Taste perception with age

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This thesis describes experiments studying age-related differences in taste perception. Thresholds, supra-threshold intensities and pleasantness for ten different tastants, representing the five taste qualities sweet, sour, salty, bitter and umami were measured in the same group of elderly and young subjects. The tastants were dissolved in water and in product. Age has a deteriorating effect on taste sensitivity, which is already noticeable in the young-old group of elderly. First, this effect is generic in nature, i.e. more than 90% of the total variance attributable to age is due to age alone and less than 6% to age-related differences in the perception of the different taste qualities. Secondly, the differentiation between the different taste qualities is less distinct for elderly than for young people. A change in the signal-to-noise ratio at neural or perceptual level might be put forward to explain these phenomena. The outcome might support the hypothesis that the primary taste cortex is the locus of most accurate coding. Neither thresholds nor supra-threshold sensitivity were good predictors of the most preferred concentration of the tastants in product.
Although the perceived intensities were lower for the elderly than for the young, the most preferred concentration of the tastants in product were similar for both age groups. It is suggested that the information about perception and affection might be processed in different regions of the brain.
The most intriguing finding in this thesis is that smell seems to play a crucial role in taste perception. When the olfactory input is blocked, about 70% of the age differences in taste perception disappeared. Since taste and smell are so intimately related and accompanied by other sensations, such as mouthfeel, temperature and spiciness, it might not be a bad idea to investigate taste perception with a multimodal/multimethod approach, including all oral sensations in the investigation.

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Chapter 1

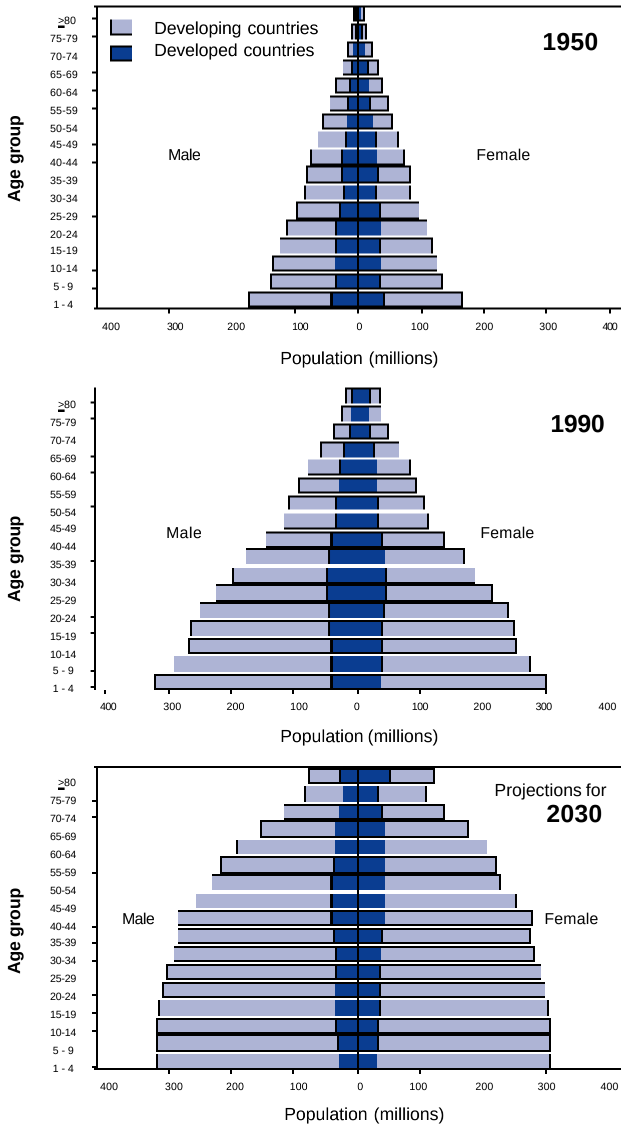
General introduction

This introductory chapter will be devoted to the elements of the context of this thesis. First, the world-wide increase of the elderly population and age-related changes in body functions, in cognitive ability, and in sensory perception will be described. Subsequently, a brief introduction in the taste system will be given, from the receptor cell at the periphery into the areas in the brain. Finally, the outline of the objective and the structure of this thesis will be drawn.

The ageing population

The world's elderly population is increasing dramatically. Currently, in many Western European countries, in Japan, and in the United States the elderly population already presents over 15% of the total population. From 2000 to 2030 many European countries will experience a growth rate of more than 50%, while the elderly population of the United States is estimated to increase by just over 100%. Developing countries are also experiencing a rapid growth in their elderly population, it is predicted to increase by 2-4-fold by 2030 (Report of the United Nations Population Division, 2002). According to the U.S. Census Bureau (2001) the world's population age 65 and older is growing by an unprecedented 800,000 people a month. By the middle of the next century, the developed countries of Europe, Asia and North America may have more grandparents than children (see Figure 1.1). World-wide, the average life span is expected to extend another 10 years by 2050.

The growing number of older adults puts demands on the public health system and on medical and social services (OECD, 2000). As a consequence, there is a growing need to understand the development and changes that occur in the later years of life. What are normal changes that occur in the body of these elderly people and what are the implications of these changes? Since this thesis focuses on the change in taste perception with age, a brief overview of age-related changes connected with eating and drinking behaviour is given next.



Source: United Nations, 1999, and U.S. Bureau of the Census, 2000

Figure 1.1 Population age distributions for developing and developed countries, by age and gender - world-wide: 1950, 1990 and 2030.

Age changes in body functions

Respiratory changes associated with ageing increase the difficulty in taking deep breath, thus less air reaches the inner lung with a normal breath.

In general, g*astrointestinal function* seems not to diminish much with age, although some changes occur. In the oral region, saliva production diminishes, the saliva composition is changed, the chewing efficiency is diminished with age, and the number of taste buds decreases. Schieber (1992) reported that a person may lose 20 to 60% of their taste buds after the age of 60.

In the stomach, reduced basal and stimulated gastric acid secretion is found. Furthermore, a modest slowing of gastric emptying can be noticed, which may predispose to weight loss and anorexia by prolonging gastric distension and increasing meal-induced fullness and satiety. Common problems in the aged are faecal incontinence and constipation in the intestine area. The pancreas undergoes structural changes with age, but these changes do not significantly affect pancreatic exocrine function. Ageing is well recognised as a major risk factor for glucose intolerance type II (non-insulin-dependent) diabetes mellitus. The liver's ability to withstand stress may decrease with age, while the prevalence of gallstones increases with age.

Kidney's and bladder changes occur with age. The kidneys are less efficient in removing waste material, less able to keep the body hydrated, and may have a decreased ability to concentrate urine, resulting in an increased thirst. The bladder becomes less expendable with age, does not always empty completely, and gives less warning before starting to contract.

Cardiovascular changes show that in later life the hart muscle becomes thicker, stiffer, weaker, and has more fat tissue. Thickening of arteries and blood vessels may lead to high blood pressure.

Age changes in cognitive ability

In addition to the changes described above, ageing has also a slowing down effect on cognitive processes. The central question in studies on ageing is whether this slowing down process is generic or specific in nature. Several researchers presume a generic slowing down of the information processing (Birren, 1974; Cerella, 1985; Madden, 1985). Studies on speed of peripheral and central information processing in vision with elderly and young subjects have shown that the elderly need about 33% more time in central processing to identify a single character than the young. This slowing down is less strong for peripheral information processing (Walsh, 1976, 1979). A slowing down in peripheral processing seems to occur also in audition (Kausler, 1982).

The difference between automatic and controlled information processing has been used to study the selective attention with age. Automatic processes, such as word recognition do not require attention or effort, and do not interfere with ongoing cognitive activities. Controlled information processing requires attention and processing capacity. It is generally assumed that controlled processing slows down with age, but automatic processing speed is retained (Cerella and Fozard, 1984; Plude and Hoyer, 1981).

Although it is also often assumed that learning and memory are impaired in the elderly, it has been demonstrated that this is not true for all learning and memory tasks. Age takes indeed its toll on performance in many explicit memory learning and memory, but in a large number of mainly incidental and implicit learning tasks the elderly perform just as well as the young (Hoyer and Lincourt 1998) and the same holds for implicit memory (Schacter 1996). In experiments on olfactory memory involving explicit learning and/or odour identification the elderly perform also less well than the young (Murphy et al., 1991), but in memory based on incidental learning of odours the elderly are just as good (Møller, Wulff and Köster, 2004a) or even better (Møller, Wulff and Köster, 2004b) than the young.

Several, not mutually exclusive noise hypotheses could be put forward to explain an impairment in information processing (Essed and Eling, 1986). First, the neural noise hypothesis may apply. A change in the gustatory signal-to-noise ratio lowered by a decrease in intensity of the signal, or an increase in the level of spontaneously firing neurons, or both, would make it more difficult for the elderly to detect differences between a tastant and a blank in taste experiments. A diminished signal or an increase in neural noise caused by a decline in functioning or by a loss in brain cells with age has been put forward to explain this phenomenon (Salthouse and Lichty, 1985). A second factor may be stimulus persistence. If in the aged nervous system the neural activity after a taste stimulus lingers longer, the signal-to-noise ratio will be diminished when the next stimulus is presented. Elderly people often have problems with speech perception. The neural representation of speech sounds may interfere with the perception of the following sounds. This hypothesis can be considered as a variant of the neural noise hypothesis, since both hypotheses predict a decrease in the signal to noise ratio with age. Third, there may be a problem with selective attention: the ability to neglect irrelevant information may be decreased. The irrelevant information may be considered as a type of noise, but at a psychological/perceptual level rather than at a neural level (Stroop, 1935; Rabbitt, 1965; Farkas and Hoyer, 1980; Wright and Elias, 1979).The three hypotheses discussed so far, focus on noise at the input level. The fourth and fifth hypotheses assume increased noise at the retrieval process. The fourth hypothesis is the disinhibition hypothesis. Elderly people could have problems with the selective retrieval of relevant information from memory to connect with new information (disinhibition of irrelevant items) (Warrington & Weiskrantz, 1971). Finally, the fifth hypothesis is the contextual integration hypothesis. It might be that older people store information in a way less integrated with context than younger people do, with contextual information serving as a tool to separate otherwise similar events. So when older people try to retrieve events from memory, more ‘nearly right’ candidates will come up as a result of a storage problem (Rabinowitz et al., 1982).

Age changes in sensory perception

Changes in vision. Starting around their forties, people need higher levels of illumination, greater degrees of contrast between objects and their backgrounds, and they will find it harder to accommodate, i.e. to rapidly focus on objects at different viewing distances. As focussing becomes more difficult, vision may become increasingly blurred and fuzzy. There is often less depth perception, less tolerance to glare, and distinguishing colours may become more difficult (Mendez et al., 1996). Inadequate lighting and colour contrast between the tabletop and the dinnerware can result in problems that lead to inadequate nutritional intake (Koss and Gilmore, 1998; Calkins and Brush, 2002).

Changes in hearing. With age, the ear structures deteriorate. The eardrum thickens, which leads not only to a diminished hearing, but it can also affect balance adversely. Changes to the nerve may lead to difficulty in hearing high-frequency sounds (presbycusis). The sharpness of hearing may decline and the “cocktail party syndrome”, i.e. the phenomenon that in rooms where many people are talking, elderly people often have great difficulty listening specifically to the person who is speaking directly to them, may occur.

Changes in touch, vibration and pain. Elderly may have reduced or changed sensations of pain, vibration, cold, heat, pressure and touch. The reduced ability to detect vibration, touch and pressure increases the risks of injuries, including pressure ulcers. Impaired touch may also have consequences for texture- and localisation perception in the mouth and for swallowing; the elderly have a higher risk of choking.

Changes in taste and smell. The loss in taste and smell acuity will extensively be discussed in chapters 5-9. Here, some generally believed statements will be made about the influence of age on taste and smell its consequences. It is commonly believed that the sense of smell decreases with age, and that the sense of taste remains relatively robust throughout the lifespan. It is also assumed that loss in taste and smell perception inevitably will lead to diminished pleasure in eating, which in turn will lead to a diminished food intake followed by a diminished health and well-being. However, there is no substantial evidence to support the idea of such a causal relationship.

The impact of sensory sensitivity on appetite or intake has been investigated by a number of authors and here also contradicting results were reported. The majority of these authors found no relationship (Pangborn and Pecore, 1982; Mattes, 1985; Mattes et al., 1990; Pérez et al., 1994; Drewnowski et al., 1996; Vickers et al., 2001; Mattes, 2002). In contrast, an impact was found by Yeomans et al. (1998) on appetite and by Schiffman and Warwick (1993) and Schiffman (1994) on intake. The impact of pleasantness on appetite or intake has also been investigated by a number of authors. No relationship was found by Bobroff and Kissileff (1986), Lucas and Bellisle (1987), and Drewnowski et al. (1996), whereas an impact on appetite was found by Yeomans et al. (1998), and on intake by Mattes and Mela (1986), Stone and Pangborn (1990), Yeomans and Symes (1999), De Castro et al. (2000), and Vickers et al. (2001). Since in the present studies the effect of taste sensitivity on appetite or intake has not been studied, the above mentioned results will not be described in detail.

Ageing clearly has many effects on human capacity, and is characterised by an increase in variability of capabilities, both within a population and within individuals. Thus, there is a greater variability in the capabilities of a group of elderly (in their mid-seventies) than in a group of young (in their mid-twenties) persons.

The sense of taste

In every day life, the word taste is commonly interpreted as the sensation elicited by flavour, i.e. the combination of taste *and* smell, accompanied by mouthfeel and a variety of other oral sensations (Pangborn, 1960). Flavour perception plays a crucial role in human drinking and eating behaviour where it has a dual function. It should assess the palatability of fluids and foods on the one hand, and the noxious features on the other hand. Since humans usually eat several times a day, taste in this broad sense will probably be the most frequent mediator of pleasure.

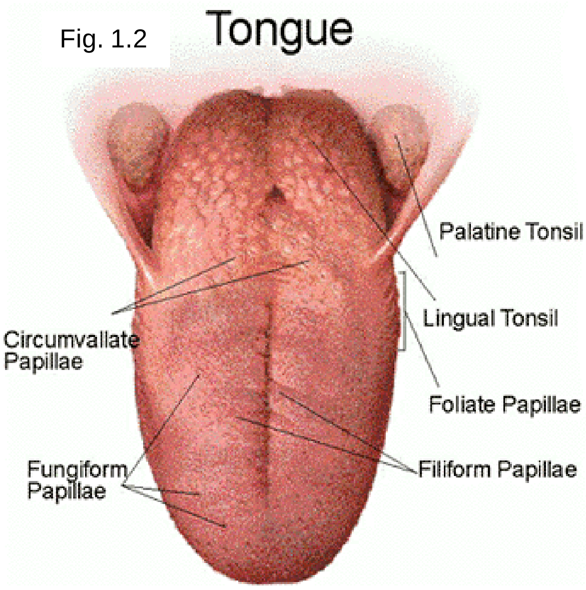
Although the variety of flavours seems endless, we can only recognise a few taste qualities. In current scientific research, four or five basic taste qualities are distinguished: sweet, salty, sour, and bitter. The more unfamiliar fifth taste quality is umami, meaning “delicious” in Japanese. It is defined by the taste of amino acid glutamate (MSG or ve-tsin). Debate still goes on about whether or not these qualities describe all taste qualities (Miller and Bartoshuk, 1991).

In the countless flavours of food such as tomato soup, chocolate drink, mayonnaise and ice-tea different combinations of these basic taste qualities are activated, which in combination with other sensory modalities help to make the food-tasting experience unique. Texture and temperature are important, and pain sensations are essential to the hot, spicy flavour of foods laced with capcaicin, the key ingredient in hot peppers, but smell sensations arising from food in the mouth are perhaps most prominent, because they appear as most intimately integrated with the sense of taste.

The taste system

The general structure and most of the facts in this section are rather directly borrowed from the excellent review of Bear, Connors, and Paradiso (1996) who are experts in the fields of neuro-anatomy, physiology and molecular biology, whereas the present author, who is very much indebted to them, is not. An overview of the basic facts in taste perception is nevertheless a necessary prerequisite for understanding the consequences of the findings in the present experiments and for formulating hypotheses about the mechanisms that might explain these findings.

Fig. 1.2



Tongue. Spread over the surface of the tongue there are taste sensitive areas, called papillae. Within these papillae are the taste buds, and within the taste buds the taste receptor cells can be found. Anatomically different papillae are found in different regions of the tongue (see figure 1.2). Fungiform papillae are found on the anterior part of the tongue. Foliate papillae are situated along the lateral edges of the tongue (see figure 1.2). Circumvallate papillae are on the back of the tongue (about 9 of them, larger than the other papillae). The total number of taste buds is around 4000, although exceptional cases range from 500-20000. In different papillae there are different numbers of buds: 100–200 taste buds in each circumvallate papilla, about 600 taste buds in each foliate papilla. More than half of all fungiform papillae contain no taste buds, although each fungiform papilla may contain from 1-36 taste buds (Arvidson, 1979). In addition there are 2500 taste buds on the epiglottis, soft palate, laryngeal and oral pharynx. The number of taste buds declines with age. The well-known tongue map is a common myth. It is not true that different areas of the tongue are sensitive to different tastes.

Although the different regions are slightly different in sensitivity for certain tastes, every cell is sensitive to all five taste qualities. This was already shown by Hänig (1901) who reported that the thresholds for each of the four basic tastes did not remain constant as locus was varied.

Taste buds. Taste buds are collections of 50-150 elongated epithelial cells, which are arranged within the bud like the sections of an orange. Most of these cells are taste receptor cells, but many have only a sustaining function.

Taste buds can not be seen with the naked eye. They have a taste pore, a small opening on the surface of the tongue where the taste cells are exposed to the contents of the mouth (see figure 1.3 and 1.4). A sufficient amount of saliva is critical for proper functioning. Taste buds also have basal cells, derived from surrounding epithelium. Most of the basal cells differentiate into new receptor cells before they migrate to their position in the taste bud in order to replace dying taste cells. Taste cells have a high turn-over rate: within about three weeks they are replaced.

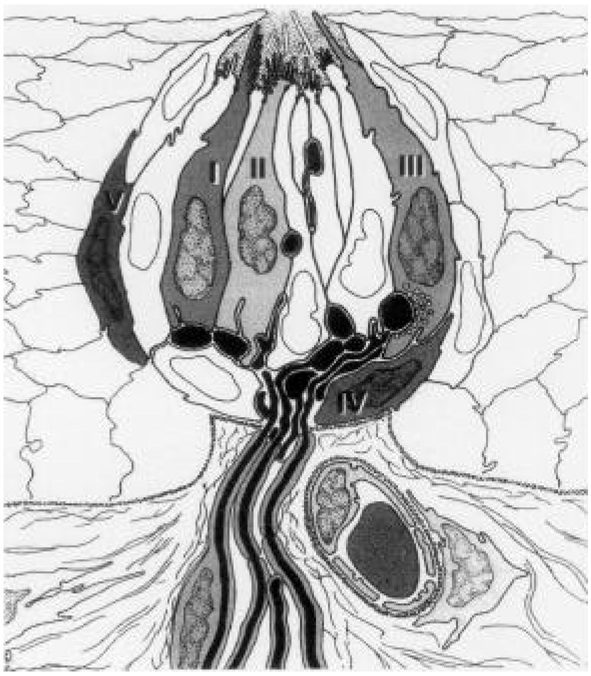


Fig. 1.3 Drawing of taste bud in the papillae. Cells of type I, II and III end with different types of microvilli within the taste pit and may reach the taste pore. Type IV cells are basal cells, type V marginal cells.

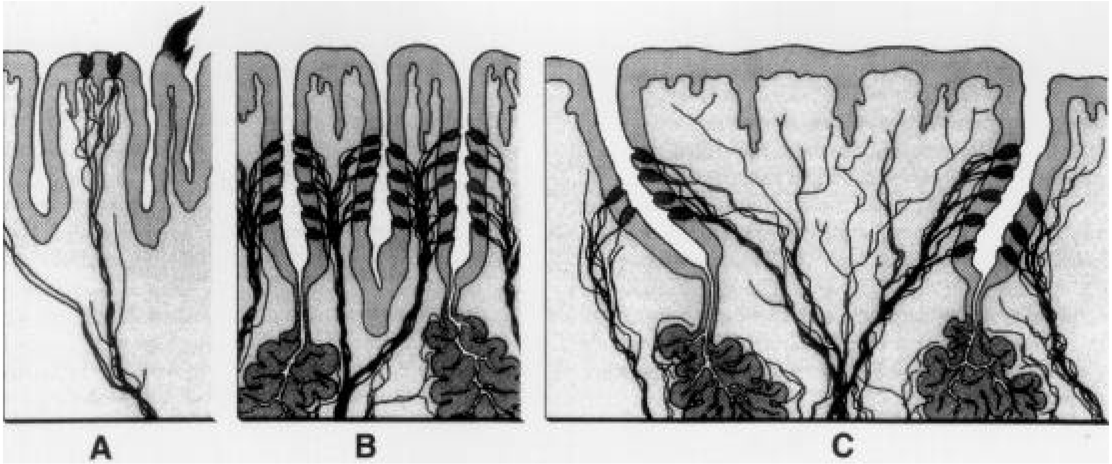


Fig. 1.4 Drawing of taste bud-bearing papillae, (A) Fungiform papilla with on the right side, a (taste bud-free) filliform papilla, (B) Foliate papilla, and (C) Circumvallate papilla. In B and C the taste buds are directed to the lateral trenches of the papillae

This process depends on an influence of the sensory nerve, because when the nerve is cut, taste buds will degenerate. Concentrations of taste stimuli that are too low will not be tasted, but at some critical point the stimulus will evoke a taste sensation. This is the threshold concentration. At concentrations just above threshold, most papillae tend to be sensitive to only one basic taste. At higher concentrations, most papillae become less specific.

Taste receptor cells. The chemically sensitive part of a taste receptor cell is its small membrane region, called the apical end, near the surface of the tongue. The apical ends have thin extensions called microvilli that project into the taste pore. Taste receptor cells are not neurons, but they do form synapses with the endings of the gustatory afferent axons near the bottom of the taste bud. Taste receptor cells also make synapses onto some of the basal cells; some basal cells synapse onto the sensory axons, and these may form a simple information-processing circuit within each taste bud.

When a taste receptor cell is activated by an appropriate chemical, its membrane potential changes, either depolarising or hyperpolarising. This voltage shift is called the receptor potential. Depolarisation of the receptor membrane causes voltage-gated calcium channels to open; Ca^{2+} enters the cytoplasm, triggering the release of transmitter molecules. This is basic synaptic transmission, from taste cell to sensory axon, resulting in an action potential that is ultimately transmitted to the brain.

More than 90% of receptor cells respond to two or more of the basic tastes. This means that even the first cell in the taste process is relatively broadly tuned to chemical types. However, taste cells and their gustatory axon differ widely in their response preferences (Kinnamon, 2000). Why will one cell respond only to a single chemical type, while another responds to three or more categories of chemicals? The answer is that the responses depend on the particular transduction mechanisms present in each cell.

Taste transduction. The process by which an environmental stimulus causes an electrical response in a sensory receptor cell is called transduction. The nature of the transduction mechanism determines the specific sensitivity of a sensory system. Taste transduction involves several different processes, and each taste quality uses one or more of these mechanisms. Taste stimuli, or tastants, may (1) directly pass through ion channels (salt and sour), (2) bind to and block ion channels (sour and bitter), (3) bind to and open ion channels (some sweet amino acids), or (4) bind to membrane receptors that activate second messenger systems that in turn open or close ion channels (sweet and bitter).

Saltiness. The salty taste of sodium chloride is mostly initiated by the cation Na^+ that enters the cell through the amiloride-sensitive sodium channel. When tasting salt, the Na^+ concentration raises outside the receptor cell, and the gradient for Na^+ across the membrane is made steeper. Na^+ then diffuses down in its concentration gradient, which means that it flows into the cell and the resulting inward current causes the membrane to depolarise. The anions of salts affect the taste of the cations. For example, sodium chloride tastes saltier than sodium acetate, apparently because the larger an anion is, the more it inhibits the salt taste of the cation. The mechanisms of anion inhibition are poorly understood. Another complication is that as the anions become larger, they tend to take on tastes of their own. Thus, sodium saccharin tastes sweet because the Na^+ concentrations are far too low to taste the saltiness.

Sourness. Acids dissolve in water to generate ions (protons or H^+). The protons are the cause of the acidity and the sourness, and they are known to affect sensitive taste receptors in two ways. First, H^+ can permeate the amiloride-sensitive sodium channel. This causes an inward H^+ current and depolarises the cell. Second, H^+ ions can bind to and block a K^+-selective channel. When the K^+ permeability of a membrane is decreased, it depolarises. These may not be the only mechanisms of sour taste transduction, since changes of pH can virtually affect all cellular processes.

Sweetness. Molecules evoke a sweet taste when they bind to specific receptor sides and thereby activate a cascade resulting in a second messenger. Sweet receptors are G-protein-coupled membrane receptors triggering the formation of cAMP (the second messenger) within the cytoplasm, which activates protein kinase (PKA), which phosphorylates a K^+-selective channel (apparently a different one from that involved in sourness), causing a blockade resulting in the depolarisation of the receptor cell. There may also be a second transduction mechanism for sweetness that does not involve second messengers. In this case, a set of cation channels may be gated directly by sugars.

Bitterness. Bitter taste receptors are poison detectors. There are different mechanisms for bitter taste transduction, perhaps because poisons are so chemically diverse. Some bitter compounds, such as quinine, can bind directly to K^+-selective channels and block them. There are also specific membrane receptor proteins for bitter substances, which activate G-protein-coupled second messenger cascades that are different from those of the sweetness mechanism. One type of bitter receptor triggers an increased production of the intracellular messenger inositol triphosphate (IP_3).

Umami. The umami taste is mediated by the metabotropic glutamate receptor (mGluR4) binding to the receptor activates a G-protein and this may elevate intracellular Ca^{2+} (Chaudhari et al., 1996; Kurihara and Kashiwayanagi; 1998). In addition, there are ionotropic glutamate receptors (linked to ion channels), i.e. the NMDA-receptor, on the tongue. When activated, non-selective cation channels open, thereby depolarising the cell.

All transduction mechanisms result in an increased firing in the primary afferent nerve.

