the top of the nasal cavity just under the brain. The olfactory receptor cells located in the epithelium are actually the dendrites of the olfactory neurons. The dendrites are shaped like knobs with projecting cilia. The locations of the membrane sites at which the odourants bind are uncertain, but the sites are thought to be on the proximal ends of the cilia, possibly on the knobs (Weiffenbach and Bartoshuk 1992).

*Figure 2. Epithelium of the human nasal cavity. Olfactory epithelium (OE); Bowman’s glands (BG); olfactory nerve (ON); olfactory receptor cells (R); sustentacular cells (S); respiratory epithelium (RE); squamous epithelium (SE); transitional epithelium (TE); nasopharynx (NP); hard palate (HP); inferior turbinate (IT); middle turbinate (MT); superior turbinate (ST) (Lewis and Dahl 1995).*

Inhaled air comes in to contact with three other epithelial types in the nasal cavity: squamous, transitional and respiratory (Figure 3). These epithelial regions differ in metabolic capacities, but they can all alter the chemical composition of the inhaled odourant before they reach the olfactory mucosa. The respiratory mucous contains ciliated cells. Mucous-secreting goblet cells play the major role in the production of nasal secretions and clearance of inhaled materials. The olfactory epithelium is made up of four primary cell types: olfactory receptor cells, sustentacular or supporting cells, the basal cells, and the duct of Bowman’s glands. Cilia containing olfactory receptors project from the receptor cells into the mucous layer lining the nasal lumen. Two factors make the olfactory receptor cells unique.
1) These cells project directly into the brain before their first synapse, which makes them the only cells directly connecting both the central nervous system (CNS) and the external environment.

2) Olfactory receptor cells, in contrast to other nerve cells, regenerate from basal cells after damage (Lewis and Dahl 1995).

Figure 3. Cellular anatomy of the olfactory mucosa. Nasal airway (NA); olfactory receptor cells (R); olfactory dendritic knobs (OK); reptor containing cilia (C); sustencular cells (S); basal cells (B); basal lamina (BL); Bowman’s glands (BG); olfactory nerves (ON); blood vessels (BV); and cribiform palate (CP). Tissues of the lumenal side of the basal lamina compose the olfactory epithelium (OE); and tissue inferior to the basal laminaforms the lamina propria (LP); The two layers are included in the olfactory mucosa (OM) (Lewis and Dahl 1995).

Olfactory receptor cells generate signals from volatile odourant molecules and transmit that information to the main olfactory bulb (OB). Via output fibres from OB the information is sent directly to the secondary centres of the primary olfactory cortex (Kratskin 1995).

**Trigeminus**

In addition to the specialised taste and smell systems, there is also a more general chemical sensitivity in the nose and mouth, and over the whole body. A variety of everyday flavour experiences arise from trigeminal stimulation (Lawless and Heyman 1998a). The chemical sensitivity of the skin and the mucous membranes derives primarily from nerve endings that belong to the sensory systems classically defined as temperature (warmth and cold)
and pain (Green 1996). There is for instance the fizzy tingle from carbon dioxide in soda, the burn from hot peppers, pungency from black pepper and from spices such as ginger and cumin, the nasal pungency of horseradish, and the bite of onions and garlic, not to mention their lachrymatory effects (Lawless and Heyman 1998a). Peppermint evokes coolness and sting because menthol stimulates cold fibres and pain fibres (nociceptors), and chili pepper evokes burning because capsisin stimulates heat-sensitive pain fibres. Some chemicals, including odourants, produce more trigeminal stimulation, also called nasal pungency, than others, and at a low concentration some likely produce no or little trigeminal activity (Stevens, Plantiga and Cain 1982). The trigeminal system is less sensitive to odourants than the olfactory system and most of them if not all are likely to stimulate the trigeminal nerve in a high concentration for at least some individuals (Doty 1995). Carbon dioxide is an almost odourless but pungent substance, while iso-amyl-butyrate with a fruity odour can be regarded as a nonirritating stimuli according to Stevens et al (1982).

The term “chemestesis” in an analogy to somesthesis or body/tactile sensations has been used for these systems (Lawless and Heyman 1998a). Trigeminally mediated sensations contribute to “odour” sensation not only in such extreme cases as horseradish or ammonia, but they also add a slight pungency or crispness to wide variety of common odourants (Stevens, Plantiga and Cain 1982).

Figure 4. Primary branches of the trigeminal nerve that innervate the nasal and oral cavities (Doty 1995).
**Physiology**

Chemesthesia has very different characteristics compared with taste and smell (Green 1996). In humans, nerve endings from branches of the trigeminal nerve (CN V) are found in the epithelia of the nose and the sinuses, the oral cavity, the eyelids, and the cornea (**Figure 4**). Branches of the trigeminal nerve innervate the nasal and oral cavities, and a number of fibre types are found within each of these branches (Doty 1995). The trigeminal nerve is the largest of the cranial nerves and relays both sensory and motor information (i.e. muscles of mastication) (Lanza and Clerico 1995).

**Psychophysics**

The study of the relationship between physical stimulus and the sensory experience is the oldest branch of experimental psychology and is called psychophysics. The term psychophysics covers the functional and mathematical relationship between physical stimulation and the magnitude of the resulting sensations as human observers report to perceive it (Lawless and Heyman 1998a). Classical psychophysics is focused on stimulus and on threshold values, dividing a stimulus continuum into those stimuli which elicit a certain sensation and those that do not (Engen 1986).

Fechner (1801-1887), also one of the originators of psychophysics, was a physicist trained in medicine who became profoundly interested in the philosophy and psychology of how mental events are related to physical events. Threshold is a key concept of classical psychophysics. Fechner deduced that in threshold studies, the sensation varies as the logarithm of the physical stimulus eliciting it (Engen 1986). The threshold is that stimulus change that separates stronger stimuli that are perceived and weaker ones that are not (Weiffenbach 1991).

Psychophysical evaluation methods have subsequently found widespread application assessing sensory function in many fields. Today any procedure that provides a quantitative measure of sensory function and requires a verbal or conscious overt response on the part of the examinee is considered to be a psychophysical procedure (Doty and Kobal 1995).
A variety of quantitative psychophysical tests can be used in clinical settings to evaluate chemosensory functioning in the elderly. These include detection, recognition and suprathreshold tests. This gives an accurate assessment of the degree of loss of taste and olfaction (Schiffman 1997).

**Psychophysical test procedures**

**Detection tests**

A detection threshold is a measurement of the ability to detect the presence of a stimulus. The subject is not required to recognise or identify the quality of the stimulus in the detection task (Murphy 1986). The absolute or detection threshold is the lowest physical energy level of stimulus or lowest concentration, in the case of a chemical stimulus that is perceivable. In the method of limits, the energy or physical intensity level would be raised and lowered, and the average point at which the observer changed response from “no sensation” to “yes I perceive something” would be taken as a threshold (Engen 1986; Lawless and Heyman 1998a). Two types of threshold procedures that have received the most clinical use are the ascending method of limits (AML) and the single staircase (SS) procedures. In an AML procedure stimulus are presented sequentially from a low to high concentration and the point of transition between no detection and detection is estimated. In an SS method the concentration of the stimulus is increased following trials on which a subject fails to detect the stimulus and decreased following trials when correct detection occurs (Doty and Kobal 1995). In all cases the stimuli are presented in small steps, determined in preliminary work, in order to determine the border of transition value as precisely as possible (Engen 1986). Forced choice methods are often used in threshold measurements (Murphy 1986).

**Capacity and tolerance**

Absolute threshold represents one extreme effect of stimulation and terminal threshold another at the upper end of the stimulus dimension (Engen 1986). Terminal threshold is the concentration or region where no further increase in response is noted from increasing physical stimulation. The sensory response has reached some saturation level, beyond which no further stimulation is possible due to maximal responding of receptors or nerves or some physical process limiting access of the stimulus to the receptors. In practice this
level is rarely approached (Lawless and Heyman 1998a). This is a modality that receives little attention in psychophysics (Engen 1986).

**Signal detection tests**

Signal detection theory (SDT) is fundamentally different from that of classical threshold theory. In this type of measurement response bias is taken into account and subjects expectancies and rewards all influencing the detection decision. This kind of procedure requires a relatively large number of trials to be reliable (Doty and Kobal 1995). If two levels of stimulus are to be evaluated, for example the background or blank stimulus, called noise, and some weak but higher level of stimulus intensity near threshold called signal, the two stimuli are presented one at a time, several times, and the observer is to say if there is a signal or a noise. The results are presented in a response matrix. These methods are applicable in taste and smell or other sensory modalities as well. They can be used in questions about foods and consumer products as a question of whether a taint or off-aroma is detected by consumers. Ingredient substitutions, formula changes, packaging, shelf life, and processing experiments can also be analysed from a signal detection perspective (Lawless and Heyman 1998b).

**Discrimination or difference tests**

In discrimination threshold testing the task of observers is to demonstrate that they can differentiate some low level of stimulus from some background (Lawless and Heyman 1998a). It is the ability of the subject to detect change in the present level of stimulation. The subject is presented sets of stimuli in pairs, and is told to rate if the samples are perceived to be the same or different. The smallest amount of a stimulus that has to be changed to make it perceptible as stronger or weaker is termed “just noticeable difference” or JND, also called difference or differential threshold (Engen 1986).

The size of the increment of an odourant concentration ($\Delta I$) required to produce a JND increases as the comparison concentration ($I$) increases, with the ratio approximating a constant; i.e., $\Delta I/I = K$ (Weber’s law). $K$ is a rough index of the sensory system’s sensitivity. A smaller $K$ indicates a more sensitive system to fine changes in stimulation (Doty and Kobal 1995).
Suprathreshold scaling procedure

The perceived intensity of a stimulus varies as a function of its strength or concentration. Therefore ratings or other measures of perceived intensity can be used to evaluate suprathreshold sensory function (Doty and Kobal 1995; Weiffenbach 1991). Suprathreshold measurements are used to correlate increases in perceived taste intensity with increases in concentrations of the sample being tested (Tepper and Genillard-Stoerr 1991).

Rating scales can be used to estimate the intensity of a psychological attribute perceived by a subject. Two types: category scales and line scales (also called visual analog or graphic scales) are popular in chemosensory assessment. In the latter, the strengths of the sensation is indicated by the subject by placing a mark along a line that has descriptors, called anchors, located at its extremes (e.g., very weak – very strong) (Doty and Kobal 1995).

In intensity matching procedures, cross-modal matching is the most popular. In crossmodal matching the perceived intensity of a stimulus is estimated by using another sensory modality or cognitive domain. Magnitude matching and magnitude estimation are among the most commonly used cross-modal matching procedures. In magnitude estimation the subjects assign numbers relative to the magnitude of the sensations. Subjects can assign any number to the stimuli as long as they reflect the relative magnitudes of the perceived intensities. The absolute values of the numbers are not important, only the ratios between them. The magnitude estimation task is relatively complex in that accurate responses to a stimulus require a good memory for the prior stimulus. If too much time lapses between the two stimuli, the memory fades. But if the two stimuli are presented within too short a distance in time, adaptation can distort the relationship. The problems can be minimised by ensuring that the instructions, test procedures, and test stimuli are being standardised and monitored.

In the most common method of magnitude matching, judgements of the intensity of sensations of two modalities (e.g., loudness, odour intensity) are made on a common magnitude estimation scale (Doty and Kobal 1995).

Hybrid techniques

Category-Ratio scale or the Labeled Magnitude Scale (LMS) is a hybrid technique with a vertical line-marking task and verbal anchors spaced according to ratio-scaling
instructions. A semantically labelled scale of sensation intensity is developed for the study of oral somatosensation and gustation. For setting up this scale subjects provided magnitude estimates for different verbal descriptors after giving estimates to familiar oral sensations (Green, Shaffer and Gilmore 1993; Green et al. 1996; Lawless and Heyman 1998c).

**Quality discrimination tests**

The most straightforward chemosensory quality discrimination test requires individuals to decide whether two stimuli have the same or different quality. A variant of this theme is when the subject is asked to point out the “odd” sample in a series of three. This is called *triangle-test* (Doty and Kobal 1995).

**Quality recognition tests**

In the recognition threshold paradigm the subject is required to identify the quality of the stimulus (Murphy 1986). There are two general classes of this kind of test. In the first class the subject is simply asked if the stimulus is recognised, without an identification being required. In the second class, the subject is given a “target” stimulus, and is told to match the target with one of a larger set of stimuli. The number of correct answers gives the test score. *Stimulus matching task* is a variant of this theme. The subject is given a set of stimuli and is required to match the stimuli, one by one, to those of a set of identical stimuli (Doty and Kobal 1995). The minimum level that takes on the characteristic taste or smell of the stimulus is often higher than detection thresholds. For example, dilute NaCl is not always salty, but at low concentrations just above detection threshold it is perceived as sweet. The concentration at which a salty taste is apparent from NaCl is much higher (Lawless and Heyman 1998a).

**Quality identification tests**

Among the most popular procedures for assessing taste and smell function are those that require stimulus quality identification. Such tests can be divided into three groups: *naming tests, yes/no identification tests*, and *multiple choice identification tests*. In the naming test the subject is to provide a name for the stimulus, in the yes/no test signify whether the stimulus smells or taste like the object named by the examiner, and in the multiple choice task identify the stimulus from a list of names (Doty and Kobal 1995).
Test validity and reliability

The utility of a psychophysical test of sensory function depends on the degree to which it is reliable (consistent, dependable, or stable) and valid (accurately measures what it portends to measure). Related to a test’s validity are its sensitivity and specificity. Sensitivity refers to the ability to detect abnormalities when present and specificity the ability to detect such abnormalities with a minimum of false positives (Doty and Kobal 1995).

Stimulus presentation

Gustatory measurements

There are two general approaches to taste tasting: regional testing and whole-mouth testing. In regional testing function, different taste bud fields are assessed separately. This requires that stimuli are limited to specified areas in the oral cavity, which for example can be done by using cotton-tipped swabs to “paint” taste solutions on areas of the oral cavity. In whole-mouth testing taste stimuli may reach all taste bud fields (Bartoshuk 1989a; Frank et al. 1995). The carrier for the stimuli is most often deionised water (Murphy and Withee 1986; Stevens et al. 1995). It could also be food products e.g. beverage base (Murphy and Withee 1986) chicken broth (Drewnowski et al. 1996) or yoghurt (de Graaf, Polet and van Staveren 1994). Water rinse between stimuli is nowadays more or less a standard, which it was not earlier (Weiffenbach 1991). A mouth rinse with water between stimuli was first used by Harris & Kalmus and is sometimes called the Harris-Kalmus procedure and eight-cups technique (Frank et al. 1995; Harris and Kalmus 1949). A water rinse between stimuli in a threshold procedure ensures that saliva has been flushed out of the oral cavity and that the subject is reporting the response to the stimulus in the aqueous test solution. When the saliva has not been washed away the response includes a “water taste” as well as a solute taste. The taste of water is dependent of which stimulus that proceeds it (Murphy 1986).

Olfactory measurements

Different devices have been used to present odours to patients or subjects. Devices traditionally used can be seen in (Figure 5):
It is not necessary to know the exact number of molecules that enter the nose to make an psychophysical olfactory test valid. The key issue is that the odourant is presented in a reliable manner and that norms are available to establish whether the subject’s responses are normal or abnormal (Doty and Kobal 1995). A forced-choice task is most often used (Doty RL 1991c).

**Figure 5.** Procedures for presenting odourants to subjects for assessment. (A) Early draw-tube olfactometer of Zwardemaker. In this apparatus, an outer tube made of rubber or another odourus material slides along a calibrated inner tube, one end of which is inserted into the subjects nostril. When the odourized tube is slid towards the subject, less of internal surface is exposed to the inspired airstream, resulting in a weaker olfactory sensation. (B) Sniff bottle. (C) Perfumist’s strip. (D) Squeeze bottle. (E) Blast injection device. The experimenter injects a given volume of odour into a bottle and releases the pressure by squeezing a clamp on the tube leading to the nostril, producing a stimulus pulse. (F) Microencapsulated “scratch and sniff” University of Pennsylvania Identification Test. (G) Sniff ports on rotating table connected to the University of Pennsylvania’s Dynamic Air-Dilution Olfactometer (Doty and Kobal 1995).
Context Effects and Biases

Adaptation
Taste receptors begin to adapt to stimuli as soon as the initial contact occurs. If the stimulus remains constant and the tongue does not move, the taste sensation can fade completely in 20 to 30 seconds. Normally we do not experience adaptation because the tongue moves and saliva alters the stimulus concentration. But even if adaptation is only partial, sensitivity is affected. Adaptation causes thresholds to rise and perceived intensities to drop. Adaptation of one substance might have effect on the perceived taste intensity of a second substance and this is called cross-adaptation. Adaptation can also cause “water tastes”. Solutions at concentrations below that to which the tongue is adapted gives water a taste quality. Water can take on other taste qualities depending on what proceeds it (Bartoshuk 1989a). Adaptation occurs also in odour sensitivity. Olfactory adaptation also leads to a temporary decrease in sensitivity following stimulation, and can be seen in increases in odour thresholds and a decrease in odour intensities. Odours that elicit trigeminal stimulation cause less adaptation than other odours do (Cometto-Muñiz and Cain 1995).

Contrast effects
Contrast effects are common in intensity judgements and have to be considered when tests are designed, and can also occur in hedonic judgements. For example, a stimulus is judged to be weaker in the presence of stronger stimuli and stronger in presence of a weaker stimulus. The reverse effect of assimilation in the direction of the contextual stimulus, is also sometimes seen (Lawless, Horne and Spiers 2000). Poor food can seem even worse when preceded by a good sample (Lawless and Heyman 1998d).
Ageing and changes in taste thresholds

Elevated detection thresholds indicate that more molecules of a tastant are required before sensation occurs. Elevated recognition thresholds indicate that a higher concentration of a tastant is required before it can be correctly identified (Schiffman 1993).