Central taste pathways. The main flow of taste information goes from the taste buds, to the primary gustatory axons, and then proceeds into the brain stem, up to the thalamus, which projects to the cerebral cortex. Three cranial nerves, containing primary gustatory nerve fibres bring taste information to the brain. The anterior fungiform and the anterior foliate papillae are innervated by the chorda tympani branch of the facial nerve (VII). The remaining foliate papillae are innervated by the lingual branch of the glossopharyngeal nerve (IX). This last branch also innervates the circumvallate papillae. The vagus nerve (X) serves as afferent innervation further down the pharynx. These nerves are involved in a variety of other sensory and motor functions, but their taste axons all enter the brain stem, bundled together, and synapse within the nucleus of the solitary tract in the medulla. From this gustatory nucleus, taste pathways diverge.

The conscious experience is presumably mediated by the cerebral cortex. The path to the neocortex via the thalamus is a common one for sensory information. Gustatory nucleus cells project to a variety of brain stem regions, largely in the medulla, that are involved in swallowing, salivation, gagging, vomiting, and basic physiological functions, such as digestion and respiration. Furthermore, gustatory information is distributed to the hypothalamus and related parts of the basal telencephalon. These structures of the limbic system seem to be involved in the palatability of foods and in the forces that motivate us to eat.

Neural coding of taste. The fundamental question in taste research still remains. How can the brain reliably differentiate between subtle differences if single taste receptors show only small differences in response to foods? In a simple system one would expect to find specific neurons responding to specific tastes. This concept is the *labelled line hypothesis*, and it seems simple and rational. However, it is incompatible with several facts. As described before, individual taste receptor cells tend to be broadly tuned to stimuli, they are not very specific in their response. Primary taste axons are even less specific than receptor cells, and most central taste neurons continue to be broadly responsive all the way into the cortex. This means, that the response of a single taste cell is often ambiguous about the food being tasted; i.e. the labels on the taste lines are uncertain rather than distinct.

Why then are the cells in the taste system broadly tuned? If one taste receptor cell has several different transduction mechanisms, it will respond to several types of tastants (although it will respond more strongly to one or two). In addition, there is convergence of receptor cell input into afferent axons. Each receptor synapses onto a primary taste axon that also receives information from several other receptors in that papilla as well as in its neighbours. This means that one axon may combine the taste information from several papillae. If one of those receptors is mostly sensitive to sour-tasting stimuli and another to salty tasting stimuli, then the axon may relay saltiness as well as sourness. This pattern continues into the brain. Neurons of the solitary tract nucleus receive synapses from many axons of different taste specificities, and they may become less selective for tastes than the primary taste axons.

When chocolate is tasted, how does the brain sort out this apparently ambiguous information about the flavour and make clear distinctions between chocolate and thousands of other possibilities? The answer is a scheme that includes features of roughly labelled lines and *population coding*, in which the responses of a large number of broadly tuned neurons, rather than a small number of precisely tuned neurons, are used to specify the characteristics of a particular stimulus, such as a taste (Smith and Margolis, 1999). Only with a large population of taste cells, with different response patterns, can the brain distinguish between alternative tastes. A food activates a certain subset of neurons, some of them firing very strongly, some moderately, some not at all, others perhaps even inhibit below their spontaneous firing rates. The overall patterns of discharge rates will be distinctly different from another food.

In every day life, the relevant population usually includes neurons activated by the olfactory, temperature, pain, and textural features of a food, which all contribute to the ability to distinguish one food from the other.

Taste perception with age

Current research on taste perception with age shows contradicting findings. Whereas a number of researchers did not find a diminished sensitivity, others did, although not for all taste qualities. An overview of the studies on taste perception with age and their main findings can be found in chapter 3 (see Table 3.1) and in chapter 4 (see Table 4.1). These studies vary not only in the type and number of tastants, or in the age ranges of groups, but also in many other aspects, such as in the focus on and measurement methods of thresholds, intensities or pleasantness, and in instructions, concentration ranges, and number of repetitions (see Table 3.2).

Hitherto, the specificity of taste losses has never been investigated in the same groups of elderly and young subjects for the five taste qualities, each represented by two compounds. Moreover, the assumed positive relationships between threshold sensitivity, supra-threshold perceived intensities and pleasantness were never investigated in a same group of subjects. Furthermore, in most of the studies the tastants were dissolved in water, and thus, the results were based on single taste perception. Only a few studies focussed on tastants in real foods, i.e. a complex taste-smell-texture perception (see Table 4.1), whereas only in one case among the latter studies nose clips were used to block the olfactory input and thus complex taste-texture perception was studied. None of these studies were performed with the same group of subjects. This means that the influence of the context on taste intensity perception has hardly been investigated. As a result, the relevance of determining intensities of tastants dissolved in water for the ‘real life’ perception of tastes in complex food products has remained unclear.

It is expected that by using the same group of subjects in all experiments [except on the possible role of olfaction in taste perception (chapter 9)] and by comparing the different sensory contexts in this thesis can contribute to most of the unsolved problems.

Aim and outline of this thesis

The aim of this thesis is to explore the taste sensitivity in elderly and young subjects. In taste research, often threshold measurements are carried out to determine taste sensitivity. However, the interrelationship between the sensitivities for the different taste qualities was not investigated before. *Chapter 3* investigates whether there are taste losses with age when tastants are presented at threshold concentrations. If these are found, then the specificity of this loss in taste will be determined. In addition, the interrelationships between the sensitivities for the five taste qualities, salty, sweet, sour, bitter and umami, each represented by two different tastants, are determined for elderly and young separately and are subsequently compared.

The sensitivity for the supra-threshold intensities are investigated in the same groups of elderly and young subjects in *chapter 4*, using the same tastants as in the previous experiment in different matrices: in water and in variants of commercially available foods. In pre-tests, it is checked whether the concentration steps in water and in food were sufficiently large to be distinguishable by the subjects. In the main experiments the same tastants are dissolved in different concentrations in water and in food and assessed while wearing a nose clip or not to investigate the supra-threshold taste perception of elderly and young in different perceptual contexts.

The relation between pleasantness on the one hand and threshold sensitivity and supra-threshold intensity on the other is investigated in *chapter 5*. The findings of the previous studies are compared and it is questioned whether threshold measurements or measurements of tastants at supra-threshold levels which are dissolved in water bear any meaning for the perception of tastants in every day food. Furthermore, the question is raised, whether diminished taste sensitivity inevitably leads to an elevated optimally preferred concentration of the tastants in product. In this respect, the findings of this study have implications for policy makers and for the food industry.

In *chapter 6* the interactions between the experimentally varied tastes and the other taste qualities in the food products in the previous experiments are investigated for the same elderly and young subjects. The enhancing or suppressing effects exhibited by the experimentally varied tastants on the other taste qualities and age differences in attentional taste quality differentiation are described. The possibility to explain the unexpected findings in terms of a signal to noise hypothesis is discussed. The stimuli in taste research are usually considered to be odourless. This assumption is questioned in *Chapter 7*, which includes two additional experiments with new groups of elderly and young subjects. In the light of the results of these experiments, the role of olfactory deprivation, by wearing a nose clip while assessing the taste intensity in the previous experiments, will be discussed. In addition, the relation between saliva production and tastant concentration is investigated and compared for elderly and young subjects.

An outline of the experiments is shown in Figure 1.5. The findings of these experiments have implications for the interpretation of earlier research in taste and present a challenge for future work in this area.

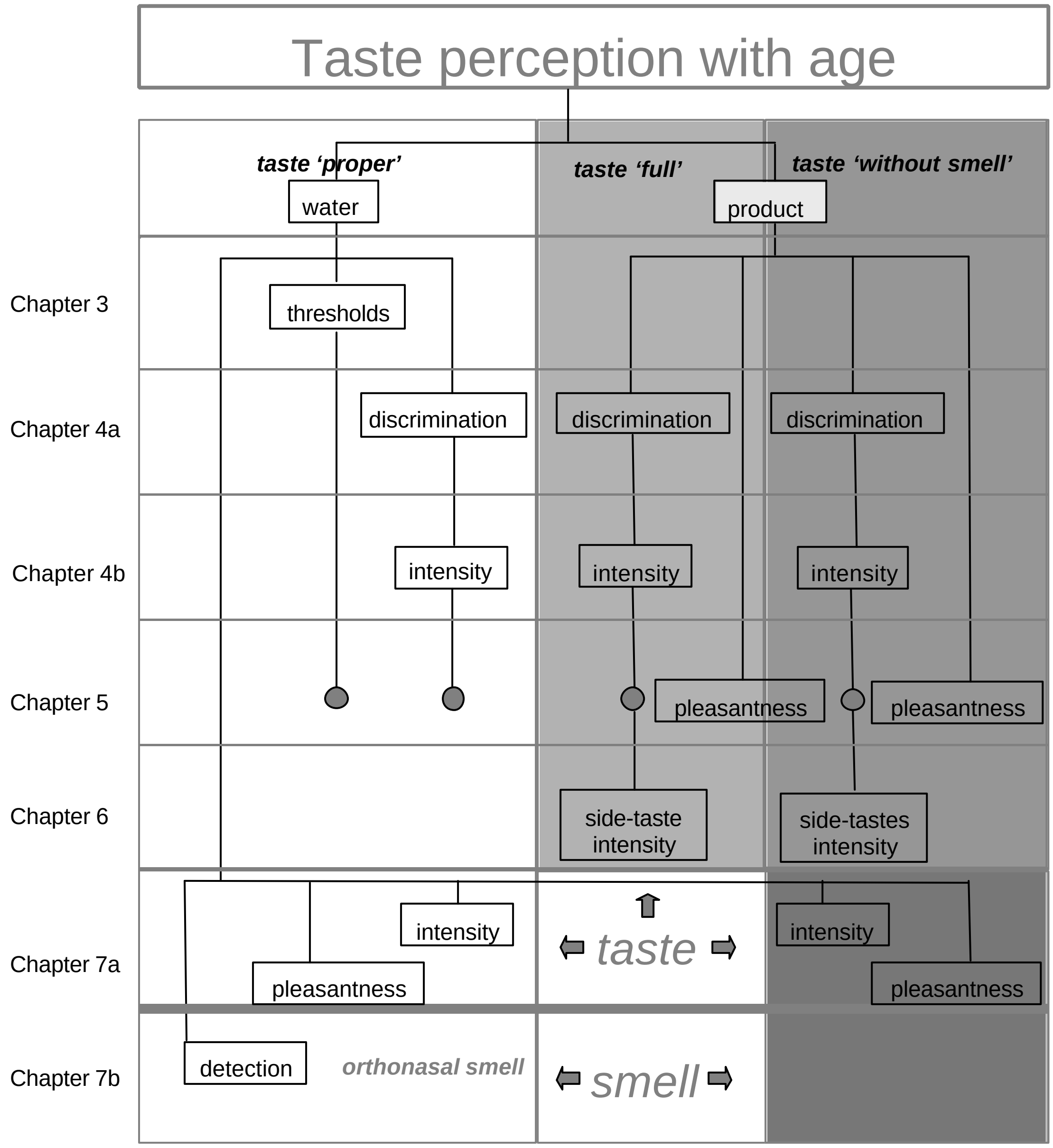


Fig. 1.5 Outline of the experiments in this thesis

Chapter 2

Materials and methods

Introduction

Studies of taste sensations reflect the methodologies available. Early studies focussed on taste quality. Discussions of the number and nature of taste sensations go back to early treatises on the nature of sensation written in eras before quantitative treatment was possible (Bartoshuk, 1978). In the nineteenth century, the precursors of threshold methodology led to the first quantitative studies of taste sensations. Direct scaling methodology was developed in the twentieth century. It permitted quantitative evaluation of taste sensations over the whole dynamic range from threshold to the strongest taste experienced.
In this chapter an overview of the methods and materials used in this thesis will be described. Since detailed descriptions of the methods and comparisons with the literature will be given in chapters 3 to 7, this overview will be restricted to the main features.

Subjects

Age. Since most of the taste research was focussed on 'normal' taste, research has usually been carried out with healthy adults. Only in the last two decades a growing research interest in aged people and in children became apparent. Some researchers considered people with an age of 60 years and over as elderly, whereas others draw the line at 80 years as the onset of old age. Much of the current research is focussed on the "young – old", a range of people (from their late fifties through their mid-seventies), since they may show some evidence of decreased abilities but, in general, still function very well and the probability of cognitive impairment is still relatively low (Schaie, 1996; La Rue, 1992). In the present experiments two age groups were used, a group of young people between 18 and 35 years of age, which is in line with the age ranges most other researchers used, and a group of young-elderly with an age between 60 and 75 years. The age ranges used by other investigators are mentioned in chapters 3 and 4.

Gender. In taste research it is not common practice to look for gender effects. Only a few researchers report to have looked into the effect of gender. Where appropriate, the results of these authors will be reported in chapters 3–7. In order to investigate gender differences, an equal number of men and women were recruited to participate in the present experiments.

Health. Over 250 commonly used drugs have been reported clinically to affect the sense of taste (Schiffman et al., 1997). Dutch people of 65 and over consume around 3 times the amount of prescribed drugs used by the average Dutch person. Therefore, our subjects were screened for health and drug use, in order to assure that possible taste deficits could be attributed to ageing and not in any way to illness or medication.

People on a prescribed diet were excluded, as were people with complete dentures. Since it was very difficult to recruit enough fully dentate elderly subjects, those with partial dentures were admitted, but they were not allowed to wear their dentures during testing. Furthermore, all subjects underwent an auditory test, in view of the use of hearing as a cross sensory modality to match taste responses. A tone audiogramme was made with 500 and 1000 Hz tones of each candidate to screen for normal sensitivity to sounds around 750 Hz. To participate in the taste experiments, the auditory thresholds should not be higher than 30 dB.

Genetic variability. The subjects in our study were submitted to a test in which their PROP-status was determined. In the literature sensitivity to 6-*n*-propylthiouracil (PROP) has been ascribed to genetic differences (Bartoshuk et al., 1994; Drewnowski et al., 1998).

According to Bartoshuk et al., people can be categorised as super-tasters, medium tasters or non-tasters. Super- tasters are said to be very sensitive to PROP, whereas non-tasters hardly taste its bitterness.

The question may be raised to what extent this specific sensitivity is related to the sensitivity to the other tastants. One way to check this is to compare the age-related change in PROP sensitivity with the age-related sensitivity changes to other tastants in the same group of people. Sensitivity to PROP was determined with the two methods described by Bartoshuk et al. (1994). First filter paper of 1cm diameter, saturated with PROP (0.0032 M) was presented and the subjects rated the perceived bitterness on a 9-point intensity scale. In the second method, the subjects rated randomly presented solutions of PROP and of NaCl on bitterness on 9-point intensity scales. Their PROP-NaCl-ratio was determined by means of the formula (P4/N4 + P5/N5)/2, in which P4 and P5 are the scale responses to 0.001 and 0.0032 M PROP respectively, and N4 and N5 are the scale responses to respectively 0.32 and 1.0 M NaCl. Both tests were conducted in duplo with the same group of 21 young (10 female, 11 male; age 19-33 years of age) and 21 elderly (11 female, 10 male; 60-75 years of age) subjects, whose taste threshold sensitivity (chapter 3) and supra-threshold sensitivity (chapter 6) for 10 tastants had been determined previously (Mojet et al., 2001, 2003). For both methods, the results showed no relationship between PROP-sensitivity and age or gender. Both methods to measure PROP-sensitivity were substantially correlated (R=0.75, p=0.0001). No significant correlations between PROP-sensitivity on the one hand and on the other hand the thresholds, the perceived intensities in water and in product, or the pleasantness in product (chapter 7) were found for either the bitter tastants KCl, caffeine and quinine HCl, or the non-bitter tastants NaCl, sucrose, aspartame, acetic acid, citric acid, MSG and IMP. These results suggest that the mechanisms involved in the perception of PROP and of the other tastants are essentially different.

The subjects in another experiment (the taste-smell experiment in chapter 7) were also tested for PROP-sensitivity. This time, three methods were used. The first method was the old-fashioned method of determining the PROP-NaCl ratio as described above. In the second method the subjects had to rate the perceived bitterness of the highest concentration of PROP (0.0032 M) on the Labelled Magnitude Scale (LMS) (Green et al., 1993) and in the third method the bitterness of the same PROP-concentration was rated on the generalised Labelled Magnitude Scale (gLMS) (Bartoshuk et al., 2001). Unfortunately, the results show no significant correlations between prop-ratio and LMS (R=0.22), between PROP-ratio and gLMS (R=0.17) and between LMS and gLMS (0.08) measurements. Moreover, the elderly and young used qualitatively very different references to compare their taste sensation with, as was shown in their descriptions of their strongest sensation ever experienced (which was often emotionally coloured). This casts some doubt upon the use of the labelled magnitude scales with age groups that differing so much in experiences. More research and perhaps better methods are needed to uncover the influence of the genetic variability in PROP-sensitivity on taste perception.

Stimuli

To be able to investigate the specificity of possible taste losses, ten tastants to represent each of the five taste qualities were used in all experiments. They were either dissolved in distilled water or in variants of commercially available foods. All of the tastants are commonly used in food products. The five product types were not only chosen on the basis of their appropriateness for varying the concentration of their dominant taste quality. They were also chosen for reasons of ‘ecologically validity’. Thus, tomato soup was chosen to vary saltiness with NaCl or with KCl, ice-tea was chosen to vary sweetness with sucrose or with aspartame, mayonnaise was chosen to vary the sourness with acetic acid or with citric acid, chocolate drink to vary the bitterness with caffeine or with quinine HCl, and broth was chosen to vary the umami taste with monosodium glutamate (MSG) or with inosine 5’-monophosphate (IMP). The five increasing concentrations and the preparation of the stimuli are described in detail in chapters 3-6.

Procedures

For practical reasons, the sessions for the elderly and young were conducted separately. The elderly required more time and more elaborate instructions.
The threshold measurements were carried out solely with the ten tastants in water. The measurement method (an ascending method of limits) is described in detail in chapter 3.

The supra-threshold measurements were carried out with the same tastants dissolved in water and in product. The subjects assessed the perceived intensities on 9-point intensity scales while wearing or not wearing a nose clip.

When the tastants were dissolved in product, they rated the intensity of all five taste qualities in the product. Thus, each stimulus was evaluated on saltiness, sweetness, sourness, bitterness and umami taste. Note that in one product type only one taste quality was experimentally varied by an increasing concentration of the dominant taste representative, such as the saltiness in tomato soup (either by NaCl or by KCl). In addition, the subjects also evaluated the pleasantness of the products on 9-point pleasantness scales while wearing a nose clip or not. In order to serve as control stimuli in cross modal intensity matching of the different sensory modalities, five levels of auditory (loudness), visual (size) and kinaesthetic/tactile (weight) stimuli were also presented and assessed. A detailed description of these stimuli will be given in chapter 6. Before the experiment started the subjects were familiarised with these stimuli by presenting the lowest and highest in the range.

The order in which taste qualities were presented differed over the three days, as did the presentation order of the stimuli within each series. In total, each taste stimulus was assessed three times and each cross-modal stimulus was assessed nine times per experiment. Since the major interest was in unconfounded differences between the two age groups, the presentation order of the tastant concentrations and the cross-modal stimuli was the same for all subjects. Possible taste order effects were considered to be strongly reduced by the interspersing of the taste stimuli with the stimuli from the other sensory modalities.

The same tastants and range of concentrations were used in the first experiment described in chapter 7, but now only three out of the five concentrations were used, the lowest, the highest and the middle one. Again, the sip-and-spit method was used and the perceived intensity and pleasantness were rated on appropriate 9-point scales. All samples, including the distilled water samples to rinse the mouth, had to be spit back in their own cup and covered with the attached lid, in order to weigh the saliva production. For the second experiment, in which the stimuli were only smelled in a four-alternatives-forced-choice (4AFC)-difference test, the highest concentration of the ten tastants were dissolved in three different waters.

The detailed procedures and accounts of the ways in which the data of the experiments were analysed in this thesis can be found in chapters 3-7.

Chapter 3

Taste perception with age: Generic or specific losses in threshold sensitivity to the five basic tastes?

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Abstract

Detection thresholds for NaCl, KCl, sucrose, aspartame, acetic acid, citric acid, caffeine, quinine HCl, Mono Sodium Glutamate (MSG) and Inosine 5'-MonoPhosphate (IMP) were assessed in 21 young (19-33) and 21 elderly (60-75) persons by taking the average of six ascending two-alternative forced choice tests. A significant overall effect was found for age, but not for gender. However, an interaction effect of age and gender was found. The older men were less sensitive than the young men and women for acetic acid, sucrose, citric acid, sodium and potassium chloride and IMP. To detect the compound dissolved in water they needed a 1.32 (aspartame) to 5.70 times (IMP) higher concentration than the younger subjects. A significant decline in thresholds with replication was shown. The age effect found could be attributed predominantly to a generic taste loss.

Introduction

The influence of ageing on taste perception has been investigated in a large number of studies. Most of these studies were restricted in either the number of perceptual aspects (thresholds, supra-threshold intensities or preference) or in the number of basic compounds considered. As a result it is difficult to estimate the relative importance and the structural interrelationship of the differences found. The experiment to be reported here is aimed at answering two questions: Whether taste losses with ageing can be found, and if so, whether these taste losses are general, basic-taste specific or compound specific. Furthermore, the influence of gender will be investigated.

For the sake of brevity, throughout the paper the term basic tastes will be used for the taste qualities salty, sweet, sour, bitter and umami, without taking a position in the controversy with regard to the acceptance of umami as a basic taste. Overviews of the results of studies concerning the effects of age on threshold sensitivity have been given by Murphy (1979, 1986) and by Rolls & Drewnowski (1996). An updated overview is given in Table 3.1.

Table 3.1 Threshold studies of basic taste compounds in aqueous solutions, that studied the effect of age on taste perception

Threshold studies aqueous solutions	year	nacl	sucrose sacch	aspart sweeteners	hcl/citr/ acetic	caffein/ quinine	glute-mate	amino acids	ptc/ prop#	age range
Richter, Campbell	1940		⇩							7-85
Harris, Kalmus	1949								⇩	10-91
Bouliere et al	1958	⇩	⇩							na
Cohen, Gitman	1959	O	O		O	O				18-94
Cooper et al	1959	⇩	⇩		⇩	⇩				15-89
Kalmus, Trotter	1962								⇩	na
Glanville et al	1964				⇩	⇩			⇩	(3)16-55
Kaplan et al	1965					O			O	16-55
Hermel et al	1970	O	⇩		⇩	⇩				4-60
Fikentscher et al	1977	⇩	⇩		⇩	⇩				0-70
Murphy	1979	⇩	⇩		⇩	⇩				5-83
Grzegorczyk et al	1979	⇩								23-92
Schiffman et al	1979							⇩		17-87
Hyde, Feller	1981	⇩	O		⇩	⇩				28-75
Dye, Koziatek	1981		⇩							41-88
Schiffman et al	1981			⇩						19-81
Moore et al	1982		⇩							20-88
Weiffenbach et al	1982	⇩	O		O	O				23-88
Bartoshuk et al	1986	⇩	⇩		⇩	⇩			O	20-92
Cowart	1989	⇩	O		O	O				20-87
Whissell-Buechy	1990								⇩	4-78
Schiffman et al	1991						⇩			20-90
Stevens et al	1991	⇩								18-89
Schiffman *	1993	⇩		⇩	⇩	⇩	⇩	⇩	⇩	na
Schiffman et al	1994					O / ⇩			⇩	20-90
Schiffman *	1994	⇩		⇩	⇩	⇩	⇩	⇩	⇩	na
Schiffman *	1994	⇩	O		O	O				na
Stevens et al	1995		⇩							19-87

⇩ significant decrease in sensitivity,

O no change in sensitivity

* review article, describing several experiments

\# ptc: phenylthiocarbamide, prop: 6-n-propylthiouracil

The majority of these studies show decreases in sensitivity with age. The threshold studies directly relevant for comparison with the results to be presented here are described in more detail in Table 3.2. Wherever available, the age range, number of subjects, compounds and methods are given.

Table 3.2 Survey of threshold studies comparable to the present study

Author(s)	year	males	females	gender unspec.	nr of groups	age	compounds	age diff	gender diff	notes	method	reps
Cohen & Gitman	1959	18	27		1	18-39	NaCl, sucrose,	overall p<.07	males	recognition	2 out of 3 responses	1
		30	25		2	40-64	acetic acid, quinine		made more	sour taste most	fixed concentrations	
		144	104		3	65-94	sulphate		mistakes	frequently missed	above threshold	
Cooper et al	1959	80	20	25	1	15-29	NaCl, sucrose,	sweet, salty	no	subjects were	ascending method	3
				16	2	30-44	HCl, quinine sulph.	and bitter		blindfolded		
				23	3	45-59		sharp				
				27	4	60-74		decrease				
				9	5	75-89		after fifties				
Hermel et al	1970			24	1	4-6	NaCl, sucrose,	sweet, sour	n.a.	removal of	step up	1
				26	2	7-11	citric acid, quinine	and bitter		dentures		
				21	3	12-14	sulphate			improved		
				21	4	20-25				taste		
				33	5	48-60				perception		
Fikentscher et al	1977	20	20		1	0-10	cane suger,	sweet, sour,	females		moistened probe	1
		20	20		2	10-20	citric acid, NaCl,	salty and	more			
		20	20		3	20-30	quinine	bitter	sensitive			
		20	20		4	30-40			all tastes			
		20	20		5	40-50			sign. after			
		20	20		6	50-60			age of 40			
		20	20		7	60-70						
Murphy	1979	7	7		1	5.5-6.5	NaCl, sucrose,	overall effect	no sex and		ascending method	1
		7	7		2	11.3-12.5	citric acid, tartaric	of age, age x	no sex inter-		of limits	
		7	7		3	17.8-19.5	acid, HCl, caffeine,	tastant, age x	action effects			
		7	7		4	22.0-23.8	quinine sulphate	sex x tastant				
		7	7		5	28.5-35.0	and magnesium					
		7	7		6	48.1-58.0	sulphate					
		7	7		7	65.7-83.6						
Hyde & Feller	1981	12	12		young	28.1+ 3.4	NaCl, sucrose,	caffeine, citric	no overall	males less	comb. forced choice	3
		12	12		elderly	75.0± 6.0	citric acid, caffeine	acid	gender diff	sensitive to	discrimination and	
										NaCl	intensity scaling meth.	
Schiffman et al	1981		12		young	19-24	11 sweeteners	aspartame,		PTC tasters	noseplugs, f-choice	1
			12		elderly	75-81		monellin a.o.			triangle 3-on-a-row	
											geometric mean	
Weiffenbach et al	1982	16	15		1	< 45	NaCl, sucrose,	NaCl, quinine	males less		2AFC, up-down	1
		10	14		2	46-65	citric acid,	young vs old	sensitive to		round robin fashion	
		16	10		3	>= 66	quinine sulphate		citric acid			
Bartoshuk et al	1986	2	16		young	20-30	NaCl, sucrose,	NaCl, sucrose,		no decrease	up-down 4AFC	1
		2	16		elderly	74-93	citric acid,	citric acid,		in PROP-sens		
							quinine HCl, PROP	quinine		dentures in		
Cowart	1989	56	81		>= 19	20-30	NaCl, sucrose,	NaCl, quinine	males less		FC staircase	1
					>= 19	30-40	citric acid,		sensitive to		round robin fashion	
					>= 19	40-50	quinine sulphate		NaCl and			
					>= 19	50-60			citric acid			
					>= 19	60-70						
					>= 19	>70						
Schiffman et al	1991	6	10		young		MSG, IMP ao	MSG, IMP ao	n.a.		forced choice	1
		1	17		elderly						triangle 3-on-a-row	
											geometric mean	
Stevens et al	1991	6	15		young	18-30	NaCl	elderly less	n.a.		transformed up-down	1
		7	13		middle	35-56		sensitive than			one incorrect - up	
		5	15		elderly	67-89		young			two correct - down	

The studies mentioned in Table 3.2 differ on a number of important aspects, such as number and variety of tastants, age groups involved, health and gender of subjects, methods, and number of replications. In the following these aspects will be briefly discussed to explain the choices made in the present study.
All authors, shown in Table 3.2 used one or more of the same taste compounds as in the present study. Some used compounds for four taste qualities, but none used several compounds for each taste quality in a single experiment to study the compound specificity and basic-taste specificity of taste losses in the same subjects with no illnesses and not taking medication. In this respect the present study is more complete, even through in contrast to several of the studies mentioned above, only two age groups were used. For the young, the chosen age group of 19 to 33 is in line with the other studies. For the elderly, the age group of 60 to 75 was chosen because it is generally assumed that at sixty a decline in sensitivity occurs, and that at seventy-five the probability of major cognitive impairment is still relatively low (Schaie, 1996; La Rue, 1992). Cooper et al. (1959) found, for instance, that taste sensitivity remains unimpaired until the late fifties, after which it shows a sharp decline. This finding might be influenced by an increase in drug consumption of people with age. In the USA, the mean number of medications used by community-dwelling elderly over the age of 65 ranges from 2.9 to 3.7 medications (Schiffman et al., 1997). Dutch people of 65 years and over consume 2.9 times the amount of drugs than the average Dutch person. This ratio even rises to 4 times for people over the age of 75 (van der Heide, 1999). Over 250 commonly used drugs have been reported clinically to affect the sense of taste. This fact has not been taken into account in most studies mentioned in table 2. However, Hyde & Feller (1981) used subjects, not taking any taste-effecting medication. Murphy (1979), Schiffman et al. (1981,1991), Cowart (1989), and Stevens et al. (1991, 1995) reported that their subjects were healthy and did not indicate having any problem with their sense of taste, but the authors did not ask about medication. In elderly free of illnesses and medication, Schiffman (1994), referring to unpublished data, found only a slight trend toward elevated thresholds with age. The decrease in sensitivity only reached statistical significance for NaCl. If,

however, healthy as well as elderly persons who had some illness and were taking medication, were included (Schiffman, 1993, 1994), significant taste losses with age were found for many tastants. No other authors screened for health or drug use. In order to assure that eventual taste losses are exclusively age related and not complicated by illness or medication we decided to use only healthy subjects.

Gender differences have been reported by several authors. Cohen & Gitman (1959) found that men had a higher incidence of taste errors than women when they had to recognise the basic tastes of sour, sweet, salty and bitter. Glanville et al. (1964), using subjects from 3 to 55 years, found that both males and females showed a gradual increase in sensitivity up to the age of 16-20 years, followed by an exponential decline. Sensitivities to 6-n-propylthiouracil (PROP) and quinine were similar in the two sexes up to the age of 16-20, but from this age onward men declined at a faster rate than women. For HCl, females were more sensitive tasters from early childhood till adolescence, where almost equal maximum sensitivity for both women and men was reached. After this, sensitivity to HCl also decreased more rapidly for men than for women. Weiffenbach et al. (1982) found that within each age group the thresholds of men were higher than those of women. Other authors did not find gender differences, whereas some authors did not look for this (see Table 3.2) .

The methods vary widely among the previous studies in: procedures to determine thresholds, concentration ranges, amount of solution to be tasted, instructions, and experience of subjects with the experimental procedure. While some authors used a two alternative forced choice (2AFC) method (Weiffenbach et al., 1982; Cowart, 1989; Stevens et al., 1991), others used a 4AFC method (Bartoshuk et al., 1986), a triangle method (Schiffman et al., 1981) or a one alternative recognition task (Cohen and Gitman, 1959). Some authors used only four fixed concentrations (Hermel et al., 1970; Fikentscher et al., 1977), others used a range not broad enough to fit all subjects in (Grzegorczyk et al., 1979). While in most studies around 10 ml solution was presented to be swirled around in the mouth so as to contact all taste buds, and then to expectorated, Cohen & Gitman (1959) and Fikentscher et al. (1977)

used moistened probes to wipe across different areas of the tongue. Hermel et al. (1970) used drops of 0.1 ml solution and Grzegorczyk et al. (1979) stressed the importance of instructing subjects to rinse the mouth between stimuli. Many elderly people have increased salivary sodium concentrations (Grad, 1954) and may demonstrate higher thresholds due to salivary composition rather than a deficiency in the sensory apparatus. An effect of practice with repeated measurements has been found in several studies for olfactory stimuli (Engen, 1960; Cain & Gent, 1991).

These factors might well have influenced the absolute thresholds found per age group. The method of repeated threshold measures used in the present study has been recommended by Stevens and Dadarwala (1993) and Stevens et al. (1995) who showed that the variability in thresholds for age groups narrows markedly as the number of tests averaged increases from one up to four or six. They have also argued that a more reliable picture of a subject’s sensitivity can be obtained from several short sets of trials separated by brief rest intervals than from an equal number of trials unbroken by rests. In the present study these recommendations are followed by using six sessions. This has the added advantage that for taste stimuli a learning effect of practice, similar to the one described by Engen (1960), Rabin & Cain (1986), and Cain & Gent (1991) for olfactory stimuli can be investigated in different age groups.

Materials and methods

Subjects

Twenty-one older subjects (age 60-75, 10 male, M=66.0, SD=3.6, and 11 female, M=64.6, SD=4.2) and twenty-two young subjects (age 19-33, 11 male, M=26.5, SD=3.6, and 11 female, M=23.2, SD=3.3) participated in the experiment. All subjects were Caucasian and met the following criteria: healthy, not on a diet, not living in a home for the elderly, not taking any prescribed medicine, non-smoking, not heavy alcohol users, non-pregnant or lactating, not subject to food allergies, good dental hygiene, not wearing dentures (as it was difficult to recruit enough elderly persons without dentures, subjects with partial dentures were admitted, but they were not allowed to wear these during testing); and within the normal range at hearing sounds of 750 Hz in view of the use of hearing as a matching modality for taste in later experiments. Furthermore, a rough estimation of the individual threshold for all substances used in the experiment was obtained by a paired comparison test in which 7 concentrations (a range based on the literature, with a 0.4 log step increase) of the tastants in water were compared with blanks in an ascending staircase procedure. The subjects had to identify the solution containing the tastant and to indicate how certain they were of their choice. This pre-test enabled us to use individually tailored ranges of stimuli in the main threshold experiment, which were embedded in the total range of stimuli. Subjects were selected on a volunteer basis in response to advertisements in local newspapers and on bulletin boards in senior citizen centres. At the end of the full experiment the subjects were paid a fee for participation.

Stimuli

Stimuli representing the four classical basic tastes - saltiness, sweetness, sourness, and bitterness - as well as umami were included. For each taste two representative compounds were chosen. For each compound 14 concentrations were prepared in successive 0.2 log dilutions with distilled water. The total range of concentrations was chosen on the basis of threshold values reported in the literature (Schiffman et al., 1981; Schiffman, 1993; Cowart, 1989; Stevens et al., 1991; Bartoshuk et al., 1986; Weiffenbach et al., 1982) and were adjusted after the first measurements [After the two threshold measurements on the first day of the experiment all ranges were adjusted since some individuals occasionally detected the lowest concentration of different compounds (especially of citric acid and quinine), and the highest concentration of one compound (IMP) was not detected once by one of the older subjects]. This resulted in the following ranges of tastants in water in g/l. Saltiness: sodium chloride 1.11×10^{-2}- 6.98 and potassium chloride 2.23×10^{-2}- 8.90; sweetness: sucrose 4.09×10^{-1}- 1.63×10^{2} and aspartame 0.82×10^{-3}- 3.27×10^{-1}; sourness: acetic acid 0.60×10^{-3}- 2.39×10^{-1} and citric acid 5.28×10^{-3}- 2.10; bitterness: caffeine 7.73×10^{-3}- 3.08 and quinine hydrochloride $2.49x10^{-4}$- $0.99x10^{-1}$; umami: mono-sodium-glutamate (MSG) $7.45x10^{-3}$- 2.97 and inosine-5'-mono-phosphate (IMP) $9.85x10^{-2}$- $3.92x10^{1}$. The solutions were stored and tested at room temperature and never kept longer than 2 days.

Procedure

The subjects took part in 6 testing sessions held on 6 different days, 3 days in a row per week. The compounds were divided in two sets of 5 basic tastes each. One set contained NaCl, sucrose, acetic acid, caffeine and MSG, the other set consisted of KCl, aspartame, citric acid, quinine HCl and IMP. Per day one set was presented in a fixed order as described above, with a short break between two tastants. Thresholds for MSG and IMP were determined last because from industrial experience we have found that the affinity of MSG and IMP for taste receptors may cause spuriously high perceived intensities of some of the other compounds when they are to be tasted after the umami tastants. A second series followed after a 10-min break. Over successive days the two sets were alternated. The sessions were split for the elderly and the young for practical reasons: more time and a more elaborated instruction was required for the elderly.

The procedure entailed a two-alternative forced choice, with concentrations presented in ascending order, the so-called 2AFC-5-in-a-row method used by Stevens & Cain (1987) and based on the method developed by Wetherill and Levitt (1965). On each trial, a participant received two 30 ml disposable plastic cups, one with 10 ml taste solution and one with 10 ml distilled water. The two cups were placed side by side in front of the subject in a left-right position randomly chosen from trial to trial. The sip-and-spit method was used. At the start of the session and before each trial the subject rinsed with distilled water and expectorated. The samples, both blanks and taste solutions, were swirled around in the mouth briefly and expectorated. After indicating which cup contained the tastant, the participant received another pair. The subjects were instructed to eat a piece of cream cracker after rating the last pair of a tastant. To prevent excessive fatigue, testing began at a concentration level 2 steps below the individual threshold concentration level that had been determined in the screening procedure. Whenever the subject selected incorrectly, the next trial took place at the next higher step. When the subject selected correctly, the same concentration was presented again. Testing ceased after five correct answers in a row. However, if the first five trials were correct right away, they were followed by the next lower concentration. The geometric mean of the last and the second last concentration was calculated and taken as the individual threshold.

Statistical Analysis

Methods

Statistical analyses were conducted using SAS® and SAS/STAT®. Multivariate analysis of variance (MANOVA) was applied with age and gender as between subject factors, and basic taste, compound, and replication as within subject factors, in order to investigate the main and interaction effects of age, gender, basic taste, compound and replication. The same error was used to test the effects of the mean, age, gender and age by gender per multivariate response (e.g. compound). Repeated measures analyses of variance were applied multivariately with replication and compound, and with replication, basic taste, and compound within basic taste, as factors. Data were averaged over replications for pairwise comparisons of the older men, older women, young men and young women using the Least squares means method . Principal component analysis (PCA) (Jollife, 1986) was conducted to determine interrelationships between taste sensitivities. Separation of variances into variance components (see Results, section on 'General or specific losses') was done using Proc Varcomp of SAS/STAT.

Levels of significance

We report all effects that have a *P*-value of 0.05 or lower as 'significant'. Power Analysis shows that, with the number of subjects in our study, an effect with a magnitude of 1.3 standard deviations and a *P*-value of 0.10 still has a power of

0.90. Therefore we additionally report a selection of the more interesting effects with a *P*-value between 0.05 and 0.10. These effects will be denoted as 'trends' or 'tendencies'.

Results

Overall effects

A significant decline in thresholds with replication [$F(5,34)=7.52$ / P <.0001], indicating an effect of practice, was found. The MANOVA revealed a significant overall effect for age [$F(1,38)=10.32$ / P <.003], but not for gender, nor for the interaction age by gender. However, comparison of group means (LSMeans) taken over the six replications showed that the older men deviated from the other groups. In general, the older men were less sensitive than the young (P < .001) and tended to be slightly less sensitive than the older women (P < .07). Table 3.3 gives an overview of the mean thresholds.

Table 3.3 Mean thresholds in 0.2 log concentration steps and in g/l and standard deviations *(sd)* per age x gender group; male elderly (ME), female elderly (FE), male young (MY), and female young (FY)

compounds		ME	FE	MY	FY		ME	FE	MY	FY
	mol weight	mean conc.step	mean conc.step	mean conc.step	mean conc.step	conc.1 g/litre	mean g/litre	mean g/litre	mean g/litre	mean g/litre
NaCl	58.44	9.40	8.11	7.14	7.40	0.01106	0.83915	0.46327	0.29636	0.33407
		(2.32)	*(2.63)*	*(2.52)*	*(1.72)*					
KCl	74.55	8.78	7.64	5.94	6.12	0.02234	1.27392	0.75360	0.34446	0.37423
		(2.91)	*(2.74)*	*(2.15)*	*(2.45)*					
Sucrose	342.30	6.50	5.24	5.53	4.90	0.40882	8.15709	4.56599	5.21838	3.90423
		(2.19)	*(1.33)*	*(1.57)*	*(1.56)*					
Aspartame	294.31	7.53	6.88	6.83	7.03	0.00082	0.02629	0.01949	0.01904	0.02088
		(2.57)	*(1.83)*	*(2.22)*	*(1.83)*					
Acetic acid	60.05	8.40	6.94	7.77	6.77	0.00060	0.02872	0.01466	0.02149	0.01356
		(2.95)	*(2.54)*	*(2.52)*	*(2.20)*					
Citric acid	210.15	5.13	4.24	3.80	3.63	0.00527	0.05605	0.03720	0.03038	0.02809
		(2.61)	*(1.87)*	*(1.67)*	*(1.30)*					
Caffeine	194.19	8.48	7.61	7.39	6.70	0.00773	0.38392	0.25718	0.23239	0.16914
		(3.07)	*(1.80)*	*(2.49)*	*(2.22)*					
Quinine HCl	396.92	6.83	6.23	5.54	5.27	0.00025	0.00581	0.00440	0.00320	0.00283
		(3.13)	*(2.24)*	*(2.83)*	*(1.88)*					
MSG	187.13	9.03	8.68	7.53	8.05	0.00745	0.47660	0.40565	0.23887	0.30349
		(3.27)	*(2.45)*	*(2.81)*	*(2.43)*					
IMP	392.17	8.03	6.41	3.58	4.93	0.09851	3.97627	1.88572	0.51224	0.95384
		(3.59)	*(3.17)*	*(1.93)*	*(2.19)*					

Compounds

Age effects were not equal for all compounds [$F(9,30)=3.15$ / $P<.01$]. A more detailed analysis of the effects, specified for compounds, showed significant age effects {with all F's (1,38)} for NaCl [F=8.17 / $P<.007$], KCl [F=13.70 / $P<.001$], citric acid [F=5.49 / $P<.03$], and IMP [F=23.78 / $P<.0001$]. Only trend effects of age were found for sucrose [F=2.89 / $P<.10$] and caffeine [F=3.20 / $P<.10$], whereas sucrose elicited a gender effect [$F(1,38)=5.99$ / $P<.05$] and acetic acid showed a trend effect of age [$F(1,38)=4.04$ / $P<.10$]. Women tended to have lower thresholds for sucrose and acetic acid than men.

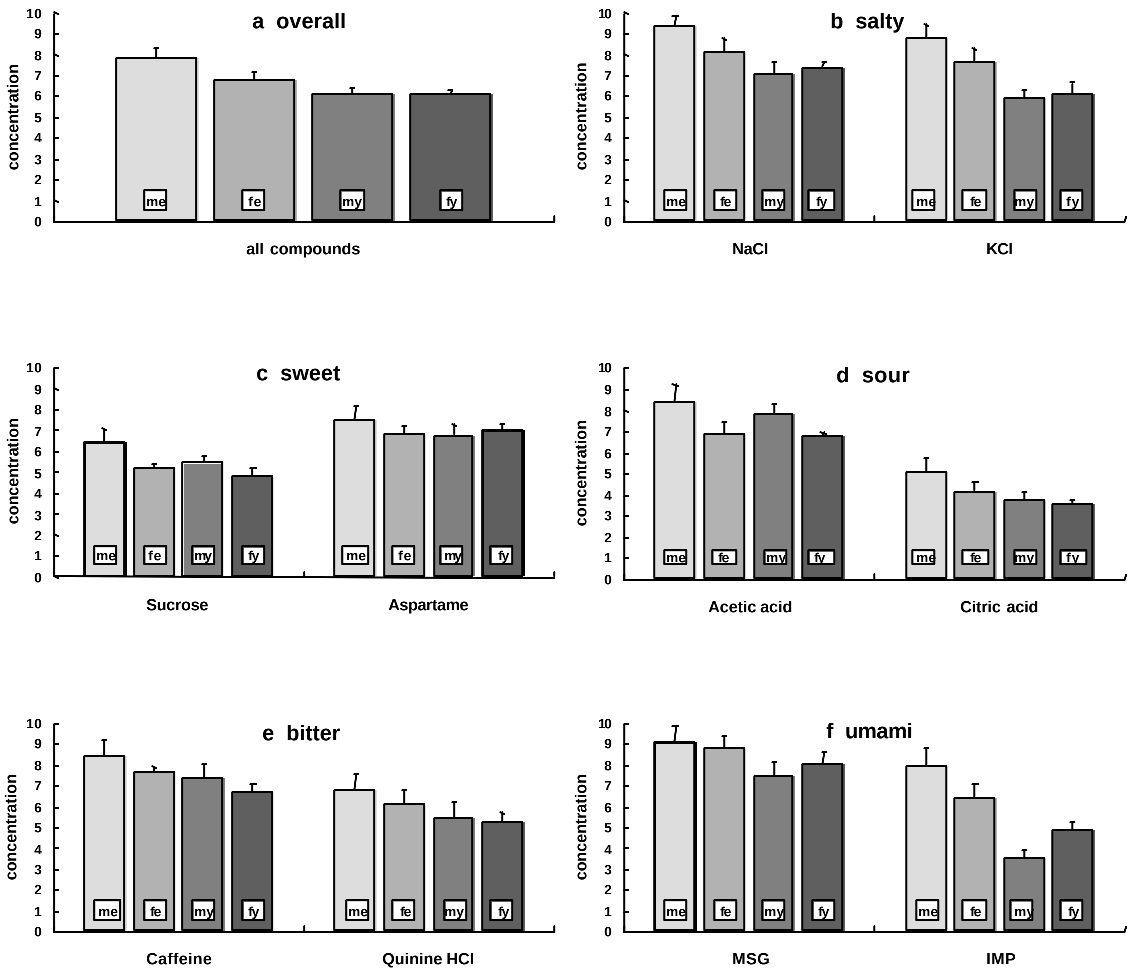

Figure 3.1 Thresholds of elderly male (me), elderly female (fe), young male (my) and female young (fy) subjects for ten compounds representing five basic tastes. Values are mean thresholds ± SEM and they are given in 0.2 log concentration steps.

Besides the age effect for IMP there was also an age by gender interaction effect [$F(1,38)=6.01$ / $P<.02$]. A comparison of group means taken over the six replications showed that the older men had significantly higher thresholds than the young women for six compounds; NaCl (p=.01), KCl (p=.003), sucrose (p=.01), citric acid (p=.02), caffeine (p=.03), and IMP (p=.001). In four of the ten cases they also had higher thresholds than the young men; NaCl (p=.004), KCl (p=.002), citric acid (p=.03), and IMP (p=.001). For sucrose (p=.03), the older men had higher thresholds than the older women, whereas for NaCl (p=.08), acetic acid (p=.10), and IMP (p=.07) the older men seemed to show a deterioration in taste compared to the older women. The older women seemed to have higher thresholds than young women for the compounds KCl (p=.08) and IMP (p=.09), and significantly higher thresholds than the young men for IMP (p=.002) (Figure 3.1).

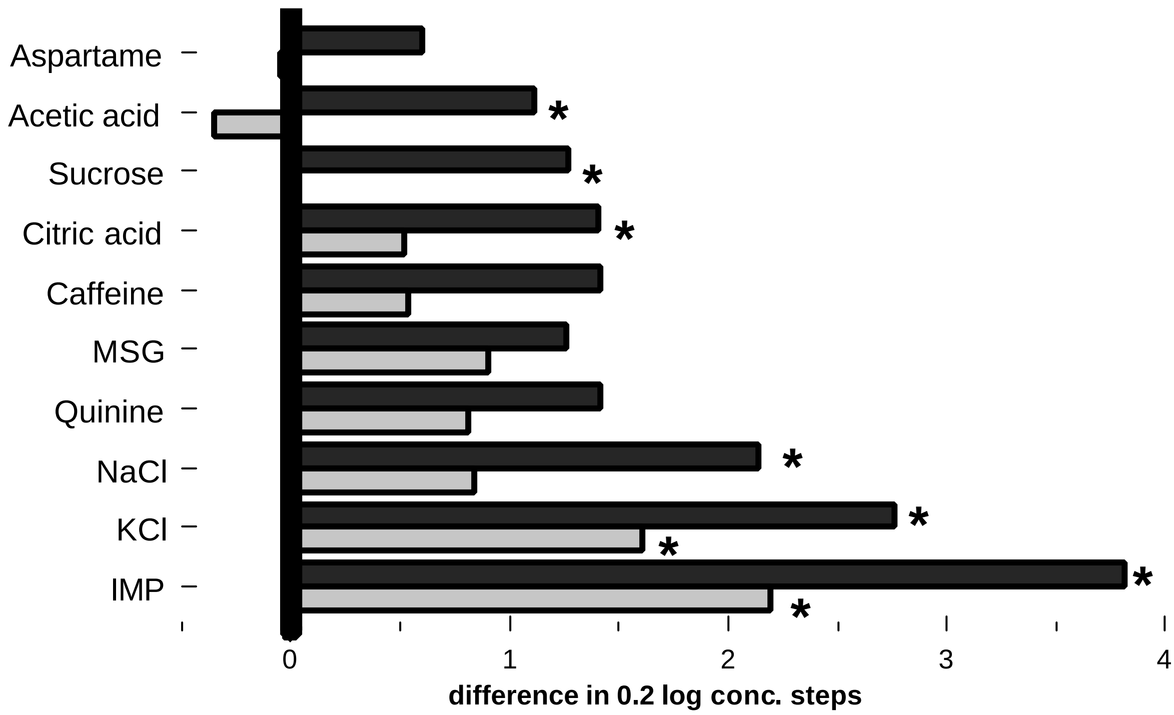

Figure 3.2 Differences in threshold between elderly male or female subjects and young persons for ten taste compounds. The vertical axis represents the mean threshold of the young subjects. Stars indicate a significant difference (P <0.05) between the mean thresholds of the elderly male or elderly female and the means of the young males and females taken together. A 0.2 log step represents a multiplication of the concentration by 1.58.

Since the young men and women did not differ significantly in thresholds, their average thresholds were taken for comparison with the results of the elderly men and women. The older men were less sensitive than this average of young men and women for acetic acid, sucrose, citric acid, sodium and potassium chloride and IMP. To detect the tastant dissolved in water they needed a 1.32 (aspartame) to 5.70 times (IMP) higher concentration than the young (Fig. 3.2).

Compounds within basic tastes

When the two compounds within the basic tastes were compared, significant differences in thresholds were found, as was to be expected, since the concentration ranges were not matched for perceived intensity. An age by compound within-basic-taste interaction effect was found for the umami taste where the difference between the elderly and the young was much larger for IMP than for MSG [$F(1,38)=9.74$ / $P<.005$]. Furthermore, it could be shown that within each of the basic tastes the sensitivity for the compound with the higher molecular weight decreased most with age.

Basic tastes

Age effects were not equal for every basic taste [$F(4,35=5.19$ / $P<.01$]. Pairs of basic taste compounds were used as contrasts in the MANOVA. The age effects were of similar magnitude for the salty, bitter and umami tastants on the one hand, and the sweet, sour and bitter tastants on the other hand. There was a larger difference between the elderly and the young for the salty than for the sweet basic tastants [$F(1,38)=9.29$ / $P<.005$] and the sour tastants [$F(1,38)=5.44$ / $P<.05$]. A larger age difference was also found for the umami than for the sweet [$F(1,38)=14.52$ / $P<.001$] and the sour tastants [$F(1,38)=6.59$ / $P<.05$]. No gender or age by gender interaction effect on the differences was found.

Cumulative threshold curves

Inspection of the group threshold curves for young and elderly people, averaged over replications, indicated four types of differences between these curves.