Many studies indicate that a general decline (elevated thresholds) is found in taste perception with advancing age, at both threshold and suprathreshold levels. Increased thresholds in elderly persons have been reported for sodium salts, sweeteners, acids, bitter compounds and amino acids including glutamate salts. Threshold studies suggest that age-related threshold losses are not uniform across taste substances, but rather vary with taste quality and chemical structure (Bartoshuk 1989b; Schiffman 1986, 2000; Schiffman et al. 1994). This phenomenon was reported by Bartoshuk et al (1986). In a correlation between thresholds and the judged intensity of the taste of water, QHCl (quinine hydrochloride) thresholds were significantly higher for those participants who judged water to have strong taste. Among the elderly participants, citric acid thresholds were also significantly higher in those who judged water to have the strongest taste. The functions for elderly participants look as if a background taste has been added to water. The background taste attributed to water and dilute solutions may reflect mild dysgeusia, that is, a chronic taste in the mouth (Bartoshuk et al. 1986).

The study also showed that detection thresholds were significantly elevated for sucrose, NaCl citric acid and QHCl, but not for (phenylthiouracil) PROP. This was probably due to genetic variation, as more elderly persons in this study were found to be (phenylthiocarbamide) PTC/PROP blind than the young (Bartoshuk et al. 1986). Harris and Kalmus (1949) reported elevated thresholds for PTC with age; the study was carried out with only male subjects (Harris and Kalmus 1949).

According to Bartoshuk (1989) elderly subjects show elevated thresholds for some taste stimuli. Discrete taste losses occur more often in the elderly than in the young but usually go unnoticed. She suggests that localised losses occur for some elderly subjects, and these losses may contribute to elevated thresholds when an area of loss is stimulated. When samples are at high concentrations, when the subject judges total intensity rather than typical quality, and when the whole mouth is used to do the testing, the taste responses of
elderly look much like those of the young. The whole-mouth tasting for the same elderly seems to be normal (Bartoshuk 1989b).

In a study by Bartoshuk et al (1986) the sense of taste of elderly adults was assessed. Elderly adults (age ranged 74 to 93 years old, and a mean age of 82.8) and young adults (age 20 to 30 years old with a mean age of 24.4) were tested and evaluated using different methods. The methods used included threshold measurements by an up-down method, intensity magnitude estimation and magnitude matching methods using sound as a reference. The results showed elevated thresholds for all the elderly adults (Figure 6). Persons with reduced natural dentition tended to have higher taste thresholds than persons with full upper- and lower dentures (Bartoshuk et al. 1986).

![Figure 6. Detection thresholds for sucrose in molar concentration (A) and NaCl in mmolar concentration (B) as a function of age (Bartoshuk et al. 1986).](image)

According to Tepper & Genillard-Stoerr, 1991, the detection thresholds for bitter or salty tastes change more than thresholds for sweet or sour. Amino acids have clear taste qualities, and the taste and thresholds for amino acid also increased with age (Schiffman 1986; Tepper and Genillard-Stoerr 1991). In a study where recognition thresholds for one hundred subjects were studied, water solutions of varying concentrations of sweet, salty,
sour and bitter were used. No significant effect was seen for the basic taste sensations except for sweet taste (Sanders, Ayers and Oakes 2002). Kaneda et al found that sweet taste seems to be more robust across age groups, with no difference between young and elderly subjects in threshold concentration (Kaneda et al. 2000). A study by Easterby-Smith et al. (1994) showed elevated recognition thresholds for sugar and saccharine but not for aspartame (Easterby-Smith, Besford and Heath 1994). However, Cowart (1989) found no significant difference in detection thresholds for sucrose and citric acid with age. For sodium chloride (Figure 7) and citric acid a difference with gender could be seen. Females tended to be more sensitive (had lower thresholds) to sodium chloride and citric acid than males (Cowart 1989).

![Figure 7. Taste thresholds for sodium chloride as a function of age, expressed in log molar units (Cowart 1989).](image)

Weiffenbach et al. (1982) carried out a study of detection taste thresholds of sucrose, sodium chloride, citric acid and quinine sulphate using a two-alternative forced choice procedure. The assessors were 81 adults, 39 female and 42 male. Sodium chloride detection thresholds increased progressively with age (Figure 8). The threshold for quinine sulphate rose somewhat with age while sucrose thresholds showed no age-related change. The thresholds for citric acid did not change markedly or consistently with age. These results support the theory that an age-related elevation in threshold is quality-specific, and that sensitivity to sweet stimuli is least affected by age (Figure 8) (Weiffenbach 1991; Weiffenbach, Baum and Burghauser 1982).
Figure 8. Taste detection thresholds for salt (A) and sucrose (B) as a function of age for 81 participants (42 men and 39 women) in the Baltimore Longitudinal Study of Ageing (Weiffenbach 1991).

Some studies regarding thresholds for sodium chloride, amino acids, and sweeteners showed elevated thresholds 2 to 2.5 times higher for elderly persons compared to young
(Schiffman 1986). Schiffman (1993) carried out a study of detection thresholds for a broad range of sweeteners, sodium salts, acids and bitter compounds, comparing the results from elderly and younger subjects. The results for the elderly showed 2.75 times higher detection thresholds for sweeteners, 11.58 times higher for sodium salts, 4.29 times higher for acids, 6.94 times higher for bitter compounds, 2.48 times higher for amino-acids and 5.04 times higher for glutamate salts presented alone or with the enhancer inosine-5’-monophosphate. This certainly shows an increase in threshold for all tastes with age, although it is following the same pattern with more elevated thresholds for sodium salts and bitter compounds. The average loss over all tested taste qualities showed 5.41 times higher detection thresholds for the elderly compared to the young (Schiffman 1993).

Schiffman et al (1994) carried out a study where they compared elderly (mean age 87.5) and young (mean age 23.8) subjects regarding thresholds (detection and partly recognition) and preferences for MSG (monosodium glutamate) and MSG+IMP (inosine-5’-monophosphate) respectively in different types of food. The detection thresholds where higher for the elderly subjects in foods, and the highest was seen for tomato soup. The threshold was 0.746 % (w/w) MSG+0.5mM IMP for the younger subjects compared with 3.621% for the elderly subjects. The detection thresholds differed between the different types of food, and this is probably due to different original concentrations MSG and synergetic compounds present. All foods were preferred at a concentration below detection threshold of MSG. This is not understood, but what happens could be that MSG reacts with other chemicals in the food, forming a new taste (Schiffman et al. 1994).

Stevens et al. (1995) evaluates age-related elevation in detection threshold through six repeated measures of sucrose sensitivity with a forced-choice up-down tracking method. They investigated individual thresholds rather than averages for age groups, because they believed that averaged thresholds could give the misleading conclusion that all elderly have elevated thresholds. Their results are in line with other studies (Bartoshuk et al. 1986) i.e. elevated thresholds with increasing age. They also concluded that there were differences among compounds, and individual differences in the sensitivity to them. The individual differences to quinine hydrochloride, for example, were far more pronounced than the differences to sugar. They also pointed out that thresholds have to be considered as a particular cut of statistical concept. This means that the same stimulus might on one presentation elicit a response and on another no response. Thresholds may be defined
exactly in terms of the operations used to measure it, whereas sensitivity is a less definable, more hypothetical construct. Sensitivity can fluctuate over time, as when a person gets tired, grows older, undergoes sensory adaptation or suffers from disease or accidents that impair the sense organs. Thresholds then become an index of sensory change. Threshold is a statistical concept, because the fact that the same stimulus might on one presentation elicit a response and on another no response. The nature of intra-individual differences i.e. source of variation is important to consider (Stevens et al. 1995).

**Ageing and changes in odour thresholds**

Most studies suggest that the sense of smell is even more impaired by ageing than the sense of taste. This is seen at both threshold and suprathreshold concentrations. Elevated thresholds have been reported for a broad range of food odours and single volatile compounds (Schiffman 1997; Tepper and Genillard-Stoerr 1991). There are noticeable losses in odour sensitivity at the age of 60. These losses are greater in men than in women (Doty 1997). The identification and recognition abilities of odours decline dramatically with age. Although large cross-sectional age differences in thresholds have been established, some older persons have adequate olfactory function and may perform better than many younger persons. (Weiffenbach and Bartoshuk 1992)

In a study conducted by Duffy et al (1999) elderly needed 49 times the concentration compared to young subjects. No significant gender differences were seen within either age group. Their results indicated that elderly subjects showed greater impairments to retronasal perception of olfactory flavour than to orthonasal perception of odours (Duffy, Cain and Ferris 1999). Schiffman reports in a review that older subjects have thresholds that are 2 to 15 times higher for most odours than young subjects, and they have also shown reduced suprathreshold response (Schiffman 1993). Tepper & Genillard-Stoerr, 1991, indicated that detection thresholds for a wide variety of odours may be increased by between 5 and 11 times in elderly subjects (Tepper and Genillard-Stoerr 1991).

A threshold investigation was carried out with 26 young (20-25 years) and 23 elderly (65-70 years) subjects. Stimuli were isoamylacetate and isobutyraldehyde. For both odours the effect of age was significant indicating that with age olfactory perception declines (Griep
et al. 1995). A study of Cowart (1989) showed elevated olfactory thresholds with age (Figure 9), but no difference with gender (Cowart 1989).