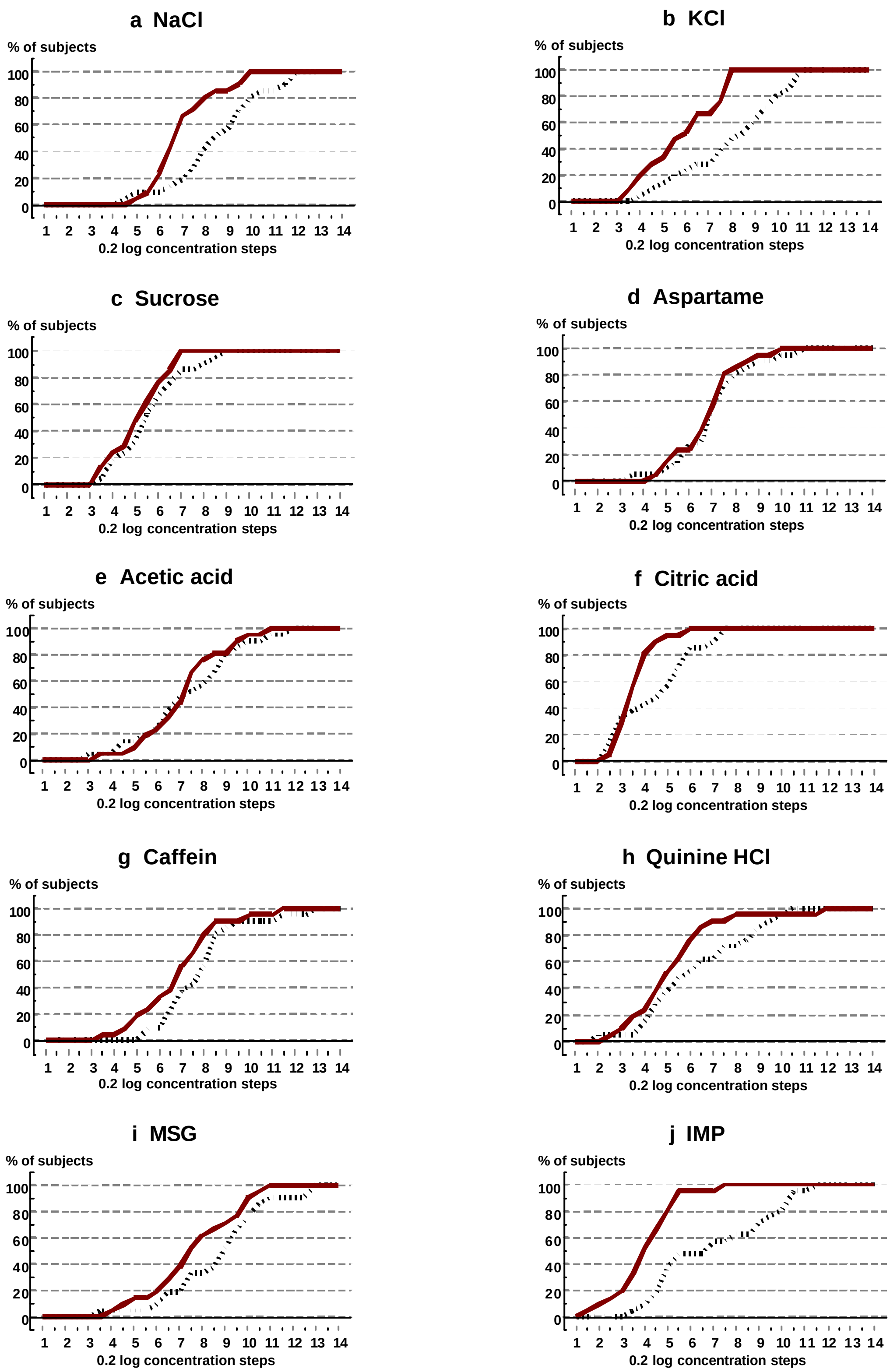

Figure 3.3 Cumulative threshold curves of 21 elderly and 21 young subjects for ten taste compounds. Straight lines represent the young and dotted lines represent the elderly subjects.

The first type, observed for aspartame, acetic acid, and perhaps sucrose, shows hardly any difference between the young and the elderly: The onset and the completion of the curve are located at about the same concentration, and the slope is similar in steepness (Figure 3.3d, e, c), indicating that the young and elderly did not differ in mean thresholds and standard deviations. In the second type, observed for citric acid, sodium and potassium chloride, the onset of the curve is at the same concentration for the young and the elderly, but the curve is completed at a higher concentration in the elderly (Figure 3.3f, a, b). Thus, the slope of the curve is less steep for the elderly, indicating that the mean thresholds were higher and the standard deviations larger for the elderly than for the young. The third type, observed for caffeine and MSG, shows the onset and completion of the curve both at a higher concentration for the elderly than for the young, while the slope for the elderly and young is similar (Figure 3.3g, i). The last type of curve, obtained for quinine and IMP, also shows a later onset and completion, but in the case of the elderly the slopes are flatter, indicating that the mean thresholds for these compounds were higher and the standard deviations larger (Figure 3.3h, j).
In no cases was the onset and/or completion at lower concentrations or the slope steeper for the elderly than for the young.

Overall learning effect

MANOVA revealed that the overall effect of replication was due to a linear learning effect [$F(1,38)=38.69$ / $P<.0001$]. There was no significant age or gender effect, but there was a significant interaction effect of age by gender [$F(1,38)=5.32$ / $P<.05$]. Taken over all compounds the thresholds for the older men did not decrease significantly, whereas the decline in threshold curve was most pronounced for the young men and the thresholds for the women showed an intermediate decline (Figure 3.4a).

Learning effect per compound

Specified for the different compounds MANOVA showed a significant linear learning effect with $F(1,38)$ for NaCl [$F=4.80$ / $P<.05$], sucrose [$F=4.14$ / P

<.05], aspartame [F=6.01 / *P* <.05], acetic acid [F=18.61 / *P* <.0001], citric acid [F=41.31 / *P* <.0001], caffeine [F=8.25 / *P* <.01], and MSG [F=4.18 / *P* <.05], whereas a trend effect could be seen for KCl [F=3.33 / *P* <.10]. No significant age by linear learning interaction effect was found, although a trend could be noticed for NaCl [F=3.91 / *P* <.10].

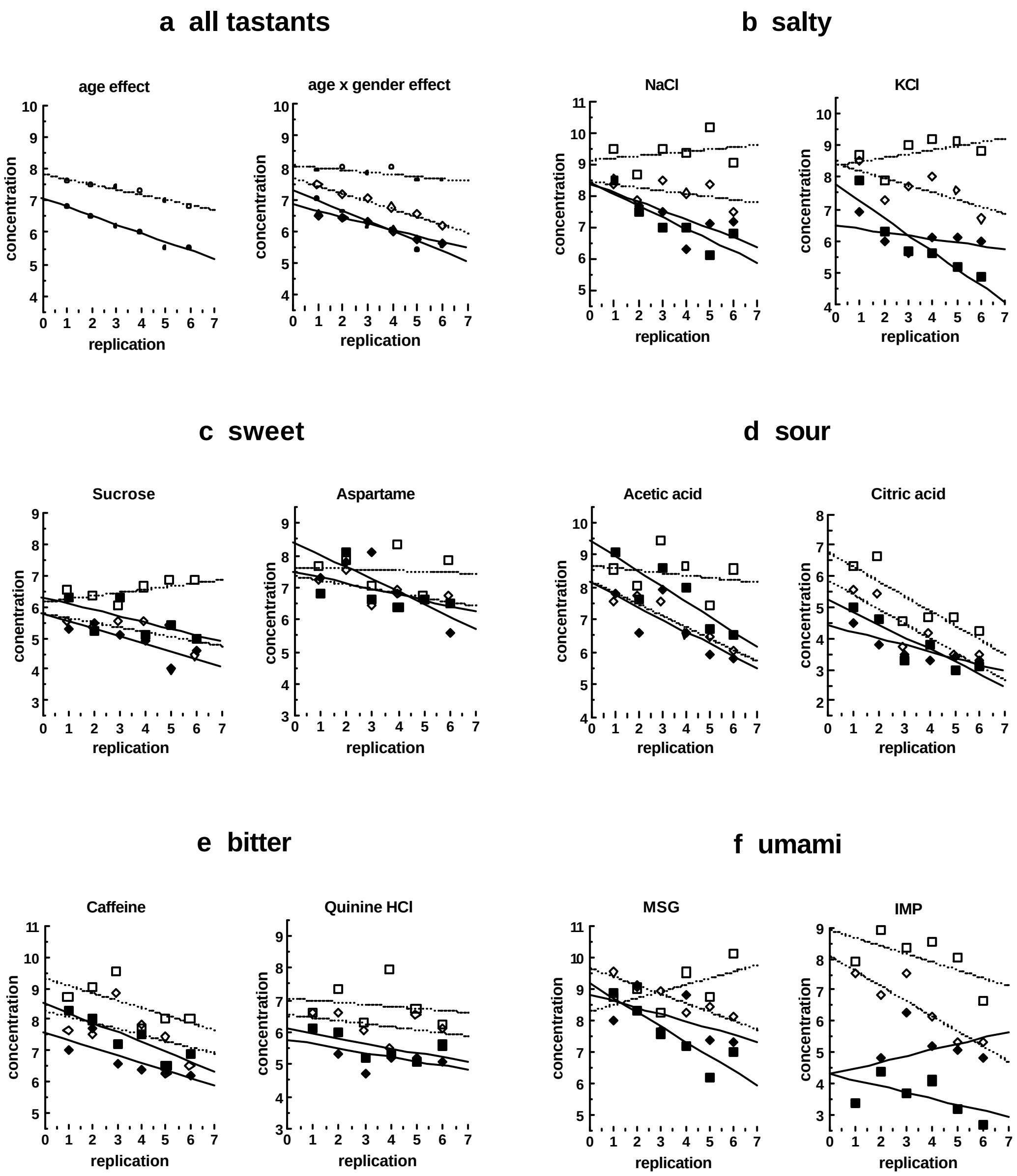

Figure 3.4 Repeated threshold measurements for ten taste compounds in young and elderly male and female subjects. Thresholds are given in 0.2 log concentration steps. The young subjects are represented by straight lines and filled marks, the elderly by dotted lines and empty marks. The male subjects are represented by square marks and the female subjects by diamonds.

For sodium chloride the older men seemed to differ from the other subgroups. They did not learn to detect sodium chloride at a lower concentration.

In general, the performance of men and women did not differ with practice, but a significant interaction effect of age by gender by replication was found for MSG [F=4.12 / *P* <.05], and a trend for KCl [F=3.66 / *P* <.10]. In both cases the thresholds of the older men increased while the thresholds of the young men decreased most strongly over sessions.

Although no quadratic learning effect was found when the thresholds for the compounds were pooled, such an effect was observed for citric acid [*F(*1,38)=10.03 / *P* <.005] and IMP [*F(*1,38)=9.15 / *P* <.005] when analysed separately. A tendency towards an age by quadratic learning interaction effect was found for NaCl [*F(*1,38)=2.84 / *P* <.10] and for aspartame [*F(*1,38)=3.31 / *P* <.10] (see Figure 3.4b-f).

Differences in compound learning within the basic tastes

Within the basic tastes the linear learning effect was not different for the two compounds. An age by compound (within basic taste) by replication effect was observed with the sour tastants [*F(*1,38)=4.37 / *P* <.05], where the elderly showed a flatter slope in the learning curve for acetic acid than for citric acid, while the slopes of the young were identical. This flatter slope was caused predominantly by the elderly men, who, over sessions, did not learn to detect acetic acid at a lower concentration, as did the other subgroups. But the elderly men did learn at the same rate as the others when citric acid was the tastant. The umami taste also showed an age by replication by compound (within basic taste) effect [*F(*1,38)=4.96 / *P* <.05]. The slope for the elderly was more or less flat for MSG, while the slope for IMP was flat for the young. For MSG the thresholds of the young and for IMP the thresholds of the elderly decreased over sessions. Figure 3.4f shows that this contrast was caused by the different behaviour of the elderly men in the case of MSG and by the young women in the case of IMP. The large difference in initial thresholds for IMP between the elderly and the young largely disappeared over replications due to the results of the women. For IMP the difference between the older and the young men remained constant, but the older women showed considerable learning, whereas the young women seemed to become less sensitive to IMP over time.

Differences in learning between basic tastes

No significant difference in overall linear learning effect was observed between the salty, sweet, bitter and umami tastes, although the learning effect for the sour taste was stronger than that for the other basic tastes (all p's <.05).

General or specific losses

The total variance due to age could be separated into the following variance components: age 93%, age x basic taste 4%, age x compound (basic taste) 1%, and error 2%. This shows that the age effects found can be attributed predominantly to a generic taste loss.

Relationships between the sensitivities to different tastants

Table 3.4 shows that the sensitivities to the tastants were more strongly interrelated for the elderly than for the young. For the elderly, almost all sensitivities to tastants were correlated, but no significant correlation was found between the sensitivity to sucrose on the one hand, and to that of sour and bitter tastants on the other. Sensitivity to KCl was not correlated with that of either acid while sensitivity to NaCl was. The sensitivities to aspartame, MSG and IMP were correlated with those to all other tastants. Remarkably, for the young no correlation was found between the sensitivity to IMP and any other tastant, and the sensitivity to NaCl was only significantly correlated with that to acetic acid.

Biplots are used in Figure 3.5 to demonstrate the main information in the data. The sensitivities to the tastants are represented on the map by vectors running from the centre. The relationship between the sensitivities to the tastants is expressed by the angle they form at the origin. The smaller the angle the higher the correlation. Sensitivities to tastants running in opposite directions had a high negative correlation. The length of a vector is proportional to the standard deviation of the threshold scores for that particular tastant.

Table 3.4 Correlation coefficients between sensitivities for the ten basic taste compounds for elderly and young people

elderly	NaCl	KCl	Sucr	Aspa	Acet	Citr	Caff	Quin	MSG
KCl	0.45 ***							intercorr.=	0.32
Sucrose	0.40 **	0.41 ***							
Aspartame	0.27 *	0.35 ***	0.30 **						
Acetic acid	0.33 **	0.23	0.15	0.39 ***					
Citric acid	0.26 *	0.12	0.18	0.29 *	0.42 ***				
Caffeine	0.15	0.18	0.06	0.28 *	0.42 ***	0.45 ***			
Quinine	0.10	0.31 **	0.19	0.25 *	0.35 ***	0.38 ***	0.39 ***		
MSG	0.25 *	0.27 *	0.30 **	0.44 ***	0.54 ***	0.42 ***	0.39 ***	0.26 *	
IMP	0.54 ***	0.38 ***	0.41 ***	0.29 **	0.36 ***	0.36 ***	0.27 *	0.23 *	0.41 ***
young	NaCl	KCl	Sucr	Aspa	Acet	Citr	Caff	Quin	MSG
KCl	0.15							intercorr.=	0.18
Sucrose	0.16	0.19							
Aspartame	0.14	0.14	0.33 **						
Acetic acid	0.26 *	0.20	0.15	0.17					
Citric acid	0.21	0.31 **	0.09	0.06	0.29 *				
Caffeine	0.16	0.17	0.33 **	0.30 **	0.20	0.23 *			
Quinine	0.15	0.23 *	0.27 *	0.23 *	0.16	0.15	0.36 ***		
MSG	0.19	0.08	0.34 ***	0.37 ***	0.02	-0.03	0.37 ***	0.36 ***	
IMP	-0.02	0.13	0.09	0.11	-0.03	0.03	-0.15	0.34	0.07

* $p<=0.01$ ** $p<=0.001$ *** $p<= 0.0001$

The perpendicular projection of a subject point on a particular vector represents the threshold score of that subject for the corresponding tastant. A point on the vector far from the origin indicates a high threshold score, meaning that that person was relative insensitive to the particular tastant; a point far from the origin in the opposite direction on the extended vector indicates a low threshold score, meaning that that person was relatively sensitive to that tastant. The dimensions in a biplot are arranged in order of amount of explained variance. Note that the primary axes have no meaning of their own, but that they derive their meaning from the major discriminating tastant sensitivities that are highly correlated with them. The co-ordinates for the origin are calculated by taking a mean threshold score across all subjects for each individual tastant. This means that in order to find a subject at the origin he or she would need to have the overall mean threshold scores for each of the tastants. In a sense, he or she would be a person of “average” sensitivity.

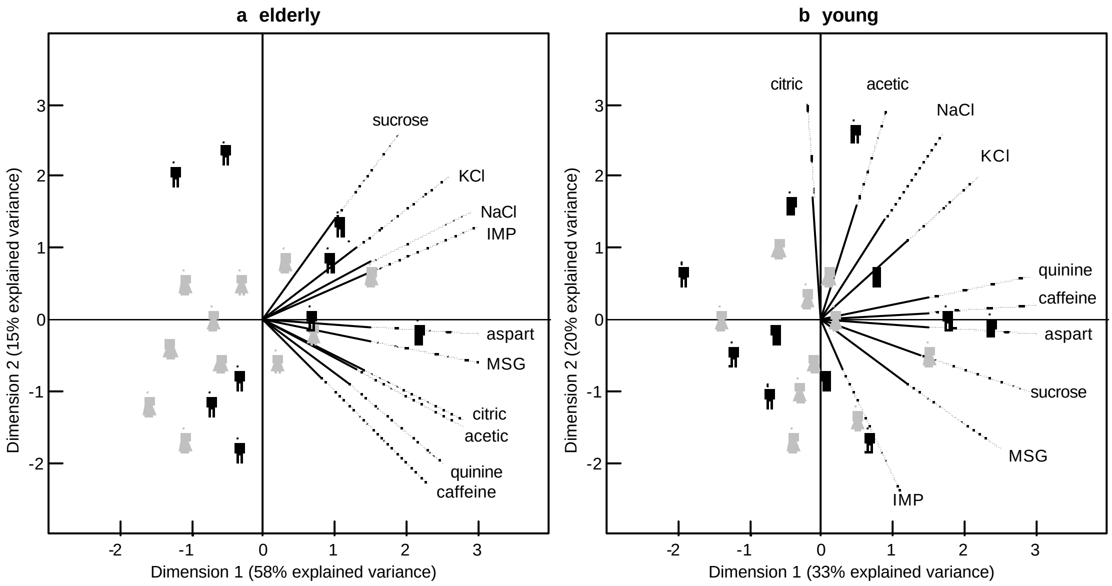

Figure 3.5 Biplots of the threshold means for ten taste compounds by the elderly (a) and the young (b) subjects.

For the elderly only two dimensions were needed to explain 73% of the variance in the threshold data, whereas for the young four dimensions were needed to explain almost the same amount of variance and their compound vectors were more spread over and within the dimensions, meaning that specificity in taste perception was greater in the young than in the elderly. There were also differences in the groupings of the taste sensitivities between the age groups. Taste sensitivities of the elderly were clustered in two groups: sucrose-KCl-NaCl-IMP and aspartame-MSG-citric acid-acetic acid-quinine-caffeine, each with highly correlated tastants, meaning that when an older person had a high threshold for one of these tastants, he or she had high thresholds for the other tastants as well. Only 53% of the variance in the threshold scores of the young were displayed by the first two dimensions. Citric acid, acetic acid and NaCl formed one cluster, while quinine, caffeine, aspartame, sucrose and MSG formed another cluster. The third and fourth dimension, taken together, explained another 24% of the variance for the young subjects. The sensitivity to IMP lay in the third dimension, while that to KCl lay predominantly in the fourth dimension. Thus, not only is there a general loss in sensitivity with age, but this loss also expresses itself in a diminished specificity of the taste sensitivity.

Discussion

Although the results of this study confirm the findings of other authors with regard to a general decrease in taste acuity in the elderly (Cooper et al., 1959; Fikentscher et al., 1977; Murphy, 1979; Bartoshuk et al., 1986), they contain additional information on a number of points which are still under discussion. Of the variance attributable to age and its interactions, age appeared to be accountable for 93%, basic taste qualities for 4%, and compounds for 1%. Thus, it becomes clear that the decrease in sensitivity with age found here was is generic in nature, even though the extent of the decrease differed for the basic taste qualities and, to a lesser degree, for the compounds within a basic taste. The salty and umami taste qualities seemed to be affected most (Figure 2). The findings in our study are not in accordance with the findings of Cohen & Gitman (1959) and Hermel et al. (1970) on the acuity for sweet, salty, sour and bitter tasting compounds. Cohen et al. reported no significant general decrement in taste recognition, but their data seem to indicate a significant loss of sensitivity for NaCl between age group 1 (18-39) and age group 2 (40-64). Hermel et al., who used subjects aged 3 to 60 years, found a decrease in taste acuity with age for sucrose, citric acid and quinine sulphate. However, they did not find a difference in level of sensitivity to salt, but since the presentation of their data on salt contains an obvious error (the percentages of adult subjects recognising salty taste do not add up to 100, p.41), no conclusion can be drawn on the veracity of their results. In agreement with our findings, a decline in sensitivity with age for NaCl has been found in all the other studies in which salty taste was investigated.

Unlike Schiffman et al. (1981), no significant decrease in sensitivity with age for aspartame was found (Figure 2). For quinine HCl we did not find a significant decrease either, as opposed to Bartoshuk et al. (1986), who also used quinine HCl, and unlike Hermel et al. (1970), Weiffenbach et al. (1982), Cowart (1989), and Cooper et al. (1959), who all used quinine sulphate in their studies. The fact that our elderly subjects proved to be more PROP-sensitive than our young subjects might explain the difference between our results and the general pattern.

Sensitivity for umami taste has been reported by Schiffman et al. (1991). Although they found only a trend effect of age for MSG (p=0.10) and IMP (p=0.11), the threshold ratios elderly/young in their data were 3.14 for MSG and 4.63 for IMP, respectively. In the present study the elderly/young ratio of 1.64 for MSG was much smaller. The difference with the young is somewhat more marked (ratio 1.77) for the elderly men. For IMP the threshold ratio elderly/young of 3.96 is more comparable with the ratio found by Schiffman et al., but again, the elderly men needed a higher concentration (ratio elderly men/young 5.70) to detect the difference from the blank. The latter ratio was the highest found in the present study. A number of other studies, comparing young and elderly adults have reported differences varying from two- to nine-fold in threshold concentration. The lack of concordance in these studies is almost certainly due to procedural differences and in part to the large variance among the elderly. Another reason could also be the higher drug consumption by the elderly that might influence both taste sensitivity and variance.

Several authors have looked at gender differences in taste threshold studies. The findings of the present study are not in agreement with those of authors who failed to find a gender difference (Cooper, 1959; Hermel et al., 1970; Murphy, 1979; Stevens et al., 1991). Admittedly, the results of the present study were obtained with small samples, but nevertheless showed significant differences and had sufficient power, when the averages of the six replications per subjects were compared. Other authors have found a gender difference for all the taste qualities they investigated. Fikentscher et al. (1977) found that women were more sensitive than men for sodium chloride, cane sugar, citric acid, and quinine (sulphate or chloride); this difference became significant beyond the forties. Cohen & Gitman (1959) investigated sensitivity to sodium chloride, sucrose, acetic acid and quinine sulphate and found that in general men made more errors in the recognition of taste qualities. In agreement with the findings of the present study these findings seem to indicate that the decline in sensitivity with age is generic in nature and is more severe in men than in women. A few authors, who investigated thresholds for the four primary tastes, have reported gender differences in sensitivity to one or to just two substances. Hyde & Feller (1981) noted that men were less sensitive to sodium chloride than women and Cowart (1989) found that men were less sensitive to sodium chloride and citric acid. In agreement with the present study, the perception of sodium chloride has been found to be more affected by age in men than in women, and more affected than sucrose, citric acid, caffeine and quinine. However, the effect of gender was not always a subject of study (Bartoshuk, 1986; Schiffman et al., 1981, 1991).

The use of different methods and procedures, as outlined in the introduction, can not only generate differences in threshold values, but can, in a statistical sense lead to a difference in sensitivity with age and gender effects. To increase the chance of detecting possible effects of age and gender, in the present study the method of repeated threshold measures is applied. A facilitating effect of practice for olfactory stimuli has been reported by Engen (1960), Rabin and Cain (1986) and Cain & Gent (1991). Engen found an effect of practice over a rather limited period, after which no further learning occurred, whereas Rabin and Cain found that increments in acuity with experience transferred between odorants, which revealed itself in the fact that for the first three odours investigated there was a learning effect which was not shown for later odours. In contrast to the findings of Engen, the thresholds in the present experiment continued to decrease over all sessions and in contrast to Rabin and Cain, the thresholds decreased to some extent over almost all compounds and continued to do so over all sessions. Since in our experiment there never was a succession of two identical stimuli, whereas Engen presented eight series for one odour per day, interference in the learning process by the succession of stimuli of different quality, might explain the difference in findings. The results of Cain and Gent (1991), who also used a procedure in which there was no succession of identical stimuli and who found lowered thresholds for all compounds, and for each session, point in the same direction. These authors reported a uniform decline in all thresholds over four sessions of, on average, 25% per session. In a pilot study they also found increments in sensitivity which developed over all five sessions, either with or without feedback. Cain and Gent suggested that “subjects presumably learn over time to focus more clearly on the stimulus and to separate it from background noise, achieving greater consistency and acuity in the process”.

In our experiment the older men became more sensitive only to citric acid, caffeine and IMP. Thus, an explanation in terms of general learning, e.g. by moving the solution in their mouth in order to discriminate better, must be excluded. It could be that older men find a way to discriminate specific features of citric acid, caffeine and IMP and thus can detect the tastant at a lower concentration. In contrast, the detection of MSG became even more difficult over time for the older men. We do not have an explanation for this, or for the fact that young women became less sensitive to IMP over time.

The conclusion of this study must be that there is a general loss with age in taste acuity and in the specificity of taste sensitivity and that men are more prone to losses than women. If these findings are considered as the possible result of impairment in cognitive processes at different levels of information processing, several not mutually exclusive hypotheses based on findings in the literature on vision and audition (Essed & Eling, 1986), could be put forward to explain them. First, the neural noise hypothesis. The signal to noise ratio lowered by a decrease in intensity of the signal, by an increase in the level of spontaneously firing neurones, or both, would make it more difficult for the elderly to detect differences between the tastant and the blank. Second, the stimulus persistence hypothesis. If in the aged nervous system the neural activity after a taste stimulus lingers longer, the signal-noise ratio will be diminished when the following stimulus is presented. Third, the perceptual noise hypothesis is characterised by a decrease in the ability to neglect irrelevant information. The irrelevant information could be considered as a type of noise, but on a psychological/perceptual level and not on a neural level (Stroop, 1935). Fourth, the disinhibition hypothesis. Elderly people could have problems with the selective retrieval of relevant information from memory to connect with new information (disinhibition of irrelevant items (Warrington & Weiskrantz, 1971)). Fifth, the contextual integration hypothesis. It might be that older people store information in a way less integrated with context than younger people do, with contextual information serving as a tool to separate otherwise similar events. So when older people try to retrieve events from memory, more ‘nearly right’ candidates will come up as a result of a storage problem.

In our experiment the elderly have a less specified taste acuity than the young, for which the noise hypothesis provides an explanation, either at a neural level, at a psychological level, or at both levels. However, an explanation in terms of physiological ageing cannot be excluded. Although it seems that renewal and redundancy in the taste system preserves gustatory function in old age (Miller and Bartoshuk, 1991), it is not clear that the functioning of aged taste buds is not impaired.

In the group of basic taste stimuli investigated here, the compound with the higher molecular weight is every time the one most prone to a decline in sensitivity with age. Here this phenomenon remains unexplained, but it might be an interesting lead for future research.

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Chapter 4

Taste perception with age:
Generic or specific losses in supra-threshold intensities of five taste qualities?