**Figure 9.** Olfactory thresholds as a function of age, expressed in terms of the number of dilutions from a neat solution. (A) Pyridine. (B) Phenyl ethyl alcohol (Cowart 1989).
Ageing and changes in suprathreshold intensity perception

Intensity perception at suprathreshold level can be characterised by the slope of the psychophysical function, i.e. the function that relates judgements of perceived intensities to the physical strength or the concentration of the stimulus. If the slope decreases with age it indicates that for the same increase in stimulus strength older individuals experience smaller increases in intensity than younger individuals do (Weiffenbach and Bartoshuk 1992).

Taste
In a study carried out by Bartoshuk et al. (1986) old and young adults were asked to rate the perceived intensity of sucrose, sodium chloride (NaCl), citric acid, and quinine hydrochloride (QHCl) (Bartoshuk et al. 1986). The results showed flatter functions for elderly than for young, and the highest concentrations were perceived to be less intense by the elderly.

The intensity for bitter taste was perceived less intense by elderly subjects, compared to young (Drewnowski 2001). A study by Bartoshuk 1989, showed that perceived intensities for sucrose, sodium chloride, citric acid and quinine hydrochloride overlap for young and elderly, except for the lowest and highest concentrations. On the other hand Tepper & Genillard-Stoerr (1991) reported that at lower concentrations elderly people perceived intensities of bitter or sour tastes lower in than young adults and that age-related differences in taste perception only remain for bitterness at high concentrations and that the differences of sour taste disappear (Tepper and Genillard-Stoerr 1991).

In a study by Bartoshuk (1989) the perceived sourness intensity of citric acid on the front of the tongues was less in the elderly subjects (mean age 75) than in young subjects (mean age 22). But when the subjects were allowed to taste with the whole mouth, this age difference was much less noticeable. This illustrates a general phenomenon: localised taste losses can go unnoticed because whole-mouth function remains intact (Bartoshuk 1989b).

Murphy & Gilmore (1989) studied perceived intensities for two age groups, young (18-31 years) and elderly (65-83 years). Sucrose, caffeine, citric acid, and sodium chloride were presented alone or in mixtures. Magnitude matching was used to compare the two groups.
The hypothesis of the study was that there would be age-related differences in the perceived intensities of sweetness and bitterness in mixtures, whereas there would be small (or no) differences for sweetness and sourness or saltiness alone. The results supported the hypothesis and showed a significant difference in perception between elderly and young subjects (Figure 10). Elderly perceived the bitter solution as less bitter and citric acid as less sour than the younger (Murphy and Gilmore 1989).

![Figure 10](image.png)

**Figure 10.** Mean perceived intensity as a function of concentration for sweetness of unmixed sugar, sourness of unmixed citric acid and the bitterness of unmixed caffeine. White symbols: young subjects. Black symbols: elderly subjects (Murphy and Gilmore 1989).

Intensity measures using both cross-modal matching and a category scale showed an age group decline in perceived intensity of quinine sulphate (QS) and citric acid (CA) (p<0.01). The category scale results showed more distinct differences than the linear-matching procedure that was used. Intensity rating of sucrose did not differ with age (Cowart 1989).

**Odour**

At suprathreshold concentrations, efficiency of odour perception diminishes and the changes are generally uniform across odour types, in contrast to taste. Many odours are trigeminal stimulants, and contribute to the sensation of ‘nasal pungency’ or ‘bite’ of various foods; trigeminal sensation also diminishes with age. Thus in contrast to the age-
related changes that occur in taste perception, the reduction in odour perception tend to persist across the entire psychophysical range (Tepper and Genillard-Stoerr 1991).

de Graaf, Polet & van Staveren, (1994) studied perceived intensities of enhanced flavour in bouillon, tomato soup, orange juice and strawberry yoghurt. Yoghurt was also measured for higher sugar content. The average perceived flavour intensity in bouillon and tomato soup was lower for the elderly than the young subjects (Figure 11) (de Graaf, Polet and van Staveren 1994).

![Figure 11](image)

**Figure 11.** Mean responses of perceived intensity (± SD) to five series of food stimuli, as a function of relative concentration, judged by a group of 23 elderly subjects (*) and 32 young subjects ( ). Panels refer to series of bouillon in water (A), tomato juice flavour in water (B), orange juice flavour in water (C), strawberry yoghurt (D), and sugar in unsweetened yoghurt (E). (de Graaf, Polet and van Staveren 1994)

De Graaf et al (1996) studied intensity perception of different foods at various flavour levels. Bullion, tomato soup, chocolate custard and orange lemonade with different flavour
levels were studied. Elderly subjects showed lower perceived intensity than the young (Figure 12) (de Graaf, van Staveren and Burema 1996).

![Graphs showing perceived intensity vs. relative concentration for different food stimuli.](image)

**Figure 12.** Mean responses of perceived intensity (± SD) to five series of food stimuli, as a function of relative concentration, judged by a group of 34 elderly subjects (---) and 36 young subjects ( ). Panels refer to series of different flavour concentration in bouillon, tomato juice, chocolate custard, and orange lemonade (de Graaf, van Staveren and Burema 1996).

Intensities of five odours were estimated and compared between young and elderly subjects in a study by Stevens & Cain (1985). Significant age-related differences were found. The losses occur at such suprathreshold levels as you meet in everyday life (Stevens and Cain 1985).

According to Wysocki & Gilbert (1989) odour perception declines with age, but the decline is not uniform across different stimuli. Large changes were noted for the ability to smell andosterone. The ability to smell rose was quite high, at least until the eight or ninth
decade of life. The results for mercaptans were surprising. Many people, even in midlife years, failed to detect the agent present in natural gas (Wysocki and Gilbert 1989).

Stevens et al (1982) presented results that suggested that both olfactory and common chemical sensitivity declined with age. But the olfactory and common chemical losses seemed to be unrelated; ageing can dull one sense and leave the other acute (Stevens, Plantiga and Cain 1982).

Ageing and changes in ability to identify tastes and odours

Taste
Age-related decline in the ability to identify the tastes of sucrose, sodium chloride, citric acid and quinine sulphate was shown in a test by Cowart, (1989). See (Figure 13) (Cowart 1989).

For taste stimuli, it is often possible to name the sensory components and even rate the relative contribution of each taste (Weiffenbach 1984). Suprathreshold taste recognition and identification abilities are well preserved in elderly people; with a few exceptions, the ability to recognise and identify the basic taste stimuli and the taste of simple substances (e.g. sugar and salt) does not diminish with age (Tepper and Genillard-Stoerr 1991).

![Figure 13](image-url)

Figure 13. Scores on a taste identification task as a function of age (Cowart 1989).
**Odour**

An olfactory identification test performed by Cowart (1989) showed a general age-related decline in the ability to identify odours (**Figure 14**) (Cowart 1989). Murphy reported also a decreased ability to identify odours with age (Murphy 1986). An age effect was even seen in the age span of 19 to 66 years of age in an odour identification test with a battery of 80 different odours (**Figure 15**) (Murphy and Cain 1986). According to Doty et al. (1991) only a small percentage of persons under the age of 65 have decreased ability to detect and identify odours. More than half of those between the ages 65 and 80 and over three-fourths of those over the age of 80 years show major impairments (Doty et al. 1991). Doty et al. (1984) performed a study of 1955 persons ranging in age from 5 to 99 of ability to detect 40 odours. This study reports that the average ability to identifying odours reaches a peak between 20 and 40 years of age. It begins to decline monotonically after this time. Women of all ages were more accurate than their male counterparts in identifying odours (**Figure 16**) (Doty et al. 1984). Even when elderly and young are compared via much less demanding multiple-choice tasks, the elderly were unable to identify odours to the same extent as the young (Cain and Stevens 1989). The ability of the trigeminal system to perceive chemical stimuli and to identify the quality of such stimuli showed only little age-related change (Laska 2001).

**Figure 14.** Scores on an odour identification task as a function of age (Cowart 1989).
**Figure 15.** Percentage correct identification of a battery of 80 odorants plotted as a function of age (Murphy 1986; Murphy and Cain 1986).

**Figure 16.** University of Pennsylvania Smell Identification Test (UPSIT) scores as a function of age and gender. Numbers by data points indicates sample size (Doty et al. 1984).
Problems with measurements

An important thing to notice is that task performance may vary with age as a result of task-relevant but nonsensory differences between age groups (Weiffenbach, Cowart and Baum 1986).

A problem with some measurement procedures, including thresholds, is the lack of objective criteria in assessing whether the subject is responding correctly (Griep et al. 1995).

Persons differ greatly in the way they assign numbers to stand for apparent magnitudes. For the same stimulus set some tend to use larger ratio of numbers than others, leading to differences in the slopes of their psychophysical functions. Subjects differ greatly in their different size of the numbers used, leading to differences in the intercepts (up-down positions of their psychophysical functions). More concrete: for the same stimuli one subject may use the numbers 1 to 15 and another 1 to 10, and this gives mainly slope differences. If one subject uses the numbers 1 to 10, and another 1 to 100 it makes the position different. Young and old subjects may not use the same numbers to assess the same magnitude, as they may differ systematically for cognitive or experimental reasons (Stevens, Bartoshuk and Cain 1984). In magnitude matching another stimulus as e.g. signal can be used as a reference. Loudness could be a problem when using older subjects, since hearing is known to decrease with age (Murphy 1986). Sounds near threshold level are more affected by ageing than loud sounds and high frequencies more than low frequencies. By using relatively loud noises of low frequencies the effects of auditory losses can be minimised (Bartoshuk et al. 1986).

Memory

Traditionally, memory research has been focused primarily on memory for information that is experienced by our visual and auditory sensory systems, and has largely ignored the olfactory sensory system. There is an important distinction between implicit and explicit memory tasks in the context of the relationship between awareness and memory. In tasks
of explicit memory like recall or recognition tests, instructions and explanations are
directed towards conscious recollection of a prior test or study episode, giving an
awareness of what will happen. In contrast, in implicit memory tasks like perceptual
identification, fragment completion and steam completion, no reference is given to prior
learning episodes. The subjects are not informed of the connection between the study and
the test (Bäckman et al. 1990; Larsson 1997).

The human memory can be decomposed into five interrelated memory systems. 
Procedural memory is expressed through skilled behaviour and cognitive procedures.
Perceptual representation system (PRS) or priming is primarily concerned with improving
identification of perceptual objects. Semantic memory is concerned with acquisition and
use of factual knowledge. Working memory registers and retains incoming information in
highly accessible form, for a relatively short period of time. Episodic memory requires
conscious recollection of personally experienced events acquired in a particular place at a
particular time. Relation between memory systems and states of awareness could be as
follows, called the system theory. To recollect or remember something is a product of the
episodic system, feelings of familiarity or knowing a characteristic of retrieval from
semantic memory, which is thus implicit in nature. Lack of awareness is characteristic of
retrieval from the procedural and PRS systems. Working memory or primary memory
gives rise to a fleeting awareness of recently experienced events. An alternative to system
theory is process theory, which emphasises process differences within a unitary memory
system. Semantic memory is related to odour identification tasks, and episodic memory is
related to odour recognition tasks. In normal subjects, it is common to smell an odour and
to recognise it as familiar and belonging to a general class or category, but still be unable
to produce a specific label. This is called the ‘tip-of-the-nose’ phenomenon. Then persons
cannot answer any questions about the name of the odour, but about the odour quality like
taxonomic category, or say something about objects associated with it. Odour
identification is heavily dependent upon odour discrimination ability.

Age-related deficits in episodic memory for various types of information are well
established. The relative impact of these factors on olfactory memory is still an unexplored
issue. However, considering that the olfactory system processes information more slowly
than other sensory modalities, this in combination with age-related cognitive slowing may
be one reason why age differences have been proven to be exacerbated in olfactory memory relative other types of information (Cain and Stevens 1989; Larsson 1997).

Preferences

When functioning optimally the sensory system subserving taste and smell responds discriminately to a wide variety of complex chemical stimuli. Taste and smell signals are integrated with sensory input from the mouth and other parts of the body (Weiffenbach and Bartoshuk 1992).

In a study by Murphy (1986) the existence of changes in preferences for various concentrations of the same single tastant in more complex chemosensory mixtures were studied. Subjects were divided into three groups the ages 18 to 26 (mean 21), 32 to 45 years (mean 37) and the last group 65 and older (mean 73). There were 100 subjects in each age group. The stimuli were four concentrations each of NaCl (0.05, 0.10, 0.20, and 0.40 M), sucrose (0.075, 0.15, 0.30, and 0.60 M), and citric acid (0.0006, 0.0012, 0.0024, and 0.0048 M) in an aqueous base. The same concentrations were used for NaCl in a vegetable juice and for sucrose and citric acid respectively, in lemon-flavoured beverage base. The same concentrations of sucrose and NaCl were perceived as less pleasant in the aqueous base than in a beverage base. Citric acid was perceived as less pleasant in the beverage base than in an aqueous solution. Older subjects rated sugar and salt as more pleasant in higher concentrations than the younger subjects did (Figure 17) (Murphy 1986; Murphy and Withee 1986).

The data from the stimuli dissolved in beverage apply not simply to pure taste stimuli, but to chemosensory mixtures, since the background base contains volatiles. The fact that pleasantness judgements for the same concentrations shift when a stimulus is presented in a beverage base instead of an aqueous base underscores the importance of other chemosensory elements in determining pleasantness. Blended food contains volatiles, both odourants and trigeminal stimuli. Elderly subjects had more difficulty in identifying the items in a blended food than the younger subjects had. Elderly men had more difficulty than elderly women in identifying the items. When subjects were told to pinch their
nostrils before the same stimulus/food was presented, the young subjects fell to the same level of performance as the elderly subjects (Murphy 1986).

Figure 17. Mean pleasantness or unpleasantness as a function of concentration for sodium chloride, sucrose and citric acid in aqueous base (upper graph) and in beverage base (lower graph) for subjects in three age groups: young adults (open circles), middle aged adults (striped circles), and the elderly (shaded circles) (Murphy 1986).

These results suggested that the elderly found salt and sugar more pleasant in higher concentrations than the younger subjects did (Murphy 1993; Murphy and Withee 1986). The reason for these results may be cultural, contextual, or sensory. If these results were a consequence of taste loss, the perceived pleasantness would occur because they were not perceived as strong. Then age-related changes in suprathreshold intensity should show differences between elderly and young subjects in slopes or interprets, or both. If the elderly on the other hand found a more pleasant stimulus to be perceived as equally sweet as the young, then these findings would reflect nonsensory differences in preference. A study performed by using a chemosensory mixture, a stimulus solved in a beverage base, showed that there was clearly an age effect. That is, the elderly subjects had more difficulty in identifying the items than the younger subjects (Murphy 1986). In a preference study elderly women expressed an increased liking for bitter cruciferous vegetables and
salad greens, which is an interesting finding since bitter taste seems to decline more with increasing age than other tastes (Drewnowski 2001).

In another study the effect of sucrose in breakfast items were studied regarding pleasantness and food intake. Optimal preferred sugar concentration was higher for elderly subjects, but the sugar concentration had no effect on the total amount consumed. These results indicate that the flavour concentration judged as being the most pleasant by the elderly for a small amount of stimuli in a lab setting, does not necessarily predict the pleasantness and food intake in a real setting (de Jong, de Graaf and van Stavaren 1996).

In a study by Drewnowski et al (1996) the link between salt taste perception and preferences and sodium intake as a function of age and gender was studied. The subjects were 24 young adults aged 20 to 30 years, and 24 older adults aged 60 to 75 years. Taste stimuli were five aqueous-based salt solutions (0.04, 0.08, 0.016, and 0.032M sodium chloride). Additional stimuli were eight samples of specially prepared chicken broth containing 0.04, 0.08, 0.016, 0.032, 0.40, 0.48, and 0.64M sodium chloride. Nine-point category scales were used. The intensity scale was attributed at each end with “not at all___” and “extremely___” and the hedonic preference scale ranged from “dislike extremely” to “like extremely”. Older subjects showed a slight downward displacement of the intensity functions at the higher salt concentrations, giving rise to an age-by-salt interaction (Figure 18). Older subjects also gave higher hedonic ratings to salt solutions than did younger people at all salt concentrations tested, and the main effect of age was significant. The results may be seen (and analogous data have according to the authors been seen by other researchers) as showing that older people found saltier solutions to be more pleasant. The downward slope of the hedonic curve shows that the salt solutions in the range were not preferred but merely less disliked by older subjects. The whole-mouth perception for salt in soup was not influenced by age. On an average older people preferred lower salt concentrations in soup. The age-by-salt level was significant (Drewnowski et al. 1996).
Figure 18. Saltiness intensity rating (top) and hedonic preference ratings (bottom) for an aqueous stimulus and for salted chicken broth as a function of age. Data are expressed as means and standard errors (Drewnowski et al. 1996).

Rolls (1999) is questioning if testing hedonic response to taste stimuli in a laboratory assessment will help to predict how food intake will be affected by variations in the sweet taste (Rolls 1999).

de Graaf et al. (1994, 1996) performed studies where perceived intensities and pleasantness response to the different stimuli were compared (Figure 19 & Figure 20). For bouillon, tomato soup, and orange juice flavour, the pleasantness increased with increasing concentration for the elderly (Figure 19). The results suggest that the elderly group preferred higher concentrations of bouillon and tomato juice flavour than the younger subjects did. Elderly and young subjects showed different psychophysical functions. In the case of the orange juice flavour, the group of young and elderly subjects had similar psychophysical function, but the elderly preferred higher perceived intensities than the young subjects (de Graaf, Polet and van Staveren 1994). In the other study, by de Graaf et al. (1996), bouillon, tomato soup, chocolate custard and orange lemonade were studied. See Figure 20 for intensity-pleasantness functions (psychohedonic) for the young and the elderly subjects. For all of the four food flavours, elderly subjects had higher optimal preferred perceived intensities than did the young subjects (de Graaf, van Staveren and Burema 1996).
Figure 19. Mean responses of pleasantness of five series of food stimuli, as a function of mean response to perceived intensity, judged by a group of 23 elderly subjects (*-----*) and 32 young subjects (□ □). Panels refer to series of bouillon in water (A), tomato juice flavour in water (B), orange juice flavour in water (C), strawberry yoghurt (D), and sugar in unsweetened yoghurt (E) (de Graaf, Polet and van Staveren 1994).
Figure 20. Mean responses of pleasantness of five series of food stimuli, as a function of mean response to perceived intensity, judged by a group of 34 elderly subjects (---) and 36 young subjects ( ). Panels refer to series of different flavour concentration in bouillon, tomato juice, chocolate custard, and orange lemonade (de Graaf, van Staveren and Burema 1996).