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Abstract

The influence of ageing on supra-threshold intensity perception of NaCl, KCl, sucrose, aspartame, acetic acid, citric acid, caffeine, quinine HCl, monosodium glutamate (MSG) and inosine 5'-monophosphate (IMP) dissolved in water and in 'regular' product was studied in 21 young (19-33 years) and 21 elderly (60-75 years) persons. While the relative perception (intensity discrimination) seems to be remarkably resistant to the effect of ageing, the absolute perception (intensity rating) decreased with age for all tastants in water, but only for the salty and sweet tastants in product. When assessed while wearing a nose clip, only the perception of salty tastants was diminished with age. The slopes of the psychophysical functions were flatter in the elderly than in the young for the sweet, bitter and umami tastants in water, and for the sour tastants in product only. The age effects found were almost exclusively generic and never compound-specific within a taste. This study indicates that the relevance of determining intensities of tastants dissolved in water for the 'real life' perception of taste in complex food is rather limited.

Introduction

A variety of studies shows that taste perception diminishes with age. Most of these studies were restricted, either in the number of perceptual aspects (thresholds, supra-threshold intensities or preference) or by the medium in which they were presented or/and in the number of compounds considered. None of them investigated all of these aspects in the same group of people. As a result it is difficult to estimate the relative importance and the structural interrelationships of differences found between the age groups. An overview of the results of studies on the effect of age on supra-threshold taste intensity perception is given in Table 4.1. In this overview only studies are mentioned in which one or more taste compounds used are the same as in the present study. Some authors cited in Table 4.1 used compounds for four taste qualities but no one used several compounds for each taste quality in a single experiment to study the compound specificity and taste quality specificity of taste losses in the same subjects. In this respect the present study is more complete, even though, in contrast to several of the studies mentioned above, only two age groups were used. For the young, the chosen age group of 19 to 33 is in line with the other studies. For the elderly, the age group of 60 to 75 was chosen because it is generally assumed that at sixty a decline in sensitivity occurs, and that up to seventy-five the probability of major cognitive impairment is still relatively low (Schaie, 1996; La Rue, 1992).

All but one of the studies using salt dissolved in water show no decrease in salt taste intensity perception with age. Half of them found a flattened slope for the elderly. When the perceived saltiness of foods was studied, no effect of age was found but Little and Brinner (1984) found a flattened slope for the elderly which they ascribe to salivary composition. In studies in which a sweet tastant was dissolved either in water or in product, none of the authors found a decreased mean intensity perception for the elderly, although sometimes a flatter slope of the psychophysical function was found for sucrose. In all these cases, the elderly perceived a concentration near threshold level as stronger and relatively high concentrations as weaker than the young did.

This phenomenon might be explained for tastants in water by a higher background taste attributed to water by the elderly (Bartoshuk et al., 1986) which, according to Shafar (1965), might reflect mild dysgeusia, a chronic taste in the mouth. For citric acid dissolved in water most authors found differences between the elderly and the young either in mean intensity or steepness of the slope, and most authors found a decrease in the bitterness perception of caffeine or quinine with age. Only one author (Schiffman et al., 1991) investigated the age effect on umami perception. Elderly subjects perceived supra-threshold concentrations of monosodium glutamate (MSG) in water as less intense than young subjects did, while the mean slope for the young was steeper than the slope for the elderly. Age effects on umami perception in food have not been reported. Screening for health and medication does not seem to have a large impact on the results, as the studies not mentioning health do not show more age losses than the studies that did report screening for health.

Table 4.1 Studies reporting age effects in the supra-threshold perception of taste intensity

Supra-threshold studies	year	method	reps	medium	salty NaCl	sweet sucr/aspart	sour citric	bitter caff/quin	umami msg/imp	age
Enns et al	1979	me	1	water		O				avg10.5/18.8/71.0
Dye and Koziatek	1981	me	1	water		O				40-88
Hyde and Feller	1981	is	3	water	O	O	⇩	⇩		18-94
Schiffman et al	1981	me	1	water		flatter slope				18-26/74-82
Stevens et al	1984	me	4/2	water	flatter slope					20-25/65-78/80-95
Weiffenbach et al	1986	cmim	3	water	O	O	O	O QS		23-88
Bartoshuk et al	1986	mm	5	water	flatter slope	flatter slope	flatter slope	flatter slope		20-92
Chauhan and Hawrysh	1988	me	3	water			flatter slope			20-29/70-79/80-99
Bartoshuk	1989	mm	5	water	flatter slope	flatter slope	flatter slope	flatter slope QH		20-30/74-93
Cowart	1989	cmim	1	water	⇩	O	⇩	⇩ QS		19-35/45-60/65-80
Murphy and Gilmore	1989	mm	1	water	O	O	⇩	⇩		18-31/65-83
Weiffenbach et al	1990	cmim	2	water	O	O				25-93
Schiffman et al	1991	me	1	water					⇩	25.6 / 86.9
Schiffman et al	1994	me	2	water				⇩ C/QS/H		27.4 / 81.3
Drewnowski et al	1996	is	1	water	flatter slope					20-30/60-75
Stevens and Lawless	1981	is	1	fruits/veg.	O	O	O	⇩		18-25/36-45/56-65
Little and Brinner	1984	is	>15	tomato juice	flatter slope					20-40/55-69/70-88
Warwick and Schiffman	1990	is	1	dairy products	O	O				avg 22.4/82.3
Chauhan and Hawrysh	1988	me	3	apple drink			flatter slope			20-29/70-79/80-99
Zallen et al	1990	is	1	potatoes/broth	O					20-35/>65
De Graaf et al	1994	is	1	yoghurt		flatter slope				20-25/72-82
Drewnowski et al	1996	is	1	chicken broth	O					20-30/60-75

⇩ significant decrease in perception, **O** no change in perception

me = magnitude estimation, mm = magnitude matching, cmim = cross model intensity matching, is = intensity scaling

Gender differences are reported in two studies only. Hyde and Feller (1981) found gender effects for citric acid and caffeine. The gender main effect for citric acid was due to the fact that the young women rated the sourness higher than the elderly men did, and the main effect for caffeine was due to the large difference between young women who perceived the bitterness most, and the elderly men who perceived the bitterness least strongly. The young women differed significantly from the other three groups, the young men differed significantly from the elderly men but not from the elderly women, and both elderly gender groups did not differ. Chauhan and Hawrysh (1988) found steeper slopes for women than for men for sour taste intensity, both in water and in apple drink. Other authors did either find no gender differences or did not look for them.

The studies mentioned vary not only in the number of compounds or age ranges of groups but also in the method of measuring intensity, in instructions, concentration ranges, number of repetitions, and the degree of experience of subjects with the experimental procedure. While in these studies the concentrations of compounds used vary widely, and are in a number of cases far outside the normal range of every-day use, the concentrations chosen in the present studies are chosen around (and include) the concentration found in 'regular' food products.

Several authors not mentioned in Table 4.1, found that the elderly have a diminished ability to discriminate between ascending concentrations of taste compounds dissolved in water. Gilmore and Murphy (1989) found that ageing was associated with higher Weber ratios at medium and high concentrations, but not at a low concentration, of caffeine, and reported a 74% increase in 0.005 M caffeine to be needed to produce a perceptible difference for the elderly, whereas only a 34% increase was needed for the young. The Weber ratios for sucrose did not differ between the two age groups. For weak and moderate concentrations of NaCl, KCl, and $CaCl_2$, Schiffman (1993) observed that young subjects generally needed only a 6 to 12% difference in concentration to perceive a change, whereas the elderly subjects required an increment of 25% to distinguish a difference in intensity. In their study on regional sensitivity to three concentrations of NaCl (0.01, 0.1 and 1.0 M), Matsuda and Doty (1995) observed that, unlike young subjects, elderly subjects are unable to distinguish among different stimulus concentrations, and were not more sensitive at the tip of the tongue than in a region 3 cm posterior to the tip. Finally, Stevens et al. (1991) showed that the average discrimination score for ten NaCl 0.25 log concentration steps (0.003 to 0.56 M) in tomato soup at room temperature, decreases with rather sharply from 79% correct discrimination in young subjects to 56.5% at middle age, and then more slowly to old age (53.8%). When corrected for chance guessing, the performance of the young group exceeded that of the middle and old age groups significantly.

The experiments to be reported here are the second part of a larger study with a fixed group of young and elderly subjects in which the influence of ageing on taste perception has been investigated. In a first paper (Mojet et al., 2001), the effects of ageing on threshold sensitivity to the basic tastes were reported. In the present study, pre-tests were carried out first with both elderly and young subjects to ascertain that the concentration ranges to be used in the main experiments were wide enough to perceive concentration differences in distilled water and in product when subjects were wearing a nose clip or not. The subsequent main experiments have been carried out to determine whether age-related taste losses are found when supra-threshold intensities of taste compounds are presented, and if so, to what extent such taste losses are generic, taste-quality-specific, or compound-specific, and furthermore, to investigate the effect of perceptual context on taste intensity perception. Therefore, the subjects were asked to evaluate the intensities in water (single taste perception), in 'regular' products while wearing a nose clip (complex taste-texture perception) and without a nose clip (complex taste-texture-smell-perception). This should also help to verify the relevance of determining intensities of taste compounds dissolved in water for the 'real life' perception of taste in complex food products.

Pre-tests: Intensity discrimination

The pre-tests have a twofold objective. In the first place they serve to determine the concentration ranges to be used in the main experiments, and in the second place to indicate whether the acuity for intensity discrimination diminishes with age.

Materials and methods

Subjects

The same 21 older subjects (age 60-75, 10 male, M=66.0, SD=3.6, and 11 female, M=64.6, SD=4.2) and the same 21 young subjects (age 19-33, 11 male, M=26.5, SD=3.6, and 11 female, M=23.2, SD=3.3) participated in all experiments described here. They all had taken part in a previous experiment on threshold sensitivity (Mojet et al. 2001). All subjects were Caucasian and did meet the following criteria: healthy, not on a diet, not living in a home for the elderly, not taking any prescribed medicine, non-smoking, not heavy alcohol users, non-pregnant or lactating, not subject to food allergies, good dental hygiene, and not wearing dentures (as it was very difficult to recruit enough elderly persons without dentures, subjects with partial dentures were admitted but they were not allowed to wear these during testing). Furthermore, the subjects had to be within the normal range at hearing sounds of 750 Hz, in view of the use of hearing as a matching modality for taste. A tone audiogramme was made with 500 and 1000 Hz tones of each candidate to screen for normal sensitivity to sounds around 750 Hz. To be admitted, their auditory thresholds should not be higher than 30 dB. Subjects were selected on a volunteer base in response to advertisements in local newspapers and on bulletin boards in senior citizen centres. At the end of all experiments the subjects were paid for their participation.

Stimuli

Five taste qualities were included: saltiness, sweetness, sourness, bitterness and umami taste. For each taste quality, two representative compounds were chosen, which were administered at five concentration levels both in distilled water and in regular products. The compounds were grouped in two sets of five taste qualities each. One set contained NaCl, sucrose, acetic acid, caffeine and MSG, the other set consisted of KCl, aspartame, citric acid, quinine HCl and IMP. The products were versions of commercially available ice tea, chocolate drink, mayonnaise, tomato soup and broth (all five products of Unilever), which were varied by the omission or addition of the taste ingredients to be tested.

To enable the selection of the concentrations of the compounds in water and product for the main experiment, a matching task (paired comparison test) was carried out with 33 members of the descriptive panels at the Unilever sensory laboratory at Vlaardingen. For each compound, the intensities of five ascending concentrations dissolved in water were compared with the intensity of the regular concentration of the compound in the product. The panel members indicated which of the products was respectively saltier, sweeter, etc.

The differences in concentrations in the present study are in 0.1 log steps, which means an increase by a factor of 1.26. For some compounds this increase in concentration is somewhat larger than the Weber ratio found for young subjects in the literature (Schutz and Pilgrim, 1957; Pfaffman et al., 1971; Lundgren et al., 1976; McBride, 1983) but it is smaller than the Weber ratio found for impaired patients (Fischer et al., 1965) and smaller than the highest ratio (2.56) found for the elderly by Gilmore and Murphy (1989). The geometrical midpoint between the highest concentration at which the compound was perceived as weaker in water and the lowest concentration, at which it was perceived as stronger in water, was taken as the matching concentration of the compound in water.

In the pre-tests the concentration in water that matched the concentration of the regular component in product was used as the second concentration step in a series of 5 steps for each compound dissolved in water. One step down and three steps up completed the range. The difference between two consecutive concentrations in water was 0.1 log step. For the concentration in the products the regular concentration was chosen as the second concentration step in a series of 5. One step down and three steps up completed the ranges. Since the bitterness in the chocolate drink could not be left out, a very low concentration was chosen as the first step in the range. Again, the steps in the ranges increased in concentration by a factor of 0.1 log. The concentrations of the non-regular components in these products (KCl, aspartame, citric acid and IMP) where chosen on the basis of their equi-intensity with their regular counterparts in these products. An overview of the concentrations of the compounds used in this discrimination pre-test is given in Table 4.2.

Table 4.2 Tastant concentration (in g per l) used for the triangle tests

	Compounds	Dissolved in water		Log	Dissolved in product		Log
		lowset	highest	steps	lowest	highest	steps
Sweet	Sucrose	17.062	42.852	0.100	42.854	107.636	0.100
	Aspartame	0.116	0.290	0.100	0.290	0.728	0.100
Salt	NaCl	4.512	11.332	0.100	7.150	17.956	0.100
	KCl	7.150	17.956	0.100	11.328	28.452	0.100
Umami	MSG	2.510	6.304	0.100	0.794	1.996	0.100
	IMP	1.584	3.980	0.100	0.502	1.260	0.100
Bitter	Caffeine	0.198	0.498	0.100	0.398	0.998	0.100
	Quinine	0.002	0.004	0.100	0.003	0.008	0.100
Sour	Acetic acid	0.798	2.006	0.100	0.267	0.671	0.100
	Citric acid	1.580	3.970	0.100	0.019	0.048	0.100

The solutions of the compounds in water were prepared the day before testing and tested at room temperature the following day. The dry bases for the products (without the specific taste compound) and the compounds to be tested in these products, were weighed beforehand, mixed and prepared on the day of testing, with the exception of the mayonnaise, which was produced in advance at the pilot plant of Unilever Research Vlaardingen. All products were served at room temperature. Per stimulus the subjects received 20 ml in a 50-ml disposable plastic cup.

Procedures

For practical reasons, the sessions for the elderly and the young were conducted separately. More time and a more elaborated instruction were required for the elderly. Throughout the experiments the sip-and-spit method was used. At the start of the session, and before each new trial, the subject rinsed with distilled water and expectorated. The subjects were instructed to eat a piece of cream cracker at the end of a series of samples of a given tastant.

The pre-tests were held on three consecutive days. On the first day, the taste compounds were dissolved in water. The subjects had to pick the odd one out of three samples in triangle tests. The next two days, the compounds were varied in regular products. In order not to perturb the results of the other conditions, the rather unnatural experimental condition, in which the subjects had to evaluate the stimuli wearing a nose clip, was reserved for the last day. Again, the odd one had to be picked out. Each triad consisted of three samples in a row, two samples of the lowest concentration and one sample that was one, two, three or four steps higher in concentration. The place of the odd sample in the row of three samples was randomly chosen. Each triad was assessed once.

To guarantee that order effects equally biased the comparison of the performances of the subjects, the compound presentation order was kept constant for all subjects. The intensities of MSG and IMP were determined last to avoid the risk that these compounds caused an enhancement of the perception of a subsequent taste stimulus. There were short breaks between the tasting of the compounds and there was a larger break between the two series of the five taste qualities.

Statistical analysis

The results were analysed per day by calculating the number of correct responses and comparing them with the critical (minimum) numbers of correct answers to the triangle test at a 0.05 level (Meilgaard, Civille, and Carr, 1987). In the results, effects with a significance level of 0.05 are given, while a significance level of 0.10 is only described when it supports a general trend.

Results

The results of the pre-tests are shown in Table 4.3. For the salty and sweet tastants, both the elderly and the young detected concentration differences at least at a difference level of 0.2 log and higher in all presentation conditions, i.e. in water and in product while wearing or not wearing a nose clip. The elderly and the young detected both sour tastants and the bitter tastant caffeine at least at a difference level of 0.3 log or higher in all presentation conditions. When presented in water, both elderly and young perceived a concentration difference of 0.1 log in quinine HCl, a concentration difference of at least 0.2 log in the umami tastant MSG, and a concentration difference of at least 0.3 log in IMP. The concentration differences of quinine HCl, MSG and IMP dissolved in product were not systematically detected whether subjects were wearing a nose clip or not.

Table 4.3 Concentration differences in log units perceived as significantly different ($P<0.05$) in the three presentation conditions (+indicates: this and larger concentration differences)

	compounds	water		product (noseclip)		product	
		elderly	young	elderly	young	elderly	young
Salt	NaCl	0.1+	0.1+	0.2+	0.1+	0.2+	0.2+
	KCl	0.1+	0.2+	0.2+	0.2+	0.2+	0.2+
Sweet	Sucrose	0.1+	0.1+	0.1+	0.1+	0.1+	0.2+
	Aspartame	0.2+	0.2+	0.2+	0.2+	0.2+	0.2+
Sour	Acetic acid	0.1+	0.1+	0.1+	0.1+	0.2+	0.3+
	Citric acid	0.1+	0.1+	0.2+	0.2, 0.4	0.1, 0.3, 0.4	0.1+
Bitter	Caffeine	0.1+	0.1+	0.1, 0.4	0.3+	0.2+	0.2, 0.4
	Quinine HCl	0.1+	0.1+	--	--	0.1	0.1
Umami	MSG	0.2+	0.2+	--	0.2	0.3	0.1, 0.4
	IMP	0.3+	0.2+	--	0.2	--	--

Conclusions

These results show that a maximum concentration difference of 0.4 log is not sufficiently large to ensure that the elderly and the young can perceive the difference for all compounds in all three conditions. Therefore, consecutive 0.2 log concentration steps seemed recommendable for the compounds to be assessed in the main experiments both in water and in product. It is assumed that a maximum increase in concentration of 0.8 log (4 times 0.2 log) will be perceived by all subjects in all compounds. Moreover, larger concentration steps might lead to very 'unrealistic' products.

The results also show that intensity discrimination seems to be remarkably resistant to the effect of ageing, since the elderly and the young produce very similar results and in some cases the elderly even seem to be more acute than the young.

Main Experiments: Intensities of tastants dissolved in water or in product reported by subjects wearing a nose clip or not

Materials and methods

Subjects and stimuli

The same 42 subjects as in the pre-test experiment took part in these experiments, that were carried out during the 3 weeks following the pre-tests.

Based on the results of the pre-tests, 5 concentrations (ascending 0.2 log steps) of the same 10 compounds were chosen to be assessed in water and in the same food media as in the pre-tests. An exception was made for mayonnaise (ascending 0.1 log steps), since the total concentration difference could not be larger than 0.4 log for technological reasons. The concentration series are given in Table 4.4. In most cases, the second step in the range of concentrations corresponded with the regular ('every day life') concentration of the compound in the selected product. Based on the results of the pre-tests, some adjustments in the concentrations were made but in all cases the regular concentration fitted well

Table 4.4 Concentrations (in g/l) of the basic tastants used for the intensity measurements

	Compounds	Dissolved in water lowest	Dissolved in water highest	Log steps	Dissolved in product lowest	Dissolved in product highest	Log steps
Sweet	Sucrose	8.55	53.95	0.2	53.95	340.38	0.2
	Aspartame	0.06	0.37	0.2	0.15	0.92	0.2
Salt	NaCl	3.58	22.61	0.2	5.68	35.83	0.2
	KCl	5.68	35.83	0.2	9.00	56.77	0.2
Umami	MSG	1.99	12.58	0.2	1.58	9.95	0.2
	IMP	1.26	7.94	0.2	1.00	6.28	0.2
Bitter	Caffeine	0.16	1.00	0.2	0.63	3.98	0.2
	Quinine HCl	0.00	0.01	0.2	0.01	0.00	0.2
Sour	Acetic acid	0.63	4.00	0.2	0.27	0.67	0,1*
	Citric acid	1.26	7.92	0.2	0.02	0.05	0,1*

* for product technical

within the range of stimuli used. For the assessment of the compounds in water the solutions were prepared the day before testing and tested at room temperature the following day. For the assessment of the compounds in product the compounds were mixed with the dry product beforehand and prepared on the day of testing, and served at room temperature. However, the mayonnaise was prepared beforehand at the Unilever pilot plant at Vlaardingen. Per stimulus the subjects received 20 ml in a disposable 50-ml plastic cup.

In order to serve as control stimuli in cross modal intensity matching of the different sensory modalities, five levels of auditory (loudness), visual (size) and kinaesthetic/tactile (weight) stimuli were presented. For the sounds, a narrow band noise of 750 Hz was recorded. The intensity varied from 45 to 85 dB with intervals of 10 dB. The duration of a sound was kept at 1.5 seconds. The sounds were delivered by earphones, which the subjects had to wear during the test. Five weights were constructed varying in 0.2 log steps from 33.7 to 212.6 gram. The weights were hidden in small black (film) containers of equal size and had to be lifted by the top of the forefinger by means of a ring on a string that was connected to the container. For the visual stimuli, an irregular star figure was multiplied in ascending 0.2 log size steps.

Procedure

The procedure was the same in the three experiments (tastants dissolved in water or in product with subjects wearing a nose clip or not). The stimuli were presented one after the other. Similar to the pre-tests, the sip-and-spit method was used and separate sessions were held for the elderly and the young. At the start of a session and before each new trial the subject rinsed with distilled water and expectorated. The subjects were instructed to eat a piece of cream cracker at the end of a series of samples of a given compound.

The sessions of each experiment took place on three consecutive days, one per day. The ten taste compounds were presented in a balanced order over the three sessions but within each session the ten compounds, at 5 concentration levels each, were presented only once. The last series of stimuli in a session always contained the umami samples to avoid the risk that these compounds caused an enhancement of the perception of a subsequent taste stimulus. In each session the taste stimuli were intermingled with 3 replications of auditory, visual and weight stimuli at 5 levels. The presentation order of the compound concentrations and the cross-modal stimuli was the same for all subjects.

In each session, all taste samples had to be judged on linking and on heir salt, sweet, sour, bitter, umami intensities, whereas the auditory, visual, and weight stimuli had to be rated on intensity only. The intensities were marked on a 9-point scale with the anchors ‘very weak’ at the left side and ‘very strong’ at the right side. Liking of the taste stimuli was assessed on a 9-point pleasantness scale with the anchors ‘very little’ at the left side and ‘very much’ at the right side. The results of the evaluation of the intensities of the tastes that were not experimentally varied, and the results of the liking, as well as of the comparison of the intensity matching modalities will be reported elsewhere.

Statistical analysis

Methods

The statistical analyses were conducted by means of SAS® and SAS/STAT®. Multivariate analyses of variance (repeated measures analysis and manova) were applied with age and gender as between subject factors, and taste quality, compound and concentration as within subject factors, in order to investigate the main and interaction effects of age, gender, taste quality, compound and concentration. The same error has been used to test the effects of the mean, age, gender and age by gender per multivariate response (e.g. compound). Data were averaged over replications to compare the older men, older women, young men and young women pair wise, using the LSMeans method. As measures of the intensity and the slope of the psychophysical function, the average of the intensities for the five concentrations and the

$$ß\_int=(-2*int1 - int2 + int4 + 2*int5) / 10$$

were taken respectively. Separation of variances into variance components (see Results, section on 'General or specific losses') was carried out with Proc Varcomp of SAS/STAT®.

Levels of significance

All effects that have a p-value of 0.05 or lower are reported as 'significant'. Power Analysis shows that, with the number of subjects in our study, an effect with a magnitude of 1.3 standard deviations and a p-value of 0.10 still has a power of 0.90. Therefore a selection of the more interesting effects with a p-value between 0.05 and 0.10 are reported additionally. These effects will be denoted as 'trends' or 'tendencies'.

Cross-modal intensity matching

When people respond differently to a task, they may either perceive the task differently, or they may have an inherent different use of the assessment scale. In this study the elderly and the young might have a different scale usage. Cross-modal intensity matching (CMIM) is used as a method to overcome this problem. In CMIM, the same scale is offered to the assessors, but now with stimuli from a different sensory modality which are believed to be perceived in the same way by all subjects. If, in this case, differences in intensities are found between groups or individuals, these differences are interpreted as differences in scale usage and can be used to correct the responses to other modalities before any further analysis of the data. The remaining differences are then considered to be ‘real’. In the present study, ‘sound’ was selected to correct for differences in scale usage, because the sensitivity to low-frequency sound (around 750 Hz) is normally not impaired with age and because an analysis of variance of the results for each of the five sound levels did not show an influence of age or gender.

The matrix of the CMIM data consisted of 42 people, 27 replications per individual, and 5 different levels of loudness per replication. On average, the standard deviation per individual/level of loudness was fairly constant and in the order of 0.9, indicating that the standard error of an individual/level of loudness combination is in the order of 0.17 ($0.9/\sqrt{27}$). The following steps were used in the correction:

1. For each sound level the individual average and the age group average were determined.
2. The (individual minus group) averages (which also have a standard deviation of approx. 0.17) were regressed against the group averages using polynomial functions of the latter, starting with a polynomial of degree 0 (constant difference from group mean) and ending with a polynomial of degree 4 (complete fit of individual means).
3. For each individual assessor the lowest polynomial with a residual standard deviation of ca 0.17 was selected as the assessor's correction formula.
4. Each individual score on the scale was corrected by a value obtained from the individual's correction formula.

All data to be reported here are based on scores that were corrected by means of this method.

Results

Hereafter, the results of the experiment with compounds dissolved in water will be reported first, then the results of the experiment with compounds mixed in product assessed with the nose clip on, and then the results of the experiment with compounds mixed in product evaluated with unblocked noses. Finally the three data sets will be compared.

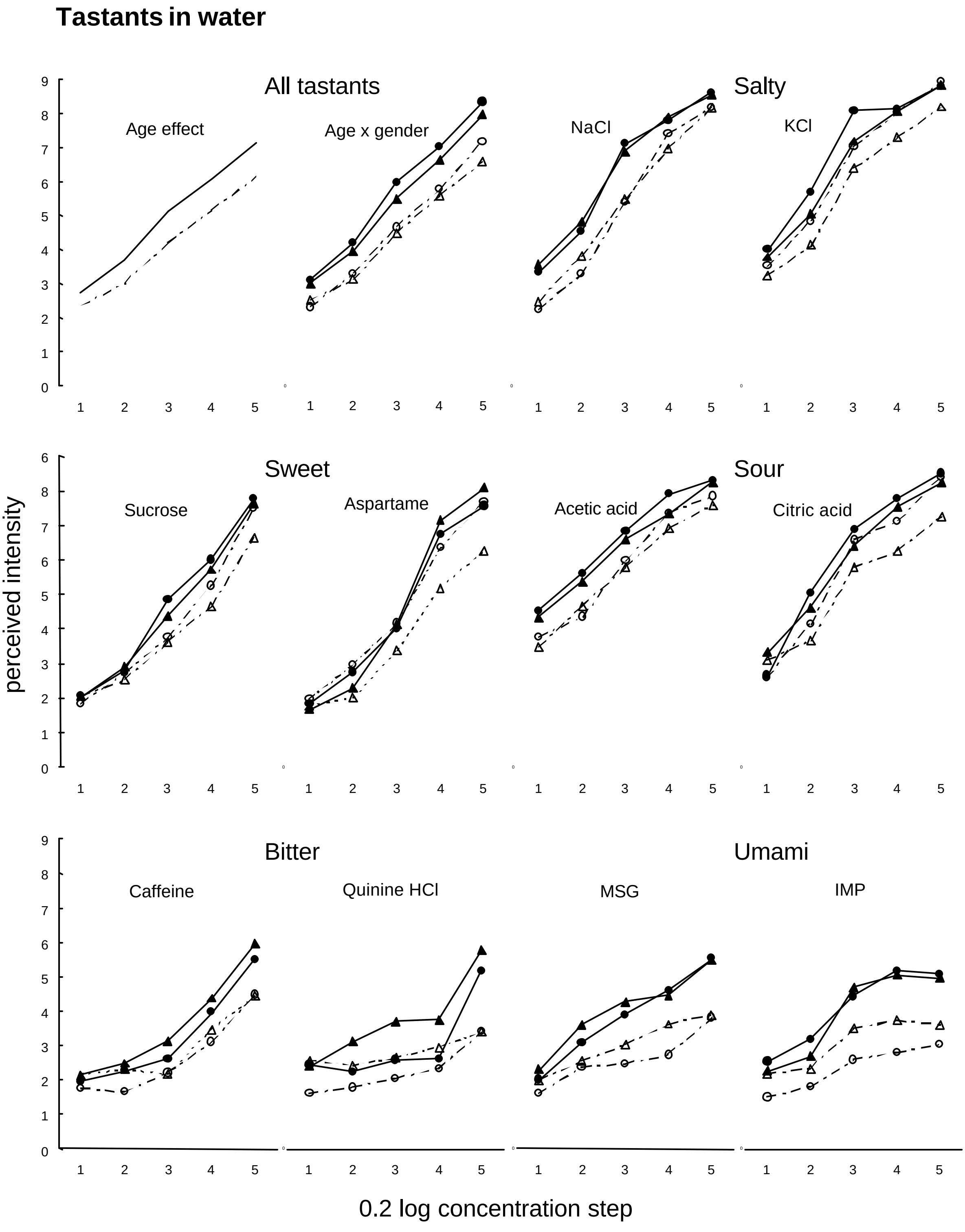

Figure 4.1 Intensity measurements for ten taste compounds dissolved in water in young and elderly male and female subjects. Intensity ratings are given in 0.2 log concentration steps. The young subjects are presented by solid lines and filled symbols, the elderly by dotted lines and open symbols. The male subjects are represented by triangles and the female subjects by circles.

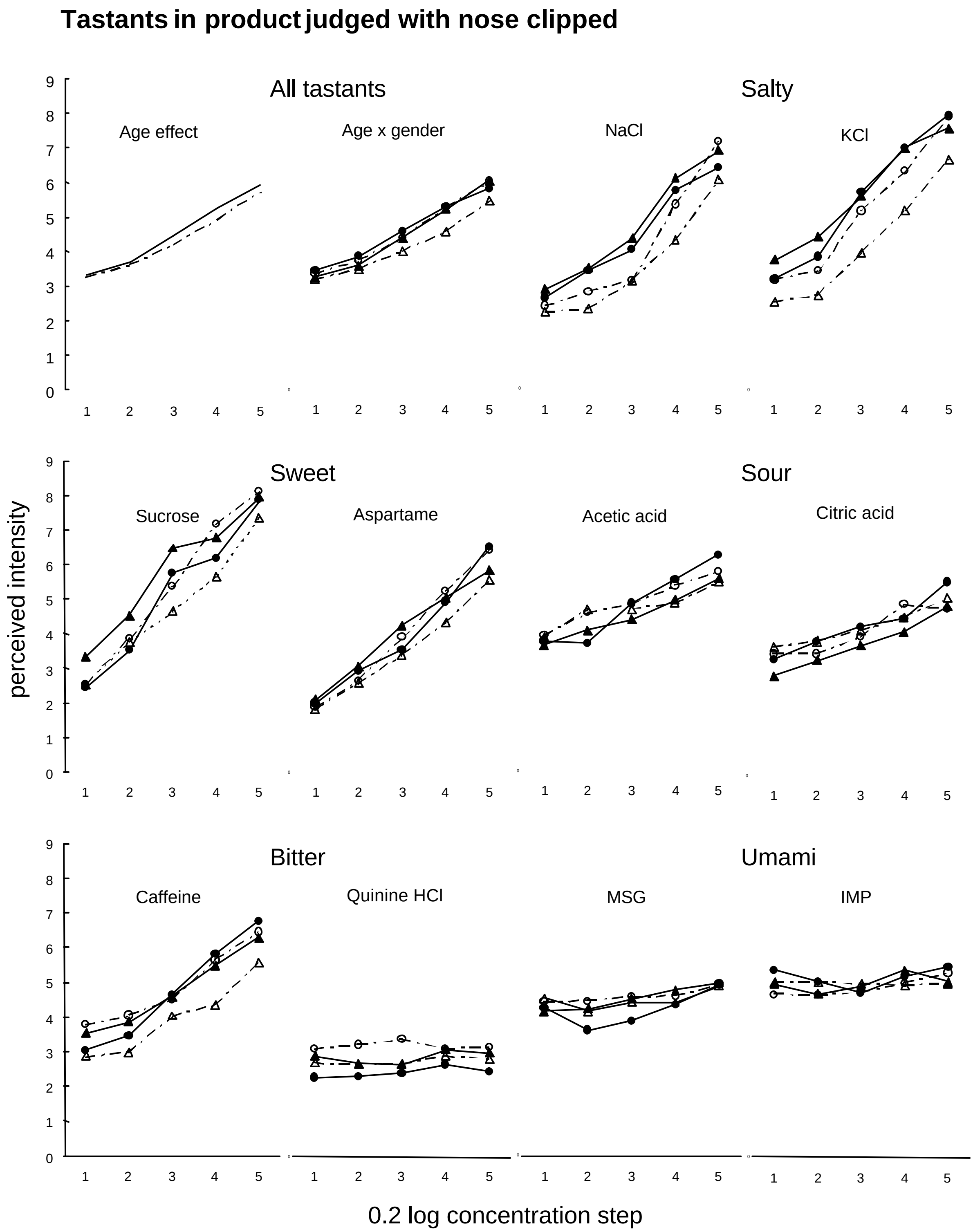

Figure 4.2 Intensity measurements for ten taste compounds dissolved in product in young and elderly male and female subjects while wearing a nose clip. Intensity ratings are given in 0.2 log concentration steps (sour 0.1 log steps).. The young subjects are presented by solid lines and filled symbols, the elderly by dotted lines and open symbols. The male subjects are represented by triangles and the female subjects by circles.

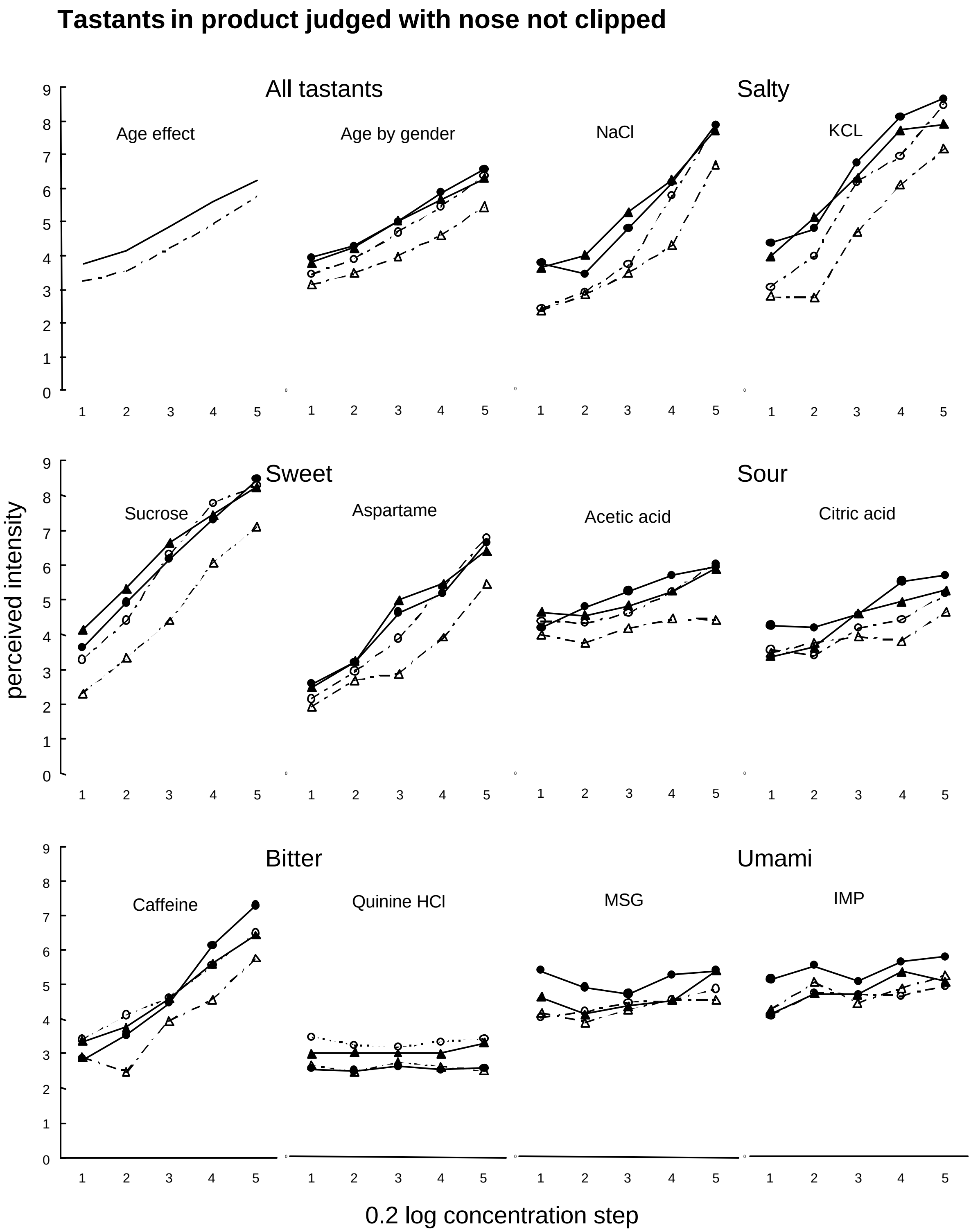

Figure 4.3 Intensity measurements for ten taste compounds dissolved in product in young and elderly male and female subject. Intensity ratings are given in 0.2 log concentration steps (sour 0.1 log steps). The young subjects are presented by solid lines and filled symbols, the elderly by dotted lines and open symbols. The male subjects are represented by triangles and the female subjects by circles.

Overall effects of age and gender :

Do age and gender influence taste intensity perception in general?

When the tastants were dissolved in water, the elderly perceived the tastants taken overall as significantly less intense than the young [$F(1,38) = 21.16$, $P < 0.0001$]. No overall effect was found for gender or age by gender. When they were dissolved in product and when nose clips were worn to block the retronasal effects of the odour of the products, no overall age, gender or age by gender interaction effects was found. Overall, the elderly perceived the tastants dissolved in product and tasted without wearing a nose clip as significantly less intense than the young subjects [$F(1,38) = 5.88$, $P < 0.03$]. No overall effect was found for gender or age by gender.

Comparison of these results show that when tested in water and in product without a nose clip, the elderly perceived the tastants overall as less intense than the young. When wearing a nose clip this significant difference disappeared.

Concentration:

Are age and gender effects concentration-specific?

Taken over all compounds, the ascending concentrations of tastants dissolved in water were perceived as different [$F(4,35) = 471.73$, $P < 0.0001$] as was to be expected, and a concentration by age interaction effect [$F(4,35) = 40.00$, $P < 0.01$] was also found. Overall, for the elderly the intensity increased less with increasing concentration than for the young, i.e. the slope of the psychophysical function was significantly steeper for the young than for the elderly [$F(4,35) = 4.00$, $P < 0.01$] as is illustrated in Figure 4.1. No significant concentration by gender or concentration by age by gender interaction effects was found.

Whereas overall the ascending concentrations were perceived as different [$F(4,35) = 157.77$, $P < 0.0001$] when the tastants were dissolved in product and assessed with a nose clip on, the slopes of the psychophysical function for quinine HCl, MSG and IMP were rather flat. The slopes of the psychophysical function were not different for the elderly and young or for the men and women. Figure 4.2 shows the results.

Dissolved in product and assessed while not wearing a nose clip, the ascending concentrations were perceived as different [$F(4,35) = 191.81$, $P < 0.0001$] when analysed overall, the slopes of the psychophysical function for quinine HCl, MSG and IMP were rather flat, and all slopes of the psychophysical function were not different for the elderly and young, nor for the men and women. Figure 4.3 shows the results.

A comparison of the three sets of results shows that in the case of the tastants dissolved in water an age by concentration effect is found, that the slope of the psychophysical function is less steep for the elderly than for the young, and that no such effect is found when the tastants are embedded in product and are assessed with or without a nose clip.

Compounds:

Are age and gender effects equal for all compounds?

When the tastants were dissolved in water, significant age effects on intensity [with all F's (1,38) => 4.15 and all P values < 0.05 at least] were found for all compounds except aspartame, for which only a trend could be observed [$F(1,38) = 3.53$, $P < 0.07$]. In all cases the young perceived the intensities as stronger than the elderly did. Gender effects on the perceived intensity were observed for aspartame [$F(1,38) = 4.34$, $P < 0.05$] where the women perceived the intensities as stronger than the men, and for quinine [$F(1,38) = 5.52$, $P < 0.03$] where the opposite was found. Age by gender interaction effects on the perceived intensity were observed for aspartame [$F(1,38) = 3.08$, $P < 0.09$] and IMP [$F(1,38) = 2.92$, $P < 0.10$] as a trend only. The elderly men did not perceive the aspartame as intense as the other three groups and they also perceived IMP as weaker than both young groups, whereas the elderly women perceived the IMP even weaker than the elderly men.

An age effect was only found for KCl [$F(1,38) = 4.38$, $P < 0.05$] and NaCl [$F(1,38) = 3.99$, $P < 0.06$] when the tastants were dissolved in product and assessed with a nose clip on. The elderly perceived the salty taste of KCl and NaCl as less intense than the young did. For sucrose an age by gender effect [$F(1,38) = 4.19$, $P < 0.05$] was found. The young men perceived this sweet taste as more intense and the elderly men perceived it as less intense than the other groups.

Assessed without nose clip, significant age effects on intensity [all F values (1,38) => 60.00 and all P values < 0.02] were found for both salty and for both sweet compounds but not for any of the other compounds. Where differences were found, the elderly perceived the intensities as weaker than the young did. Only for sucrose a gender effect [$F(1,38) = 4.34$, $P < 0.05$) and an age by gender interaction effect [$F(1,38) = 9.41$, $P < 0.004$] on the intensity were observed. Men perceived the intensity of sucrose as weaker than women did and this was especially true for the elderly men.

Comparison of the three sets of results shows that all compounds were perceived as significantly less strong (aspartame trend only) by the elderly than by the young when the tastants were dissolved in water, whereas in product this was only the case for the salty and sweet tastants, and when nose clips were worn the difference between the elderly and young was further restricted to the salty tastants only.

Compounds within taste qualities:

Are age and gender effects larger for one compound than for the other within a taste quality?

To see if the age effect is similar for the two compounds within a taste quality, the differences between the two compounds within the taste qualities were compared.

Overall, the elderly did not differ from the young in their perception of the differences between the tastants dissolved in water within a taste quality, and men did not differ from women. Also, no age by gender interaction effect was found. A gender by compound within-taste-quality interaction effect was found for the salty taste, where the women perceived a larger difference [$F(1,38) = 4.66$, $P < 0.04$] between the mean intensities of NaCl and KCl concentrations than the men. An age by gender interaction effect was found for the sweet taste [$F(1,38) = 4.55$, $P < 0.04$]. The elderly women perceived the largest and the elderly men perceived the smallest differences in intensity between sucrose and aspartame.

When the tastants were dissolved in product and nose clips were worn, there was no overall age, gender or age by gender interaction effect on the intensity differences between the compounds dissolved in product within a taste quality. When analysed more specifically per compound, there was only an age effect [$F(1,38) = 5.87$, $P < 0.03$] for the bitter taste. The distance in intensity between the two compounds was larger for the young than for the elderly.

Overall, the elderly did not differ from the young and men did not differ from women in the perception of the differences between the two compounds within a taste quality when assessed in product with no nose clip on. Moreover, no overall age by gender interaction effect was found. Univariate analysis per taste quality showed an age effect [$F(1,38) = 6.24$, $P < 0.02$] for the bitter taste, where the young perceived a larger difference between caffeine and quinine than the elderly but no other age differences were found. An age by gender interaction effect was found for the sweet taste [$F(1,38) = 4.61$, $P < 0.04$]. All groups perceived sucrose as stronger than aspartame but the young men perceived this difference as significantly larger than the elderly men did.

A comparison of the three sets of results shows that when the compounds were dissolved in water, the differences in intensity perceived by the elderly and the young remained the same for each given taste quality, regardless of which of the two compounds within that taste was measured. However, when dissolved in product, the perception is differently influenced by age for the bitter taste only. This indicates that the influence of age might be taste-quality-specific but in general is not very specific for compounds within a taste quality.

Taste qualities:

Are age and gender effects generic or taste-quality-specific? In other words: does the relation between the intensities of the tastes remain stable or change with age?

To see whether this is the case, pairs of taste quality compounds were used as contrasts in the manova. In general, for the intensity contrasts between the taste qualities, an age effect [$F(4,35) = 3.12$, $P < 0.03$] and a gender effect [$F(4,35) = 4.97$, $P < 0.003$] but no overall age by gender interaction effect was found when the tastants were dissolved in water. When the specific combinations of taste qualities were analysed, it appeared that the elderly perceived a larger intensity contrast than the young between umami on the one hand and respectively the sweet [$F(1,38) = 12.89$, $P < 0.001$], the sour [$F(1,38) = 4.22$, $P < 0.05$], and the bitter [$F(1,38) = 23.95$, $P < 0.0001$] taste on the other. The elderly perceived both umami tastants as much weaker than the young, whereas the differences between the elderly and the young were much smaller for the sweet, sour and bitter tastes.

Gender effects were found for the contrasts between the umami taste and respectively the salty [$F(1,38) = 4.61$, $P < 0.04$], sweet [$F(1,38) = 12.28$, $P < 0.002$], and the sour [$F(1,38) = 4.95$, $P < 0.04$] taste, and also between the bitter taste and respectively the salty [$F(1,38) = 7.21$, $P < 0.01$], the sweet [$F(1,38) = 9.65$, $P < 0.004$], and the sour [$F(1,38) = 6.13$, $P < 0.02$] tastes. Although all subjects perceived the umami and bitter tastants as weaker than the salty, sweet and sour tastants, in all these cases the women perceived larger contrasts than men. An age by gender interaction effect was found for the contrasts between the umami and the sweet tastants [$F(1,38) = 7.60$, $P < 0.01$]. Here, the elderly women perceived a larger contrast than all other groups.

Between the taste qualities an overall age effect [$F(4,35) = 3.11$, $P < 0.03$] on the intensity contrasts was found when the tastants were dissolved in product and when nose clips were worn by the assessors. There were no gender or age by gender effects. Age effects were found for the contrasts between the salt taste on the one hand and respectively the sour [$F(1,38) = 10.69$, $P < 0.003$], the umami [$F(1,38) = 4.70$, $P < 0.04$] and the bitter [$F(1,38) = 6.45$, $P < 0.02$] taste on the other. In the first and the second case, the young perceived the salt tastes as stronger than the other tastes, whereas for the elderly the reverse was true. In the case of salt and bitter, both age groups perceived the salty tastes as more intense but the young did so to a significantly larger extent. There was also an age by gender effect for the contrast between the salt and sour taste. The young men perceived the salt taste as much stronger than the sour taste and the elderly men perceived the sour taste as stronger than the salt taste, while both groups of women occupied a middle position.

Overall, the intensity contrasts between the taste qualities were not equal for the elderly and the young [$F(4,35) = 3.57$, $P < 0.02$] when the tastants were dissolved in product and assessed while not wearing a nose clip. No overall gender effect or age by gender interaction effect was found. When analysed more specifically for the ten different combinations of taste qualities, only one age effect was found. The elderly perceived the intensity contrast between the salt taste on the one hand and the bitter taste on the other [$F(1,38) = 10.36$, $P < 0.003$] as smaller than the young. No gender effect was found but an age by gender effect [$F(1,38) = 4.66$, $P < 0.04$] was found for the contrast between the umami and the sweet tastants. Here, the young men perceived the intensity of the sweet taste as stronger than that of the umami taste, whereas the older men perceived the umami taste as stronger than the sweet taste.

A comparison of the three sets of results shows that in water as well as in product, the elderly and young wearing a nose clip or not differed in their perception of the intensity contrasts between the taste qualities. This indicates that the overall age effect is dependent on the taste quality involved.

General or specific losses

When the tastants were dissolved in water the total variance due to age could be separated into the following variance components: age 96.4 %, age x concentration 1.0 %, age x taste quality 1.1 %, age x concentration x taste quality 0.8 %, age x compound (within taste quality) 0.3 %, age x concentration x compound (within taste quality) 0.0 % and error 0.4 %. This shows that the age effects found can be attributed predominantly to a generic loss in taste perception when tastants were dissolved in water.

When the tastants were dissolved in product and assessed while wearing a nose clip, the total variance due to age could be separated into the following variance components: age 12.1 %, age x concentration 0.0 %, age x taste quality 60.8 %, age x concentration x taste quality 4.8 %, age x compound (within taste quality) 12.4 %, age x concentration x compound (within taste quality) 0.0 % and error 9.9 %. This shows that the small age effects found can be attributed predominantly to a taste-quality- specific loss in taste perception when tastants were in food media and were assessed while wearing a nose clip.

When the tastants were dissolved in product and assessed without wearing a nose clip the total variance due to age could be separated into the following variance components: age 92.4 %, age x concentration 0.0 %, age x taste quality 5.6 %, age x concentration x taste quality 0.4 %, age x compound (within taste quality) 0.6 %, age x concentration x compound (within taste quality) 0.0 % and error 1.0 %. This shows that the age effects found can be attributed predominantly to a generic loss in taste perception when tastants were in food media and were assessed without wearing a nose clip.

Comparisons of the results described above show that age differences found in the conditions in water and in product without nose clip were predominantly generic in nature, while in the condition in product with nose clip the small amount of variance due to age and its interactions is mainly taste quality specific.

Relationships between the taste intensities

In order to reveal possible age differences in the perception of the relationships between the compounds, correlations were calculated per age group in the conditions in water and in product judged with and without nose clip.

A comparison of the results shown in Table 4.5 demonstrates that the two compounds within a taste quality are correlated in all media, with the one exception of the bitter compounds in water assessed by the young. In all cases the average correlation is higher in product while wearing a nose clip or not than in water and it is higher for the elderly than for the young. In contrast, the intercorrelation is almost similar for the elderly and young in water and in product judged with a nose clip on, whereas in product judged without nose clip the intercorrelation is clearly higher for the elderly than for the young.

Table 4.5 Correlations between the intensities measured for the two compounds of each taste quality, the average correlation for all pairs of compounds and the intercorrelation of all compounds (correlation coefficients R are given).

	tastants dissolved in water		in product assessed with nose clip		in product without nose clip	
	elderly	young	elderly	young	elderly	young
salty	0.50 **	0.55 **	0.80 ***	0.88 ***	0.69 ***	0.64 **
sweet	0.89 ***	0.58 **	0.91 ***	0.60 **	0.76 ***	0.73 ***
sour	0.70 ***	0.65 **	0.89 ***	0.92 ***	0.85 ***	0.88 ***
bitter	0.72 ***	0.23	0.87 ***	0.62 **	0.90 ***	0.73 ***
umami	0.75 ***	0.60 **	0.83 ***	0.88 ***	0.84 ***	0.89 ***
average	0.71 ***	0.52 *	0.86 ***	0.78 ***	0.81 ***	0.77 ***
intercorrelation	0.36	0.32	0.45 *	0.43	0.51 *	0.34

* *P* <0.01 ** *P* <=0.01 *** *P* <=0.001

Correlations between the results obtained in the three different perceptual contexts

The role of the perceptual context can be derived from the differences between the intensities in water (single taste perception), in ‘regular’ products while wearing a nose clip (complex taste-texture perception) and not wearing a nose clip (complex taste-texture-smell-perception). The correlations between the results obtained in the three presentation conditions are given in Table 4.6.

As expected, the correlations were highest in the two conditions in which the same media were used (products judged with and without nose clip). At the same time it is remarkable that the elderly showed very high correlations, which in nearly all cases were even substantially higher than those found for the young. The important role of the media in which the tastants are dissolved is further illustrated by the low to very low correlations found for both elderly and young, when the intensities in water were compared with those in product with subjects wearing a nose clip or not. In general, the correlations between these different media were lower for the elderly than for the young and they never reached significance for the elderly, whereas for the young they were in both conditions significant for NaCl and citric acid only.