**Food choice**

Sensory responses to taste, smell and texture of foods help determine food preferences and eating habits. However, sensory responses alone do not predict food consumption. In reality, there are multiple links between taste perception, taste preferences, and food choices and the amount of food consumed. The impact of taste factors of food intake further depends on sex and age and is modulated by obesity, eating disorders, and other pathologies for eating behaviour. Food preferences and food choices of populations are further linked to attitudinal, social, and very important – economic variables such as income (Drewnowski 1997).
The economic status is an important, sometimes regarded as the most important, factor influencing food choice in the elderly. Another important determinant is the composition of their household. Psychological factors also influence the foods chosen by the elderly. Eating is an important psychosocial activity and serves as a source of creativity, prestige, friendship and reward. Fears associated with ageing, such as loosing a mate, changing roles, moving, rejection, making new friends, and experiencing illness, can result in emotional stress, loss of appetite, and reduced food consumption. Food preferences are strongly influenced by society and culture, in all age groups. Food choices often serve as symbols closely related to traditional beliefs. As people age they continually “give up” many things. Food can be something for elderly to still have control over. The food they select may symbolise comfort, happiness and pleasure. But physiological factors may sometimes override all other determinants of foods preferred by the elderly. The energy needs for the elderly could be met with nutrient-dense foods that are convenient, easy to open, tasty, attractive at first sight, and can be purchased at a reasonable cost. In the supermarkets there are special sections for babies, but not for the elderly (Briley 1994).

The chemosensory abilities to detect and evaluate potential foodstuff are among the most basic of sensory capabilities. Many plants produce defensive compounds, often bitter-tasting alkaloid toxins dangerous to ingest in quantity, to discourage feeding. In contrast, plants do also produce pleasantly flavoured fruits to encourage feeding and thereby promote seed dispersal. Natural selection has established a preference for sweets and an aversion to bitter substances as two fundamental properties of the taste system of most of the higher animals which are not strictly carnivorous. An innate preference for sweet may favour diets rich in calories. Bitter substances are often rejected, by infants and younger children especially (Bartoshuk 1994). A need of salt can produce cravings for salty foods in humans (Bartoshuk 1989b; Oakley 1986). These taste preferences are innate, although learning does also play a significant role in the chemosensory behaviour. This could be the case with bitter compounds, as individuals do come to tolerate and like bitter foods and beverages. A taste of a substance associated with sickness or malaise will be avoided after a long period of time (Bartoshuk 1994; Oakley 1986).

It is often assumed that ageing leads to altered hedonic preferences for salt, which in turn results in increased sodium consumption. Although in a study by Drewnowski et al. (1996)
no age-associated sensory deficits were found that could be linked to and increase in sodium consumption (Drewnowski et al. 1996).

According to Tepper & Genillard-Stoerr, 1991, elderly people perceive higher concentrations of salt and sugar in their food to be more pleasant than do young adults, presumably because they perceive the lower concentration as to be weaker (Tepper and Genillard-Stoerr 1991).

As mentioned, the taste of bitterness has elevated thresholds even for quite high concentrations. Although it is rare that that bitterness is the predominant taste in food, bitter taste can enhance sensory appeal of a variety of foods and beverages, including some cheeses, coffee, tea and beer (Tepper and Genillard-Stoerr 1991).

**Olfaction**

Most of the elderly persons tested in a study by Stevens, Bartoshuk & Cain (1984), showed that even those with severe impairments, who seemed obvious to their loss, reported no loss of appreciation of food or ability to smell. It may be that when losses take place gradually enough over a long period they play a less predominant role than when losses are relatively swift or even sudden, as might follow from a blow to the part of the head that serves the olfactory nerves. The role of olfaction in the enjoyment of food, and by the extension of their nutritional state, is difficult to access. So many factors can come into play: ‘institutional cooking’, feeling of social isolation from family or friends, lack of appetite, diseases, medicines, etc. If the appreciation of foods involves chemosensory loss, substantial suprathreshold deficits of odour and nasal pungency are the most probable causes. It is therefore important to improve palatability of foods for the aged with substances that appeal to the nose (Stevens, Bartoshuk and Cain 1984).
Appetite and food intake

Factors that influence appetite and food selection are complex. They involve metabolic influences (e.g., caloric requirements, neurotransmitter levels, hormones); specific appetites (e.g., NaCl when salt deficient); disease states (e.g., diabetes, cancer); pharmacological influences (e.g., anorectic drugs); environmental influences (e.g., temperature); social influences (e.g., culture, religion); learned preferences and aversions, and hedonic factors (e.g., palatability, taste, texture, odour) (Rolls 1986).

Although it is certainly clear that the elderly have reduced olfactory ability, it is less certain which effect that reduced ability has on enjoyment of food. Some older people who complain of substantially less pleasure from their meals are found to have relatively small threshold and suprathreshold losses. However, some individuals who report little reduction in their ability to enjoy food are found to have much greater sensory losses. It seems likely that those individuals whose hedonic response has been greatly reduced have suffered concomitant losses in texture and taste sensitivity (Schiffman 1993). A study by Stevens, Bartoshuk & Cain, (1984) showed that despite severe impairments and an awareness of the impairments, most of the elderly tested did not report a decrease in the appreciation of food or ability to smell (Stevens, Bartoshuk and Cain 1984).

People eat less and make different food choices as they get older (Drewnowski and Shultz 2001). Decreases in food intake and appetite in the elderly may be associated with decreased energy expenditure, social physical factors, as well as chemosensory changes. A certain phenomena, called conditioned taste aversion (CTA), is associated with food avoidance and medical treatment. Consumption of a particular food prior to receiving a treatment such as chemotherapy induces gastrointestinal discomfort and subsequent avoidance of that food. This may also play a role in conditioned taste aversion in the elderly (Finkelstein and Schiffman 1999).

One primary feature of the ageing process that also would affect the appetite, appears to be the loss of responsivity to internal and external cues in determining physiological status, e.g. experience of thirst and fluid intake. Subjective ratings of hunger in elderly subjects were only weakly correlated with the amount eaten in a meal. Correlation between estimated stomach contents and ratings of hunger were significantly weaker for elderly
subjects than for young subjects. Changes in sensory–specific satiety might be explained by the general decline in sensory acuity associated with ageing rather than changes in appetite regulations (Hetherington 1998). Greater attention to colour and texture can enhance the visual appearance of foods and increase appetite (Tepper and Genillard-Stoerr 1991).

Sensory-specific satiety
During consumption of a food the pleasantness of its taste, appearance, smell, and texture decreases. Oral stimulation associated with consumption leads to a decreased intake of that food, or in other words satiety is specific to the sensory properties of food. In humans, sensory-specific satiety refers to the change in hedonic response to the sensory properties of a particular food as it is consumed. It is usually found that the pleasantness of the eaten food decreases significantly more than the pleasantness of uneaten food (Rolls 1986). The mechanisms underlying sensory-specific satiety are not well understood (Rolls and McDermott 1991).

Sensory-specific is defined in Rolls & McDermott (1991) as the difference between the change in pleasantness of sensory properties of the eaten food or the desire to eat the eaten food and the mean changes in the uneaten foods. In a study subjects were asked to taste and rate a range of different foods for pleasantness of appearance, odour, texture, and taste and for their desire to eat the food. All ratings were done on 100-mm visual-analog scales. This study showed that sensory-specific satiety differs across various age groups. Sensory-specific satiety was thought to limit the consumption of a particular food and to encourage switching from food to food within a meal so that a variety of foods are consumed (Rolls and McDermott 1991).

The greater the differences between foods, the greater the enhancement of intake. This means that to maximise food intake, the available foods should vary along as many dimensions as possible. On the other hand, if intake is to be kept low, the foods should be similar.

Sensory-specific satiety helps to ensure the consumption of a varied, and therefore balanced, diet (Rolls 1986). Rolls and McDermott (1991) showed that subjects over 65 years of age did not show a greater decrease in the rating for pleasantness of the taste of the food they had consumed compared to the uneaten food (Rolls and McDermott 1991).
Alliestheisa refers to a change in sensations resulting from a change in the internal state or in the physiological need for substances. The hedonic changes develop slowly during the hour after consumption and are relatively unspecific in that all food odours decrease after a sugar load and the origin of the changes is thought to be in the duodenum. Sensory-specific satiety differs from alliesthesia in that it is not produced primarily by the state of repletion or the physiological need for particular nutrients (Rolls 1986).

**Energy intake**

Longitudinal studies conducted in the USA and Sweden, described by Hetherington (1998) have demonstrated a reduction in energy intake with increasing age. This decline was achieved in part by eating less over all, but significantly by consuming a greater percentage of energy as carbohydrate and consuming significantly less absolute amounts of fat. Changes in the pattern of eating (consuming fewer snacks, having smaller meals and eating more slowly), and a reduction in fat and total intake, reflect changes in the regulatory systems controlling appetite and energy intake (Hetherington 1998).