Table 4.6 Correlations between the intensities measured in the conditions tastant in water and in product with or without nose clip (correlation coefficients R are given).

	water vs product		water vs product assessed with nose clip		product assessed with vs without nose clip	
	elderly	young	elderly	young	elderly	young
NaCl	-0.11	0.55 **	-0.12	0.46 *	0.83 ***	0.41
KCl	0.26	0.30	0.23	0.24	0.82 ***	0.57 **
Sucrose	0.32	0.30	0.21	0.14	0.76 ***	0.78 ***
Aspartame	0.31	0.18	0.24	0.42	0.84 ***	0.42
Acetic acid	-0.02	0.42	0.05	0.30	0.88 ***	0.66 **
Citric acid	0.20	0.47 *	0.18	0.40	0.93 ***	0.64 **
Caffeine	0.11	0.30	0.08	0.26	0.93 ***	0.72 ***
Quinine HCl	-0.09	0.19	0.02	0.05	0.84 ***	0.80 ***
MSG	0.17	0.15	0.32	0.42	0.85 ***	0.45 *
IMP	0.33	0.08	0.21	0.18	0.88 ***	0.54 *
average	0.13	0.48 *	0.21	0.44 *	0.92 ***	0.67 **

* P <0.01 ** P <=0.01 *** P <=0.001

Discussion

Age effects

When supra-threshold intensities of taste compounds are presented in water or in product without wearing a nose clip, the age effects found are almost exclusively generic and never compound-specific. In the product with nose clip condition, there was an indication of some taste-quality-specificity.

Furthermore, the perceptual context plays an important role in taste intensity perception by the young and the elderly. When the subjects were asked to evaluate the intensities in water (single taste perception) far more age effects were found than when they were presented in ‘regular’ products and tasted without a nose clip (complex taste-texture-smell-perception). When they were presented in products while wearing a nose clip (complex taste-texture perception) all age effects except for the salty components disappeared. Thus, the relevance of determining intensities of taste compounds dissolved in water for the ‘real life’ perception of taste in complex food products seems rather limited. This point will be treated more extensively below, but first the present data will be compared with the findings of other authors.

Age effects in water

Age effects, showing a diminished intensity perception of the elderly, have been found for all ten compounds when dissolved in water. Of the authors, who studied four tastes qualities, the findings of Cowart (1989), who found an age effect for three of the four tastants she tested are most in agreement with the present results. The other authors who studied four taste qualities in water in a single study, found either an age effect for two of the four taste qualities (Hyde and Feller, 1981; Murphy and Gilmore, 1989) or no effect of age at all (Weiffenbach et al., 1986; Bartoshuk et al., 1986; Bartoshuk, 1989). In the last two studies only a flattened slope was found for all tastants in the elderly. To a certain extent, this latter finding is in agreement with the present study in which also flatter slopes were found for the elderly than for the young for all compounds in water except for KCl, acetic acid and citric acid. In the present study however, the average intensities of the young were never lower than those of the elderly, as had been reported by Bartoshuk et al. (1986, 1989) for the lower concentrations. Thus, the present results do not support their hypothesis that, due to poor dental hygiene or to the presence of a mild dysgeusia (Shafar, 1965), the elderly attribute a higher background taste to water, which by summation with the tastes of the stimuli might lead to the heightened intensity perception at lower concentrations. Moreover, this hypothesis seems strange, since it should be assumed that with a higher background taste (Grad, 1954) adaptation would take place, and such adaptation would lead to a diminished rather than an increased intensity perception, especially at the lower concentrations. A more likely explanation for the findings of Bartoshuk et al. (1986, 1989) may be that many of the elderly have difficulty in using very small numbers (smaller than 1) in their magnitude estimations ratings. This explanation is all the more plausible since these authors used a wider range of stimuli and used more extreme concentrations at the lower end of the range than any of the other authors with the exception of

Hyde and Feller (1981) who used similarly low concentrations for salty and sweet.

Age effects for compounds dissolved in product

When the compounds were dissolved in product, an age effect was found only for the salty and sweet tastants in the present experiment. This age difference is in disagreement with the findings of all authors mentioned in Table 4.1, who found no age effect for these tastants embedded in product (Stevens and Lawless, 1981; Little and Brinner, 1984; Warwick and Schiffman, 1990; Zallen et al., 1990; De Graaf et al., 1994; Drewnowski et al., 1996), although two of them found a flatter slope for the elderly, one for salty (Little and Brinner, 1984) and the other for sweet (De Graaf et al., 1994), a finding that could not be confirmed. The present results are also partially in disagreement with Stevens and Lawless (1981) who did find an age effect for bitterness perception in pureed vegetables, whereas in the present study with chocolate milk, such an effect was not found. Only in the sourness perception of products, the present results are in concordance with the results of Stevens and Lawless who showed no effect of age, and are partially in accordance with those of Chauhan and Hawrysh (1988) who, for citric acid, found a flatter slope for the elderly, whereas in the present study this was only marginally the case. When nose clips were worn while tasting the products, no differences in intensity perception between elderly and young were found except for the salt taste.

Age effects in different perceptual contexts

From the foregoing comparison of the results with those in the literature, it is evident that far fewer age effects are found when the tastants are tested in product than in water. This casts some doubt on the relevance of experiments with tastants dissolved in water for the ‘every day life’ situation in which the tastants are almost always embedded in a complex food product. That experiments with tastants dissolved in water have little predictive value for real life situations is further illustrated by the low (young) to very low (elderly) correlations found between the water condition and the two product (with and without nose clip) conditions.

Range effects

Concentration range may also play a crucial role in the division of studies in which age effects were found or not. In the present experiment the concentration range was based on the variation of the tastes in normal everyday products. In the experiments with products, the regular product was enclosed in the concentration range and the steps in the range varied only by a factor of 1.59. This led to a range in which the highest concentration differed only by a factor 6.31 from the lowest one. This was also true for the stimuli in the experiments in water. Thus, even in water the range of the stimuli remained comparable with what subjects would encounter in products in their everyday life. Inspection of the ranges used shows that all authors who did find age effects used concentration ranges that included the range used in the present experiment and did not contain extreme concentrations to either side of it. This is most clear in the study of Cowart (1989) who used ranges with a 10-fold difference between the lowest and the highest concentrations. The two other groups of authors who found an age effect used either a 4-fold difference (Murphy and Gilmore, 1989), or a 20-fold (sour) and 40-fold (bitter) difference range (Hyde and Feller, 1981). In total, age effects were found in seventeen out of twenty-one cases for tastants dissolved in water, when a limited range of concentrations was used that included the ‘normal’ range in everyday products. The only authors who used such a range but did not find an age effect, were Stevens et al. (1984) for salty, Murphy and Gilmore (1989) for salty and sweet and Cowart (1989) for sweet. Authors who used extreme ranges of tastants (Bartoshuk et al., 1986 and Bartoshuk, 1989 for salty, sweet, sour and bitter; Hyde and Feller, 1981 for salty an sweet) found no age effects. That measurements of intensity are subject to range effects is well documented in the psychological literature (Helson, 1964; Parducci, 1974; Poulton, 1979). It seems that in the case of taste perception such range effects easily become stronger than age effects. The use of extreme stimuli (e.g. solutions of more than 600 grams of sugar in one litre of water) should perhaps be avoided.

Gender effects

About half of the authors mentioned in Table 4.1 looked at gender differences, the others did not mention or did not investigate them. Only two papers, dealing with compounds in water, report gender differences. Hyde and Feller (1981) reported higher intensities for caffeine and citric acid when rated by women than by men, whereas in the present study higher bitterness intensities were found for men than for women in both caffeine and quinine, and no gender difference for citric acid. Chauhan and Hawrysh (1988) found steeper slopes for women than for men for citric acid, in water as well as in product. In the present study a steeper slope for women was only found for citric acid in water but when assessed in product without nose clip no such effect was noticed. Main gender and age by gender effects are found for aspartame in water since elderly men rated sweetness as less strong than the other groups. The young men and women perceived the umami taste of IMP in water equally strong, but the older women perceived it as less strong than the young subjects did. Such effects have thus far not been reported. No authors reported gender differences for salty or sweet tastants in products, whereas in the present study such differences were found for KCl (trend only) and sucrose when tasted without nose clips. The gender effect for KCl and the gender and age by gender effect for sucrose were due to lower intensities perceived by the older men.

Relative and absolute sensitivity and the possible role of smell in taste perception

The elderly discriminate the concentration differences both in water and in product, with or without a nose clip, at least as well as the young but nevertheless showed in the main experiment a lower absolute intensity perception of compounds in water and in product judged without a nose clip. In view of the cross-modal intensity matching measures, this difference between the elderly and the young can not be ascribed to differences in scaling behaviour. This is an intriguing finding that may indicate that the young perceive something more than the elderly which does influence their absolute taste intensity perception but does not play a role in the discrimination of taste intensities in a comparative judgement. The fact, that in the condition where the tastants in product were judged with a nose clip, the young loose their advantage over the elderly while the judgement of the elderly remained the same in the conditions with and without nose clip, strongly suggests that the young make use of their sense of smell in rating taste intensities in contrast to the elderly who are less able to do so due to a deterioration in olfactory acuity. Such loss of olfactory sensitivity with age is well-documented (Murphy, Cain, Gilmore, and Skinner, 1991).

Although the present data do not provide further direct proof for the hypothesis that olfaction plays a role, there are at least two indications that for the young, but not for the elderly, a second factor is indeed involved in the intensity perception of the stimuli in product tasted without nose clips. In order to show this, the correlations between the intensities of the stimuli in products tasted with nose clip and those in product tasted without nose clip were calculated for both groups. The results given in Table 4.6, last two columns, show that in all cases except for sucrose, the correlations of the elderly are higher (and in most cases even substantially higher) than those of the young. Furthermore, inspection of the scatter plots shows that the lower correlations of the young are almost exclusively due to the fact that they rated the intensities of stimuli without a nose clip higher than with a nose clip. Further careful inspection of the plots showed no additional abnormalities which might explain the differences between the correlations found for the young and the elderly. As an example Figure 4.4 is given, showing the scatter plots of both groups for the averages per person over all compounds.

If one should accept the hypothesis that smell plays a role, there are two possible ways in which this might take place. First, the tastants themselves might have a smell. To the knowledge of the present authors, this possibility, unlikely as it seems for most tastants with the possible exception of acetic acid, has never been tested seriously.

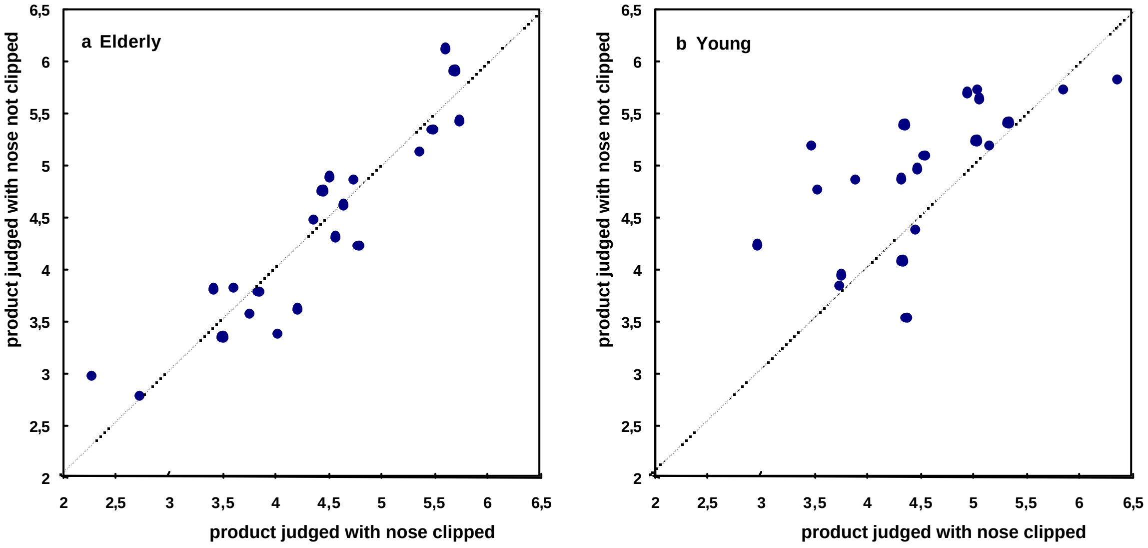

Figure 4.4 Correlations between intensities of the 10 compounds in product when assessed with and without nose clip for elderly **(a)** and young **(b)** subjects. The intensities are averaged per person over all compounds per condition.

In the second place, the presence of the tastants might interact with the olfactory perception of the medium in which they are presented. That this latter possibility exists when the tastants are presented in product is evident, since some of them (MSG and IMP) are known flavour enhancers but might this also be true in the case of water? It would suggest that water has a smell of its own which is changed by tastants. Unfortunately, in the present study this has not been tested, since there was no condition in which tastants dissolved in water were assessed with nose clips on. The results of a separate experiment, which is now underway (chapter 7), will have to clarify this matter.

Acknowledgements

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Chapter 5

Taste perception with age:
Pleasantness and its relationships with threshold sensitivity and supra-threshold intensity of five taste qualities?

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Abstract

The relationships between threshold sensitivity, supra-threshold intensity of NaCl, KCl, sucrose, aspartame, acetic acid, citric acid, caffeine, quinine HCl, monosodium glutamate (MSG) and inosine 5'-monophosphate (IMP), and the pleasantness of these stimuli in products, were studied in 21 young subjects (19-33 years) and 21 older subjects (60-75 years). For the young, threshold sensitivity was unrelated to supra-threshold intensity for all tastants and in all experimental conditions. For the elderly, in a few cases a relationship was found between threshold sensitivity and supra-threshold intensity, but only when subjects wore a nose clip. The optimally preferred concentration did not differ between the elderly and the young when the products were tasted without a nose clip, except for both sweet tastants, where elderly men showed a higher optimally preferred concentration than did the young. The optimally preferred concentration did not depend on the pleasantness of the foods and was unrelated to threshold sensitivity, but did show a negative correlation with the supra-threshold intensity of sucrose, aspartame and citric acid for the elderly and of NaCl, sucrose and caffeine for the young. This study does not support the assumption that age-related loss of taste sensitivity will inevitably lead to a preference for taste-enhanced foods.

Introduction

It is well established that sensory acuity diminishes with age and that within the chemical senses, the sense of smell is more prone to losses with age than is the sense of taste (Murphy, 1993). It is also widely assumed that such losses inevitably lead to less pleasure derived from eating (see the critical review of this notion by Mattes, 2002), and to a preference for stronger flavoured/tasting products (Pangborn, Braddock and Stone, 1983; Murphy and Withee, 1986; Schiffman and Warwick, 1993; De Graaf, Van Staveren and Burema, 1996). As a consequence, age-related changes in sensory perception and preference are believed to have a major impact on appetite and food intake. The validity of this causal relationship between sensory acuity and intake has been questioned by Pangborn and Pecore (1982), who found no correlations between taste detection thresholds, supra-threshold intensity and hedonic responses to salt in tomato juice among young adults, and concluded that these were independent behavioural measures. Their conclusions are supported by De Graaf, Polet and Van Staveren (1994), who found no increase in pleasantness with increasing sweetness of sucrose in yoghurt. However, this lack of significant correlation is not surprising when one bears in mind that hedonic ratings often show an inverted u-shape function (Moskowitz, 1977), i.e. the liking increases first, then peaks, and subsequently diminishes with increasing concentration. This will specifically be the case when commercially available products are used as the second product in the range, since these products have already been optimised for liking by their manufacturers.

A relationship between taste sensitivity and the optimally preferred concentration is described by a number of authors who have used different age groups to study differences in sensory acuity. Pangborn et al. (1983) found that elderly added more salt to chicken broth than did the young. Murphy and Withee (1986) showed that, compared to the young, the elderly preferred higher concentrations of NaCl in a low-sodium vegetable juice, and of sucrose and citric acid in a lemon flavoured drink. The same authors noticed that the elderly preferred higher concentrations of casein hydrolysate in an amino acid-deficient soup base (Murphy and Withee, 1987). The optimally preferred concentration was not related to the perceived intensity, however. Chauhan and Hawrysh (1988) reported that in a low-acid apple drink, the citric acid concentration that was assigned the highest pleasantness rating was lower for the young than for the elderly. In contrast, Chauhan (1989) found that the elderly and the young did not differ in their maximally preferred level of NaCl in low-sodium chicken soup. Mixed results were also found by De Graaf et al. (1996), who reported a higher optimally preferred concentration of appropriate food flavours for the elderly than for the young in orange lemonade, but not in bouillon, tomato soup or chocolate custard. De Jong, De Graaf, and Van Staveren (1996) found that the elderly preferred higher sucrose concentrations in orange lemonade, strawberry jam, and strawberry yoghurt, but not in chocolate spread or grain porridge. Zandstra and De Graaf (1998) reported lower optimally preferred concentrations of citric acid in orange drink among young adults, but the study was unable to demonstrate a clear difference between elderly and young adults for sucrose and orange flavour in the same product. Lastly, Drewnowski, Ahlstrom Henderson, Driscoll and Rolls (1996) found no difference in optimally preferred concentrations between age groups, but did show that, on average, the elderly showed a preference for *lower* salt concentrations in chicken soup.

The study reported here is part of a larger study, with a fixed group of elderly and young subjects, in which the influence of ageing on taste perception has been investigated. In a first paper (Mojet, Christ-Hazelhof and Heidema, 2001), the effects of ageing on threshold sensitivity to the five taste qualities sweet, salty, sour, bitter and umami, each represented by two compounds, were determined both when dissolved in water and in a food product. A significant effect was found for age, but not for gender. Nevertheless, especially the older men were less sensitive than the young men and women for most of the tastants. To detect the compounds dissolved in water they needed a 1.32 (aspartame) to 5.70 times (IMP) higher concentration than the young. The age effects could be attributed predominantly to a generic loss in taste sensitivity. The total variance due to age could be separated into 93% for age, 4% for age x taste quality, 1% for age x taste component and 2% for error.

In a second paper (Mojet, Heidema and Christ-Hazelhof, 2003), the age effects on the perception of supra-threshold intensities were determined for the same ten tastants, dissolved respectively in water and in product. In the latter case the products were assessed while the subjects were or were not wearing a nose clip in order to verify the possible influence of the product odour on the taste measurements. Difference tests were carried out first with the same elderly and young to ascertain that the concentration ranges to be used in the main experiments were wide enough to perceive concentration differences in water and in product. While the relative perception (intensity discrimination) seemed to be remarkably resistant to the effect of ageing, the absolute perception (intensity rating) decreased with age for all tastants in water (single taste

perception), but only for the salty and sweet tastants in product (complex taste-texture-smell perception). When the subjects wore a nose clip while assessing the products (complex taste-texture perception), the influence of age was further reduced to the salty tastants only. These findings underline the important role of the perceptual context and the limited relevance of assessing intensity perception of tastants dissolved in water for the 'real life' perception of taste in complex food systems. The age effects found in the water and the product assessed without nose clip condition were almost exclusively generic and never compound-specific. In the product with nose clip condition, there was an indication of some taste-quality-specificity.
The present paper describes the impact of age on the preference for 'real life' products in relation to the taste acuity at threshold and supra-threshold level in the same subjects.

Materials and methods

Subjects

The same 21 older subjects (age 60-75, 10 male, M=66.0, SD=3.6, and 11 female, M=64.6, SD=4.2) and 21 young subjects (age 19-33, 11 male, M=26.5, SD=3.6, and 10 female, M=23.2, SD=3.3) participated in all experiments described here. They had all taken part in two previous series of experiments, one on threshold sensitivity (Mojet et al., 2001) and one on supra-threshold intensity (Mojet et al., 2003). All subjects were Caucasian and met the following criteria: healthy, not on a diet, not living in a home for the elderly, not taking any prescribed medicine, non-smoking, not heavy alcohol users, not pregnant or lactating, not subject to food allergies, good dental hygiene, and not wearing dentures (however, as it was very difficult to recruit enough fully dentate elderly subjects, those with partial dentures were admitted, but were not allowed to wear these during testing). Furthermore, since hearing was to be used as a matching modality for taste, all subjects had normal hearing as tested at 750 Hz (see Mojet et al., 2001 for detailed selection criteria). Subjects were recruited by advertisements in local newspapers and on bulletin boards in senior citizen centres. All subjects were paid for their participation.

Stimuli

Five taste qualities were investigated: saltiness, sweetness, sourness, bitterness and umami taste. For each taste quality, two representative compounds were chosen, which were administered at five concentration levels (ascending 0.2 log steps) both in distilled water and in commercially available products. In a preliminary experiment, concentrations in water were matched to the perceived intensities in product by three descriptive panels, each consisting of 16 trained QDA® panellists, at the sensory facilities of Unilever Research & Development, Vlaardingen. Table 5.1 gives an overview of the compounds, concentrations and products. The compounds were grouped into two sets, containing one compound for each of the five taste qualities. One set contained NaCl, sucrose, acetic acid, caffeine and MSG, the other set consisted of KCl, aspartame, citric acid, quinine HCl and IMP. The food products were versions of commercially available ice tea, chocolate drink, mayonnaise, tomato soup and bouillon (all five, products of Unilever), which were varied by the omission or addition of the tastants to be tested. An exception in the concentration levels was made for mayonnaise (ascending 0.1 log steps), since the total concentration difference could not be larger than 0.4 log for technical reasons. Since the aim of the experiments was to study age differences in the perception of tastants in normal products rather than to investigate the effect of different tastants on a product, the tastants were embedded in products in which they do occur naturally in normal life and were not all varied in the same product. Furthermore, the second step in the range of five concentrations corresponded to the usual concentration of the compound in each selected product, except in the chocolate drink, where the customary concentration was equal to the first step. Using different products for different taste qualities, helped also to better assess the generality of the age effects in a larger food context.

For the assessment of the compounds in water, solutions were prepared the day before testing and tested at room temperature. For the assessment of the

Table 5.1. Concentrations in g/l of the taste stimuli in water and in products

Taste quality	Compounds	dissolved in water		log	dissolved in product		log	Products
		lowest	highest	steps	lowest	highest	steps	
sweet	Sucrose	8.55	53.95	0.2	53.95	340.38	0.2	ice tea
	Aspartame	0.06	0.37	0.2	0.15	0.92	0.2	ice tea
salt	NaCl	3.58	22.61	0.2	5.68	35.83	0.2	tomato soup
	KCl	5.68	35.83	0.2	9.00	56.77	0.2	tomato soup
umami	MSG	1.99	12.58	0.2	1.58	9.95	0.2	broth
	IMP	1.26	7.94	0.2	1.00	6.28	0.2	broth
bitter	Caffeine	0.16	1.00	0.2	0.63	3.98	0.2	chocolate drink
	Quinine HCl	0.00	0.01	0.2	0.01	0.03	0.2	chocolate drink
sour	Acetic acid	0.63	4.00	0.2	0.27	0.67	0.1[a]	mayonnaise
	Citric acid	1.26	7.92	0.2	0.02	0.05	0.1[a]	mayonnaise

[a] for product technical reasons

compounds in product, these were mixed with the dry product beforehand, prepared on the day of testing, and served at room temperature. However, the mayonnaise was prepared beforehand at the Unilever pilot plant at Vlaardingen. The subjects received 20 ml of each stimulus in a disposable 50 ml plastic cup.

Five levels each of auditory (loudness), visual (size) and kinaesthetic/tactile (weight) stimuli were included to be eventually used as controls in cross-modal intensity matching.

As auditory stimuli, 1.5 second bursts of a narrow band of noise centred at 750 Hz were recorded, with intensities varying from 45 to 85 dB in 10 dB steps. These sounds were delivered to the subjects through earphones. As kinaesthetic stimuli, five weights were constructed varying in 0.2 log steps from 33.7 to 212.6 grams and hidden in small black (film) containers of equal size which subjects lifted with the top of the forefinger by means of a ring on a string connected to the container. As visual stimuli, an irregular star figure was multiplied in ascending 0.2 log size steps.

Procedure

The procedure was the same in the three experiments (in water, in product with and without wearing a nose clip). The stimuli were presented one after the other using the sip-and-spit method, and separate sessions were held for the elderly and the young, since more time and more elaborated instructions were required for the elderly. At the start of a session and before each new taste quality was introduced, subjects were instructed to eat a piece of cream cracker, rinse the mouth with distilled water and expectorate. Each experiment consisted of three sessions, one on each of three consecutive days. In each session of an experiment, all ten compounds were presented once at five concentrations in five series, one for each taste quality. These taste compounds were alternated with three replications of auditory, visual and weight stimuli at five levels. This alternation prevented monotony on the one hand and prolonged the inter-taste-stimulus interval up to two minutes on the other, diminishing the induction of fatigue. Before the experiment started the subjects were familiarised with those stimuli by presenting the lowest and highest in the range. Thus, the subjects assessed 50 taste stimuli and 45 cross-modal stimuli in one session. Each session lasted two hours. Between two taste quality series within a session there was a break of 5 minutes.

The order in which taste qualities were presented differed over the three days, as did the presentation order of the stimuli within each series. In total, each taste stimulus was assessed three times and each cross-modal stimulus was assessed nine times per experiment. Since the major interest was in unconfounded differences between the two age groups, the presentation order of the compound concentrations and the cross-modal stimuli was the same for all subjects. Possible taste order effects were considered to be strongly reduced by the interspersing of the taste stimuli with the stimuli from the other sensory modalities.

All taste samples were assessed on their intensity of salt, sweet, sour, bitter and umami and on liking, whereas the cross-modal stimuli were rated on intensity only. Intensities were marked on a 9-point scale with the anchors ‘very weak’ to the left and ‘very strong’ to the right. For the taste stimuli, liking for the water or for the product was assessed on a 9-point pleasantness scale with the anchors ‘very little’ to the left and ‘very much’ to the right. Since the Dutch are raised not to admit to food dislike, this scale was considered more appropriate than a like – dislike scale. Results from the evaluation of the intensities of those tastes that were not experimentally varied, and those from the comparison of the intensity of cross modalities, will be reported elsewhere.

Statistical analysis

Methods

Statistical analyses were conducted with SAS® and SAS/STAT® with data averaged arithmetically over replications and concentrations to correlate the threshold, intensity and pleasantness data. After checking for normal distribution, influences of age and gender were analysed by means of analysis of variance to compare all permutations of the groups of elderly men, elderly women, young men and young women, using the LSMeans method. Subsequently, the optimal preferred concentration (OC) of each taste compound was determined for each subject by selecting the concentration step with the highest pleasantness rating, taking ties into account. The influence of age and gender on this OC is analysed by means of analysis of variance. All correlations were carried out with PROC CORR, and the analysis of variance was conducted using PROC GLM.

Levels of significance

All effects that have a p-value of 0.05 or lower are reported as 'significant'. Power Analysis shows that, with the number of subjects in our study, an effect with a magnitude of 1.3 standard deviations and a p-value of 0.10 still has a power of 0.90. Therefore a selection of the more interesting effects with a p-value between 0.05 and 0.10 are reported additionally. These effects will be denoted as 'trends' or 'tendencies'.