**Oral health**

Many age-related changes in the oral cavity are the result of systematic diseases and their treatments. Chewing problems associated with tooth loss and denture use can interfere with taste sensation on the palate as well as retronasal smell perception. Tooth-related infections produce noxious bacteria that can interfere with taste and smell (Finkelstein and Schiffman 1999). The influence of systematic diseases and their treatment on oral health in an older person can be profound, which can also influence taste and smell. The vast majority of older adults are taking at least one prescription medication, and many of these and other nonprescription drugs have consequences to the oral environment. Tooth loss can also have significant consequences for taste and smell. Mouth movements during eating, such as use of the muscles of mastication and chewing, probably play an important role in the perception of odours in the posterior oral-pharyngeal and nasal region. Retronasal odour perception is significantly better in the presence of mouth movements (e.g., spitting and swallowing) compared to no mouth movements. Inadequate denture hygiene may lead to
chemosensory problems (Ship 1999). In a study of sensory-specific satiety, elderly denture wearers did not show as large a decline in the pleasantness of the taste of the yoghurt as did those without dentures (Rolls and McDermott 1991). Improved dental hygiene could improve taste acuity, for sweet and salt perception. Cleansing of the tongue and gum enhances the perception of sweet and salt tastes, but not for bitter and sour tastes. The removal of dentures and a good oral health can also help to improve taste perception (Sanders, Ayers and Oakes 2002; Ship 1999).

**Saliva**

Salivary function has been demonstrated to be relatively age-independent, and healthy older persons may have salivary output indistinguishable from that of younger adults. However many older adults complain of dry mouth and have decreased salivary output. These problems are most likely caused by systematic conditions and their treatment rather than as a consequence of normal ageing. Saliva plays a predominant role in taste function, as taste is subserved by an intact salivary system. Saliva helps to dissolve tastants and transport them to the taste buds located on the tongue, palate and oral pharynx (Ship 1999). Since taste stimuli must be in the form of a solution (e.g. dissolved in saliva) in order to interact with taste receptors, abnormal saliva or decreases in the amount and speed of chewing might limit the access of taste stimuli to the receptors (Tepper and Genillard-Stoerr 1991). Therefore, older adults with a dry mouth can experience changes in taste perception (Ship 1999).

**Taste and olfaction disorders**

Changes in taste and smell experienced by the elderly can be seen at threshold and suprathreshold level in an identification or discrimination task among tastes and odours. This can result from a combination of conditions including normal ageing, disease state and drug therapy (Schiffman 1986). Chemosensory impairments are usually classified as follows:
**Taste impairments**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ageusia</td>
<td>absence of taste function</td>
</tr>
<tr>
<td>Hypogeusia</td>
<td>diminished sensitivity of taste</td>
</tr>
<tr>
<td>Dysgeusia</td>
<td>distortion of taste</td>
</tr>
</tbody>
</table>

**Olfaction impairments**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anosmia</td>
<td>no smelling capacity</td>
</tr>
<tr>
<td>Hyposmia</td>
<td>diminished sensitivity of smell</td>
</tr>
<tr>
<td>Dysosmia</td>
<td>distortion of normal smell</td>
</tr>
</tbody>
</table>

Dysgeusia and dysosmia can occur in the presence or absence of a stimulus and are not necessarily correlated with loss of sensitivity. Parosmia refers to distortion of odour perception when an odour is present, and phanosmia refers to odour sensation in absence of an odour stimulus. Cacosmia is a term that can be used to describe the subjective sense of feeling ill in response to odours (Schiffman 1997).

Anosmic patients have often learnt to compensate for their dysfunction by accentuating other aspects (i.e., taste, temperature, texture) of foods. A survey comparing a group of anosmics to a group of healthy controls and their responses for food preferences showed that preferences were a bit slighter for the anosmics, and varied with food class. The most notable group differences occurred for homogenous items (e.g. puddings, sherbets) (Mattes 1995).

**Taste versus olfaction**

According to Weiffenbach & Bartoshuk, (1992) declines for olfaction intensity are greater than those for taste intensity. Declines are greatest to the sensitivity of smell and somewhat less for sensitivity to trigeminal stimuli that are experienced as pungency or tingle. The
declines are independent. An older person whose sensitivity to odours is low may or may not also have low sensitivity to trigeminal stimuli (Weiffenbach and Bartoshuk 1992).

Losses in sensitivity may often be quality-specific for tastes, whereas losses in olfactory sensitivity tend to be relatively uniform, affecting responses to all or most odour stimuli (Cowart 1989). There is a decline in olfaction with age also according to Doty (1991). Elderly showed elevated detection thresholds as well as suprathreshold losses (Doty 1991a). An odour in sufficient concentration can act as a nasal irritant. Ageing can cause both olfactory and common chemical deficits (Stevens and Cain 1985).

In a study carried out by Stevens, Bartoshuk & Cain, (1984) levels of odourant and taste were interspersed and tested in the same session. The hypothesis of their study was that for the same stimulus sets, the elderly would, on an average, show a greater difference between olfactory and gustatory estimates than would young controls. The older the subjects, the greater would be the difference.

Three groups of subjects were used. They were:

1) The young group, 20 subjects aged 20 to 25 years (10 females and 10 males and mean age 21.4).
2) A group of 20 relatively old subjects aged 65 to 78 years (10 females and 10 males and mean age 71.2)
3) A group of 21 very old subjects between 80 to 95 years (18 females and 3 males and mean age 86.1).

_Taste stimuli_ were five concentrations of NaCl dissolved in deionized water, (0.14, 0.17, 0.20, 0.24 and 0.28M). Sip-and-spit method and room temperature solutions were used. NaCl was chosen because its psychophysical properties are well known as it has been used as a kind of a yardstick by which other taste qualities are judged. Sour and bitter tastes are unpleasant, and for sweet there seems to be more individual variations.

_Olfactory stimuli_ were five concentrations of iso-amyl butyrat (6.3, 11.3, 20.1, 37.2, 68.2 p.p.m.) in air. This compound was selected because it has a pleasant fruity odour, it is not pungent, and it has previously been used in the same kind of studies. Squeeze-type ‘shampoo’ bottles were used.
An individual index was calculated as the sum of individual olfactory estimates divided by the sum of all taste estimates. They showed that olfaction declined more with age than taste, which supports the hypothesis of the test, that ageing has, on an average, a more substantial detrimental effect on the sense of smell than on the sense of taste. They also indicated the possibility that some old people retained their sense of smell remarkably well, while some lost it almost entirely, although a complete retention of olfaction is probably relatively uncommon (Stevens, Bartoshuk and Cain 1984).

*Causes of taste and olfactory losses*

*Taste loss*

Taste nerves are vulnerable to damage of several sorts. Because the corda thympani travels through the middle ear, viruses have an easy access to it through the eustachian tube. Taste loss is, not surprisingly, associated with upper respiratory infection and ear infection (Weiffenbach and Bartoshuk 1992).

Losses in taste perception in the elderly are sometimes related to alternation in the process of turnover and renewal of taste buds. For instance, radiation treatment may destroy gustatory epithelium so completely that the taste buds are prevented from reforming; mitosis can be interrupted by some medications, including antiproliferative agents. The number of taste buds may also be affected by reduced mitosis due to low testosterone or estrogen levels. Another cause of loss of taste perception is disease or damage to the three cranial nerves (the seventh, ninth, and tenth) that innervate taste buds (Schiffman 1993). The cause of taste changes in normal ageing in absence of disease is not fully understood. Studies show that it could be due to changes in taste cell membranes (e.g. altered functioning of ion channels and receptors) rather than loss of taste buds (Schiffman 1997). According to Miller (1989) functional changes in the taste buds are responsible for the decline in sensitivity that occurs with age, rather than a decrease in number (Miller 1989; Tepper and Genillard-Stoerr 1991).

Taste is rarely completely lost. Many people with substantial damage to taste nerves notice no subjective impairments of taste experience. One reason for this, which is relevant to an examination of taste in the elderly, is the redundancy of mediation of taste. There are two mechanisms that underlie this puzzling clinical observation. First, taste intensity remains
constant because when a single nerve is injured, as the responses from some other nerves are enhanced (Weiffenbach and Bartoshuk 1992). Taste is mediated by several nerves (the corda thympani, the glossopharyngeal, the greater superficial petrosal and the vagus nerves), and the complete taste loss would require damage to all these nerves, damage to all receptors, or damage to all taste areas in the central nervous system. Such extensive damage is uncommon. The taste system seems to be “hard wired” to maintain the constancy of perceived intensity even if substantial taste areas are damaged (Bartoshuk 1989b).

The second mechanism makes a taste loss go unnoticed by a person. This is because taste sensation are normally localised by touch in the mouth. If a taste solution is painted from an area with taste (e.g., lateral margin of the tongue) into an area without taste (e.g., centre of tongue), the taste sensation produced in the first area will fill the path and seem to come from all areas touched (Weiffenbach and Bartoshuk 1992).

This constancy suggests that taste is serving important biological functions. The functions of three taste qualities have been studied extensively. The need for sodium is biologically driven so that salt need produces a craving for salty taste in humans as well as in lower species with no learning required. Similarly, preference for sweet taste is also biologically driven (for example, insulin increases and a sugar load decreases the pleasantness of sweet sensation). Bitterness on the other hand, appears to be a biological poison detector (Bartoshuk 1989b).

Medications and medical conditions play a major role in taste losses and distortion, even in healthy older persons. Neither site nor mechanism of action for most pharmaceutical compounds that include taste losses is known, but medications can act at several levels, including peripheral receptors, chemosensory neural pathways, and/or the brain (Schiffman 1997).

Other factors, such as poor oral hygiene, abnormal dentition and gum inflammation can lead to dysgeusia, which may distort the taste of low concentrations of oral stimuli and might explain elevation in taste thresholds (Tepper and Genillard-Stoerr 1991).

**Nutrition and taste loss**

Specific nutrients, including copper, zinc, vitamins A, C, B6 and B12, and folic acid, play a role in taste function, and deficiencies of these nutrients may be related to changes in
taste function. Since many elderly often are at risk of specific nutrient deficits, it has been suggested that their chemosensory losses can partly be due to it (Tepper and Genillard-Stoerr 1991).

**Olfactory loss**

Olfactory losses in the elderly result from normal ageing, certain disease states (especially Alzheimer and Parkinson’s disease), medications, surgical interventions, and environmental exposure (e.g., cumulated exposure to toxic fumes) (Doty 1991b; Duncan and Smith 1995; Kratskin 1995; Tepper and Genillard-Stoerr 1991).

The primary causes of olfactory loss are upper respiratory infection, head trauma, and nasal symptoms (Weiffenbach and Bartoshuk 1992). For persons from 50 and more years of age the primary cause is probably upper respiratory infections. Whether this reflects some age-related lack of resistance to viral insult or simply a culmination of repeated insult to the olfactory epithelium (or both) is unknown (Doty 1989). During ageing, anatomical and structural changes also occur in the structure of the upper airways, olfactory bulb and nerves, hippocampus, and amygdaloid complex, and hypothalamus including reduction in cell numbers, damage to cells and diminished levels of neurotransmitters (Schiffman 1997). Anatomical or degenerative changes in the olfactory bulb and the central nervous pathway that carry olfactory information can cause olfactory loss (Tepper and Genillard-Stoerr 1991).

The axons, carrying information of odourants to reach the olfactory bulb, must pass through small holes in the cribiform plate that forms the skull. The neurons can be shred in this point during head injuries and is the most common cause of olfactory loss. The formation of olfactory neurons from basal cells may play an important role in age-associated losses in olfaction. The basal cells may not continue to replace olfactory neurons at the same pace throughout the life span (Weiffenbach and Bartoshuk 1992).

A variety of medical conditions, including cancer, viral infections, diseases of liver and kidney, and endocrine and nervous disorders alter chemosensory function. In addition, many drugs, including antihistamines, oral hypoglycemics, antihypertensive agents and diuretics, disrupt taste and odour perception. Since many elderly people have multiple disabilities and may be taking several medications simultaneously, chemosensory losses due to ageing may be compounded by similar changes associated with diseases and with

**Sjögren’s syndrome**

Patients have elevated levels of sodium and chloride and reduced levels of phosphorus in their saliva. Cellular abnormalities and a fewer number of taste buds are reported in patients with Sjögrens syndrome. Taste receptor changes occur after 15 days of salivation and patients show an abnormal low salivary flow. Taste thresholds, detection and recognition, are reported to be elevated for patients with Sjögren’s syndrome (Christensen 1986). Many of the symptoms of Sjögren’s syndrome are related to a decreased salivary function associated with lymphoplasmacytic function. This syndrome is observed in the elderly population (Beidler 1995). Olfactory deficits have also been reported to occur in Sjögren’s syndrome (Getchell and Mellert 1991).

**Alzheimer’s disease**

Failure of the ability to smell is particularly acute in Alzheimer’s disease. Alzheimer’s disease is a form of pre-senile dementia that primarily occurs in older people (Schiffman 1993). According to a review article of Murphy (1999) Alzheimer’s patients show neuropathological changes in areas of the brain central for olfactory processing. Findings suggest that CNS regions involved with olfactory-mediated tasks are affected from the very early stages of dementia (Murphy 1999). According to Doty (1991) basic olfactory function is retained in Alzheimer’s disease, but higher order olfactory dysfunction is impaired (Doty 1991b).

**Flavour enhancement and sensory interventions**

Chemosensory deficits experienced by the elderly generally cannot be reversed. It has been suggested that poor odour perception can cause changes in food enjoyment and food consumption, diminished food appreciation and poor nutritional state among older adults (Griep, Mets and Massart 2000; Hetherington 1998; Schiffman 2000). One of the most important factor influencing food intake is enjoyment of food (de Jong et al. 1999).
Sensory properties of food, such as texture and flavour, are important determinates of food choice. Flavour perception has been rated as the strongest determinant of food consumption in older adults (Griep, Mets and Massart 2000; Rolls and McDermott 1991). Sensory interventions including intensification of taste and of odour of food can compensate for age-related perceptual losses (Schiffman 2000)

Flavour enhancement differs from more traditional methods of increasing odour and taste sensations such as use of spices, herbs and salt. Spices and herbs add different flavours to food rather than intensify the chemosensory properties of actual foods. Flavours are discriminated from spices as they do not irritate the mouth or stomach (Schiffman 2000).

A relevant question in research of sensory preference of food flavours in elderly people is whether changes in the relationship between concentration and preferences are mediated by changes in the sensory perception of flavours. There are two possible hypotheses to this. The relationship between concentration and intensity (psychophysical function) may be similar for young and elderly subjects, but elders prefer a different intensity than young subjects. That is to say that elderly people have different psychophysical function, but a similar relationship between perceived intensity and pleasantness (de Graaf, Polet and van Staveren 1994).

Amplification of the flavour levels in foods to optimal concentrations for the elderly to improve food enjoyment, have shown to have a positive effect on food intake, and foster appropriate nutritional intake. Sensory interventions in addition to flavour enhancement can be helpful when taste and smell losses impair appetite. This could be switching among different foods on the plate to reduce sensory adaptation or fatigue, or varying texture quality as well as taste or smell. Enhancing food flavour and understanding triggers for taste and smell can help older persons to adjust to the physiologic changes that occur with age and help maintain appetite and food enjoyment (Schiffman 1997).

**Effects of flavour and MSG enhancement**

Studies described in Schiffman (2000), described immune and functional improvements (increased levels of T and B cell levels and improved grip-strength) as a result of intensifying the flavour of food. Experiments with taste and odour stimuli do also show an enhanced secretion of salivary IgA.
In other experiments, elderly people suffering from malnutrition were given food enhanced with MSG and flavours. Levels were individualised on the basis of each person’s individual thresholds for taste and odour. This combination of flavour and MSG improved energy intake. MSG and flavour-enhanced food were given to relatively healthy elderly during 4 weeks. Levels of MSG and flavour were optimised to each subject’s preferences evaluated in a pre-testing session. This study shows a significant increase in satisfaction and acceptability of the enhanced food (Schiffman 2000). Several studies by Schiffman indicate that flavour enhanced foods are preferred by frail and sick elderly (Schiffman and Graham 2000).

Compared with (saturated) fat, sugar and salt, exposure to additional amounts of flavour is generally harmless and self-limiting, showing no detrimental health effects since only small quantities, well below the maximal tolerable doses are needed to give food a perceptibly stronger flavour level (Griep, Mets and Massart 2000).

Greip et al (2000) studied whether flavour amplification induced changes in preferences for skimmed milk yoghurt and Quorn®. The flavours used were all mixtures of odour molecules extracted from natural products or synthesised after chemical analysis of the natural product. For Quorn®, chicken flavour was used. This study showed that flavour amplification influenced food preferences for both Quorn® and yoghurt. Compared with young subjects, older adults reacted positively to the flavour-amplified yoghurt (Figure 21) and Quorn® (Figure 22). With age, a strong increase in the number of subjects preferring the high flavour level was observed (Griep, Mets and Massart 2000).
Figure 21. Relationship between age and preference for flavour-amplified yoghurt in women (■) and in men (□) in the study (Griep, Mets and Massart 2000).

Figure 22. Relationship between age and preference for flavour-amplified Quorn® in women (■) and in men (□) in the study (Griep, Mets and Massart 2000).

In a study by Mathey et al. (2000), the effect of flavour enhanced food was studied regarding dietary intake and weight change. A control group (n=34) and a ‘flavour
enhance’ group (n=37) were studied for 16 weeks. Results from this study showed that repeated consumption of flavour-enhanced cooked meals led to an increase in dietary intake of the enhanced meal. It also led to increased body weight, and increased daily feelings of hunger (Mathey 2000b).

*Why do flavours and MSG provide sensory enhancement?*

Flavours probably exert their effect by increasing the number of molecules that interact with receptors on chemosensory membranes in the nose and the oral cavity. This intensification of chemosensory stimulation includes more salivation, produces greater stimulation of the olfactory and limbic system of the brain and promotes immune functions. MSG on the other hand, probably exerts its effect by adding another taste quality to the food, i.e., umami that improves palatability (Schiffman 2000).
References