Cross-modal intensity matching

All intensity and liking data reported here are based on scores that were corrected by means of the Cross-Modal Intensity Matching (CMIM) method, as described in a previous paper from this group (Mojet et al., 2003). Auditory stimulation was selected to correct the present data for differences in scale usage since the sensitivity to low-frequency sounds (around 750 Hz) is normally not impaired with age and because an analysis of variance of the results for each of the five sound levels did not show any systematic age or gender variations.

The matrix of the CMIM data consisted of 42 subjects, 27 replications per individual, and 5 different levels of loudness per replication. On average, the standard deviation per individual/level of loudness was fairly constant and in the order of 0.9, indicating that the standard error of an individual/level of loudness combination is in the order of 0.17 ($0.9/\sqrt{27}$). The correction steps were as follows. First, the individual average and the age group average were determined for each sound level. Then, the (individual minus group) averages (which also have a standard deviation of approx. 0.17) were regressed against the group averages using polynomial functions of the latter, starting with a polynomial of degree 0 (constant difference from group mean) and ending with a polynomial of degree 4 (complete fit of individual means). Subsequently, the lowest polynomial with a residual standard deviation of ca 0.17 was selected as the assessor's correction formula for each subject. Finally, each individual score on the scale was corrected by a value obtained from the individual's correction formula.

All data to be reported here are based on scores that were corrected by means of this method.

Results

Influence of age and gender on pleasantness

The means and standard deviations of all data discussed in this paper are given in Table 5.2. A significant overall age effect on the reported pleasantness of the products evaluated with [$F(1,416) = 12.06$, $P < 0.0006$] and without nose clip [($F(1,416) = 5.30$, $P < 0.03$] was found. In general, the elderly liked the products more than the young. In particular, they rated the pleasantness of the tomato soup and the broth higher than the young did, both when tasted with or without nose clip.

Table 5.2 Means and standard deviations of thresholds and perceived intensities in water and in product assessed with and without nose clip (nc) by elderly (n=21) and young (n=21) subjects. Thresholds are given in 0.2 log concentration steps and intensities are measured on a 9-point visual analogue scale, averaged over 5 concentrations, and corrected by cross modal intensity matching.

	water				product				product rated with nose clipped			
	thresholds		intensity		intensity		pleasantness		intensity		pleasantness	
compounds	elderly	young	elderly	young	elderly	young	elderly	young	elderly	young	elderly	young
NaCl	8.72	7.26	5.27	6.22	4.12	5.14	3.38	2.58	3.91	4.62	3.70	2.64
	1.99	*1.37*	*0.72*	*0.81*	*0.97*	*0.94*	*1.23*	*1.40*	*1.19*	*1.10*	*1.01*	*1.36*
KCl	8.18	6.02	6.09	6.67	5.08	6.18	2.34	2.59	4.76	5.63	2.09	2.18
	2.19	*1.57*	*1.11*	*0.77*	*1.42*	*0.90*	*0.97*	*1.03*	*1.55*	*1.21*	*0.91*	*0.99*
Sucrose	5.84	5.23	4.04	4.61	5.36	6.24	3.50	3.62	5.11	5.50	3.41	3.96
	1.51	*1.09*	*0.86*	*0.60*	*1.18*	*0.74*	*1.32*	*1.39*	*1.15*	*0.92*	*1.09*	*1.65*
Aspartame	7.19	6.93	4.21	4.64	3.80	4.46	2.94	3.38	3.79	4.03	2.95	3.73
	1.64	*1.34*	*1.03*	*0.53*	*1.11*	*0.69*	*0.97*	*1.51*	*0.99*	*0.86*	*0.77*	*1.71*
Acetic acid	7.63	7.29	5.77	6.49	4.59	5.12	3.75	3.71	4.85	4.70	4.13	3.69
	2.31	*1.73*	*0.86*	*0.63*	*1.37*	*1.23*	*1.07*	*1.50*	*1.40*	*1.38*	*1.28*	*1.90*
Citric acid	4.67	3.72	5.50	6.08	4.06	4.62	3.66	3.30	4.13	3.96	3.92	3.49
	1.73	*0.80*	*1.01*	*0.84*	*1.27*	*1.06*	*1.16*	*1.36*	*1.39*	*1.14*	*1.21*	*1.65*
Caffeine	8.06	7.06	2.77	3.45	4.40	4.80	4.08	3.67	4.44	4.74	4.21	3.59
	1.78	*1.82*	*1.09*	*0.70*	*1.47*	*1.24*	*0.98*	*1.25*	*1.42*	*1.28*	*1.04*	*1.40*
Quinine HCl	6.52	5.41	2.50	3.37	2.96	2.81	4.69	5.11	2.98	2.65	4.99	5.10
	2.25	*2.09*	*0.94*	*0.94*	*1.25*	*0.94*	*1.71*	*1.58*	*1.21*	*0.99*	*1.44*	*1.45*
MSG	8.92	7.78	2.79	3.93	4.34	4.84	3.96	3.16	4.58	4.41	4.47	3.31
	2.20	*2.03*	*0.76*	*0.85*	*1.19*	*1.29*	*1.18*	*1.59*	*1.27*	*1.11*	*1.21*	*1.57*
IMP	7.18	4.22	2.68	3.98	4.67	5.08	3.98	3.02	4.94	5.08	4.42	2.92
	2.58	*1.38*	*0.75*	*0.92*	*1.23*	*1.59*	*1.56*	*1.52*	*1.49*	*1.38*	*1.31*	*1.54*

Apart from the age effect, a significant gender effect on the perceived pleasantness of the products assessed with [$F(1,416) = 62.68$, $P < 0.0001$] and without nose clip [$F(1,416) = 54.92$, $P < 0.0001$] was shown. For all five products, men reported higher liking scores than did women.

Influence of age and gender on optimal concentration

Tasted without nose clip, no significant effects of age were found for the tastants overall (lsmean =2.86 and 2.66 respectively for elderly and young), or for any of the individual compounds except for sucrose tasted in ice tea [$F(1,38) = 6.05$, $P < 0.02$], where the elderly showed a higher optimum than the young. In addition, a significant gender effect [$F(1,38) = 8.43$, $P < 0.01$] was found for sucrose in ice tea. Men preferred a higher concentration than women, and the age by gender effect [$F(1,38) = 6.65$, $P < 0.01$] indicated clearly that elderly men had not only a significantly higher optimum for sucrose in ice tea than young men and women, but also than elderly women. The age by gender effect found for aspartame in ice tea, whether tasted with nose clip [$F(1,38) = 4.85$, $P < 0.04$] or without [$F(1,38) = 11.63$, $P < 0.01$], indicated that elderly men had a higher optimum than young men and elderly women, but not than young women. Figure 5.1 shows the optimally preferred concentrations. When the products were tasted while wearing a nose clip, the optimally preferred concentration taken over all compounds was higher for the elderly than for the young [$F(1,416) = 6.34$, $P < 0.02$], due to the fact that elderly men (lsmean = 3.03) had a slightly, but significantly, higher optimally preferred concentration than young men (lsmean = 2.52) and young women (lsmean = 2.66), but did not differ from elderly women (lsmean = 2.77). Analyses by individual compound revealed that the elderly showed a higher optimally preferred concentration for acetic acid in mayonnaise [$F(1,38) = 13.90$, $P < 0.01$] and MSG in broth [$F(1,38) = 5.53$, $P < 0.03$].

Relationships between threshold sensitivity and supra-threshold intensity

In order to relate sensitivity at threshold with supra-threshold level, the thresholds values were reversed in sign. Pearson Product Moment correlation analysis showed almost no relationships between threshold sensitivity and supra-threshold intensity in water and in product. Three out of the thirty possible correlations (two positive and on negative) were found to be significant for the elderly: NaCl ($R = -0.44$, $P = 0.04$) and sucrose ($R = 0.49$, $P = 0.03$), both when the threshold sensitivity and the supra-threshold intensity in water were compared, and acetic acid ($R = 0.50$, $P = 0.02$) when threshold sensitivity and supra-threshold intensity in product were compared. This means that the more sensitive the elderly were at threshold level, the *lower* they rated the saltiness of NaCl, and the higher they rated the sweetness of sucrose in water and the sourness of acetic acid in product (mayonnaise).

For the young also three out of thirty significant correlations were found: for NaCl ($R = 0.55$, $P = 0.02$) and citric acid ($R = 0.47$, $P = 0.03$) when intensity in water and in product were compared, and for IMP ($R = -0.44$, $P = 0.04$) when threshold sensitivity was compared with intensity in product. This means that the higher they rated both the saltiness of NaCl and the sourness of citric acid in

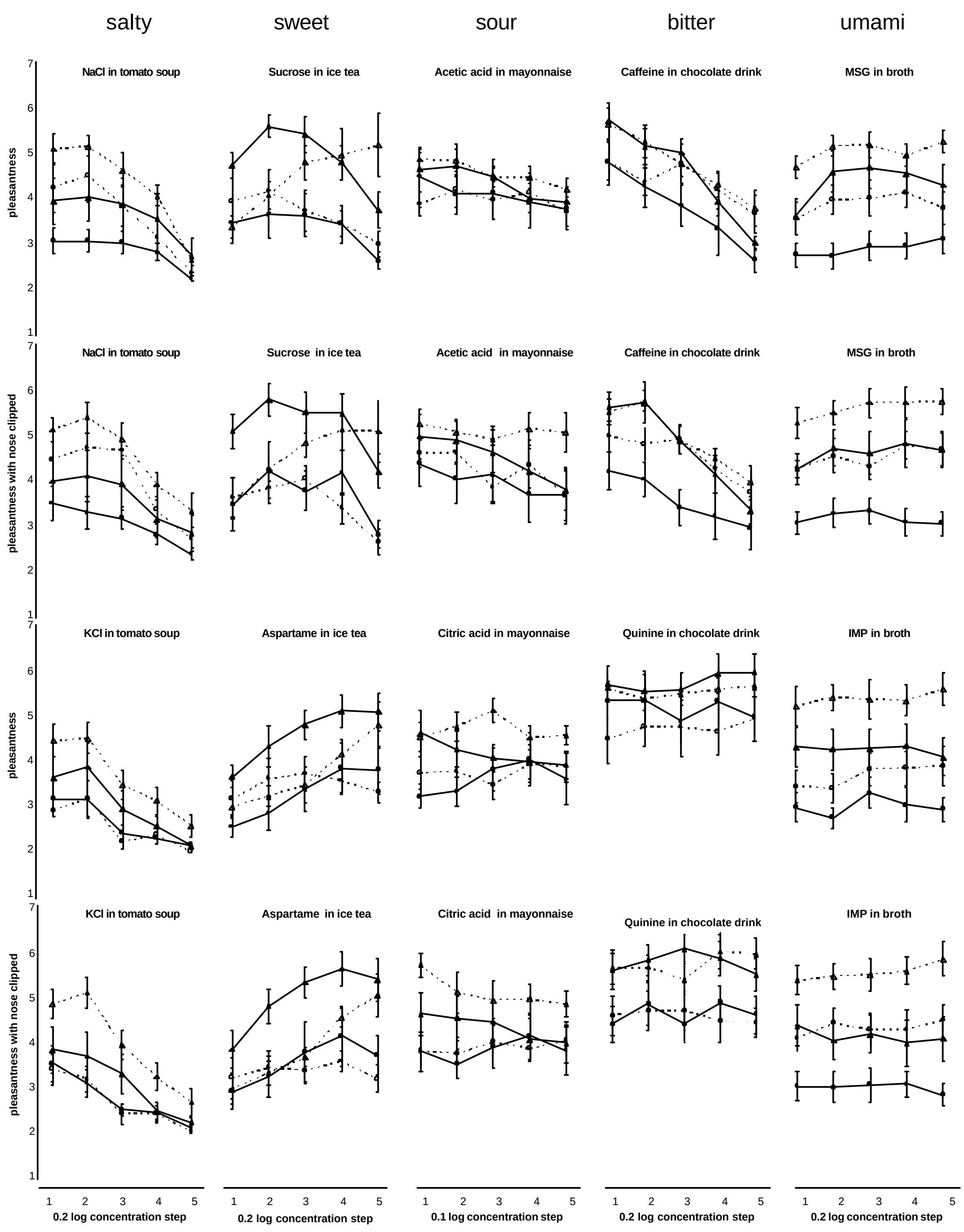

Figure 5.1 Pleasantness ratings for five concentrations of ten tastants embedded in food and assessed with nose clip or not by elderly and young male and female subjects. Elderly subjects are represented by dotted lines and open symbols, young subjects by solid lines and filled symbols. Male subjects are represented by triangles and female subjects by circles.

water, the higher they rated these tastes in product. Concerning IMP, it could mean that the more sensitive the young are at threshold level, the *lower* they rate the umami intensity of IMP in product (broth), but the significance of this correlation might well be purely accidental, since the young hardly discriminated between the different concentrations of IMP in product (Mojet et al. 2003). When multiple testing was applied none of the correlations bore significance. This casts serious doubts on the 'ecological validity' of threshold measurements, i.e. the meaningfulness of threshold measurement for the prediction of sensory experiences in normal everyday life.

Relationships of optimal concentrations with threshold sensitivities and with supra-threshold intensities

Since in the literature the suggestion is often raised that loss of sensitivity leads to diminished food liking, the relationships have been investigated between measures of sensitivity (i.e. thresholds in water and intensities in water and product) on the one hand and optimally preferred concentrations of the tastants in them on the other. Not a single significant correlation is found between threshold sensitivity and optimal concentration. A few significant negative correlations were found both for the elderly and the young when comparing supra-threshold intensity in water and optimal concentration in product, i.e. for NaCl (R = -0.50, P <0.05) and caffeine (R = -0.60, P < 0.001) assessed by the young and for aspartame (R = -0.58, P < 0.01) and IMP (R = -0.46, P < 0.05) assessed by the elderly. This means that the higher the perceived intensity is in water, the lower the optimally preferred concentration is in product.

When the optimal concentration and supra-threshold intensity both in product were compared for the young, a negative correlation was found for NaCl assessed with or without nose clip (R = -0.45, P < 0.05 and R = -0.54, P < 0.01 respectively), for caffeine assessed without nose clip (R = -0.48, P < 0.05) and sucrose (R = -0.50, P < 0.05) assessed without nose clip, and for aspartame (R = -0.53, P < 0.05) assessed with nose clip. For the elderly, a negative correlation was found for aspartame assessed with or without wearing a nose clip (R = -0.59, P < 0.01 and R = -0.77, P < 0.001 respectively), and for sucrose

(R = -0.49, P < 0.05) and citric acid (R = -0.45, P < 0.05) when they did not wear a nose clip.

Relationships of the optimal concentration with the mean pleasantness in product

To determine whether the optimal concentration (OC) was higher for products that were more liked, OCs were correlated with mean pleasantness ratings. No significant relationship was found for any of the compounds in product when tasted without nose clip. Tasted with a nose clip, a significant positive correlation was found for sucrose (R = 0.436, P = 0.05) and for acetic acid (R = 0.449, P = 0.04) in the elderly only. However, this finding of two significant correlations out of forty cases is no more than may be expected on the basis of chance. Since at the same time the correlations between the pleasantness ratings for products tasted with and without a nose clip is high in both groups (young R = 0.89, P < 0.0001; elderly R = 0.86, P < 0.0001), indicating that pleasantness ratings are well spread over the scale and stable over a week, it seems reasonable to conclude that the optimally preferred concentration of the varied tastant does not depend on the pleasantness of the product.

The influence of perceptual context on the optimally preferred concentration and on pleasantness

The perceptual context, i.e. the taste-texture perception of the product assessed with a nose clip or the smell-taste-texture perception of the product assessed without a nose clip, had no influence on the optimally preferred concentrations when analysed over all compounds or by individual compound. An interaction effect with age was found only for acetic acid, where in the taste-texture condition the elderly showed a higher OC and the young showed a lower OC than in the smell-taste-texture condition. No pleasantness ratings differed significantly under the different perceptual contexts. All correlations between the pleasantness rated with and without nose clip were higher than 0.70 and were highly significant (P < 0.001).

Discussion

Perhaps the most significant result of this investigation is the fact that, contrary to what is often assumed, the measurements of threshold sensitivity and perceived supra-threshold intensity not only do not seem to be related amongst themselves, but do also in general not seem to be related to the optimally preferred concentrations in both elderly and young. This raises questions about the importance of sensory taste cues in the appreciation of foods. Before discussing these questions the data obtained here are compared to the findings of other authors.

No relationship was found between threshold sensitivity and supra-threshold intensity in water and product for the young. This finding is in agreement with the results reported by Pangborn and Pecore (1982) for NaCl in water and tomato juice and by Mattes (1985) for bitter and sweet in water and in food with relatively young subjects. These authors also found that the three taste measures were unrelated.

For the elderly, a positive correlation was found between threshold sensitivity and supra-threshold intensity in product assessed both with and without a nose clip, but only when analysed over all ten compounds. The finding that the more sensitive the elderly were at threshold level, the lower they rated the perceived intensity of NaCl in soup was surprising and can not be explained by the present authors. The present findings do not support the assumption that measuring taste sensitivity by thresholds and supra-threshold intensities in water will predict supra-threshold intensities in foods.

All five products were more liked by the elderly than by the young and more by men than by women. Since the products are traditional foods for the subjects, this may reflect a difference in eating and drinking habits and may not be related to the experimental variation of the added compounds.

Two types of difficulties arise when the present results concerning the effect of age on optimally preferred concentrations are compared with the findings in the literature. The first difficulty lies in the extent to which results can be generalised, since different studies use different food systems. This means that the results of this study can contribute to the assessment of the generality of age effects, but can only be compared with other studies in a direct way with much caution. Differences in outcome might be due to differences in products used.

The second difficulty is related to data treatment. Different authors use different methods to calculate the optimally preferred concentration. De Graaf and Zandstra (1999) estimated the OPC by using a formula in which the four concentrations that were rated highest for pleasantness were rank ordered and multiplied by descending weighting proportions in such a way that the sum of the weights was one. In a previous paper (De Graaf et al., 1996), the value at which a fitted polynomial reached its maximum was taken as the optimal intensity. Other papers give no explanation of the calculations used (De Graaf et al., 1994; De Jong et al., 1996; Zandstra and De Graaf, 1998; Murphy and Withee, 1986; Murphy and Withee, 1987). Chauhan and Hawrysh (1988) used trend analysis in the determination of the OC. Unfortunately, it is not clear whether they used the maximum of the fitted polynomial or “the concentration level given the highest pleasantness estimate by a given subject” for this purpose, since their text is not consistent with the data in their corresponding table. In all of these experiments, including the present one, there is a discrepancy between the optimally preferred concentration taken as the concentration with the highest mean pleasantness rating for each age or age-gender group (Figure 5.1) and the optimally preferred concentrations found by averaging the OCs for each subject per age or age-gender group. Figure 5.1 presents the data actually measured and reveals whether the optimally preferred concentration is distinct from other concentrations in the given range, i.e. the width of the optimally preferred concentration can be inferred from the graph.

If, notwithstanding the differences in food systems used, the results of the present study are compared with the findings in the literature, only results for sodium chloride, sucrose and citric acid are available. In the present study elderly and young did not differ in their optimally preferred concentration of NaCl in tomato soup. This finding supports neither the findings of Pangborn et al.

(1983) nor those of Murphy and Withee (1986), who both found that the elderly preferred a higher concentration of NaCl in chicken broth and vegetable juice respectively, nor the findings of Drewnowski et al. (1996) who found that the elderly had a *lower* optimally preferred concentration of NaCl in chicken soup. No age effect on the optimally preferred citric acid concentration in mayonnaise was found in the present study. Thus, again no support was found for either of the opposing findings of Chauhan and Hawrysh (1988), who reported that the young had a lower optimally preferred citric acid concentration in an apple drink, and of Zandstra and De Graaf (1998), who found a higher optimally preferred concentration of citric acid in an orange drink. These last authors also found that the elderly preferred a higher concentration of sucrose in an orange drink, a finding that had previously been reported by De Jong et al. (1996) using sucrose in orange lemonade, strawberry jam, yoghurt, chocolate paste and grain porridge. In the present study, a higher optimally preferred concentration for sucrose was also found among the elderly when the ice tea was tasted without a nose clip. This result was mainly due to the elderly men, who also showed a higher optimally preferred aspartame concentration in ice tea, a finding similar to that reported by Enns, Van Italie and Grinker (1979). However, De Graaf et al. (1994) reported no age differences in optimally preferred sucrose concentrations in yoghurt.

Only one single paper (Mattes, 1985) has described the correlation between sensitivity, supra-threshold intensity and preferred concentration. The author reported that these measures were unrelated for sucrose in a cherry flavoured beverage and urea in tonic water. Unlike Mattes' (1985) findings, in the present study a negative correlation was found for both age groups when sucrose was assessed without a nose clip. Although some correlations are found in the present data, the threshold sensitivity, supra-threshold intensity and optimally preferred concentration were unrelated for most of the tastants. Thus, the widely spread assumption that taste losses with age will inevitably lead to a preference among the elderly for stronger tasting products is not supported by the results of this study. Although losses in taste sensitivity were found (Mojet et al., 2001; Mojet et al., 2003), the elderly showed no increase in preferred concentration when products were tasted normally, i.e. without a nose clip. Three not mutual exclusive hypothetical explanations of this stability in preferred concentration with age will be forwarded.

In the first place, taste might play only a minor role in food appreciation compared to smell and texture and therefore losses in taste would not induce food preference changes. This explanation is very unlikely, since in many cultures it is customary to provide salt, sugar and in some cultures even vinegar for the adjustment of foods to the individual optimum, which seems to indicate that they play an important role in the pleasantness of food. It has also been shown (Köster, Prescott and Köster, 2003) that people have a very precise memory for bitterness and a good memory for acidity and that these memories are highly correlated with the memory for liking. Thus, taste seems to be an important factor in liking. Furthermore, there is no evidence that losses in olfaction have more profound effects. Ferris and Duffy (1989) for instance, found no relationship between reported food intake and olfactory losses. In addition, Mattes et al. (1990) reported that patients with distorted or phantom smell and/or taste sensations tended to report weight loss, whereas those with simple sensory loss were more likely to report weight gain. This indicates that sensory losses probably do not lead to a loss of food pleasantness, but that distorted perception (probably mostly cacosmia) does. Finally, it should be pointed out that wearing a nose clip, which severely restricts (if not excludes) ortho- and retronasal olfactory stimulation, does not significantly affect the pleasantness ratings for the products in the present experiment.

A second hypothesis to explain the stability of preference with age might be that elderly are not aware of the gradual age-related changes that occur in the relative intensity of the sensory messages they receive from a food and that as a result their internal representation of the prototypical food would be tacitly adapted and changed. This might occur either because the decay of the sensitivity with age is too slow to be noted or because age-related changes in the signal to noise ratio lead to a widening of the tolerances and to more generalisation in the acceptance of slightly deviating foods. There is no evidence for the first of these two possible mechanisms since, to the knowledge of the present authors, there have been no studies in which the effects of sudden and of gradual sensory loss on food pleasantness were compared. With regard to the second mechanism, it should be pointed out that it has been shown in a preliminary experiment with the same subjects (Mojet et al. 2003) that the discriminative ability is at least as good in the elderly as in the young. In the present experiment this is also the case, because the pleasantness curves did not show flatter slopes for the elderly, indicating that the elderly were not more tolerant in their hedonic acceptance of product deviations. Therefore, an explanation in terms of the second mechanism is not very likely, but it can not be excluded that, based on the first mechanism, the stability in the optimally preferred concentration is due to a changed internal representation or mental image of the product.

A third explanatory hypothesis is that liking of a well-known food has less to do with its sensory properties than is usually assumed. Humans are omnivores and have to learn to appreciate foods. One could argue that in this learning process the sensory properties of the food act merely as signals that have become associated with the feelings of post-ingestive satisfaction (e.g. satiety, changes in blood sugar level, etc.) which are supposed to form the basic motivation for eating the food. The elderly still like the food that gives the same satisfaction, but they simply have learned to associate it with different sensory signals. In other words, the internal representation in terms of intestinal feelings of satisfaction (and not as a mental image of sensory properties) remains constant with age and this forms the basis for the stability, independently of the sensory impressions with which this internal representation is connected. Support for this hypothesis comes from the finding that the young lose their advantage over the elderly in sensory acuity when products are assessed while wearing a nose clip (Murphy, 1985; Mojet et al., 2003), while such differences are not found in their hedonic measures of the products when they are assessed under these two different sensory input conditions (taste-texture only versus taste-texture-smell). The fact that Ferris and Duffy (1989) and Mattes et al. (1990) did not find a negative effect of losses in sensory input on food intake, lends further support to this third hypothesis. Although it is difficult to exclude this last hypothesis and it is even probable that intestinal satisfaction plays a role in modulating our sensory appreciation of a food, it seems highly unlikely that sensory information plays only a secondary role in food appreciation. People do develop their taste for food during their life span and sensory impressions play an important role in the acceptation of novel foods.

Which or which combination of the two mutually not exclusive latter hypotheses best explains the fact that age-related changes in sensory acuity do not necessarily lead to changes in food preference, should be cleared by further investigation. In the meanwhile it is clear that elderly people even when they lose some sensory capabilities show a remarkable stability in their liking for food. This also means that no support is found for statements about the necessity to develop special food for the ageing population.

Chapter 6

Effect of concentration on taste-taste interactions in foods in elderly and young subjects

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Abstract

An increase in concentration of one of the tastants in a 'real food' might affect not only the perception of the taste quality of that manipulated tastant but also the other perceivable taste qualities. The influence of concentration increase of sodium or potassium chloride in tomato soup, sucrose or aspartame in ice tea, acetic or citric acid in mayonnaise, caffeine or quinine HCl in chocolate drink, monosodium glutamate (MSG) or inosine 5'-monophosphate (IMP) in broth on the other perceivable taste qualities in these foods was studied in 21 young subjects (19-33 years) and 21 older subjects (60-75 years). The results showed that for each of these tastants, except for the two acids, increasing the concentration provoked significant positive or negative interaction effects on the perception of one or more other taste qualities of the product. Especially in the young, olfaction plays a larger role in the assessment of taste intensity than has been hitherto assumed. The elderly divide their attention more over the different tastes in a product, whereas the young are more strongly focussed on the dominant taste.

Introduction

Flavours in food consist of a mixture of tastes and odours accompanied by a variety of oral sensations (Pangborn, 1960). Part of the research in this area focussed on mixtures within one sensory modality such as taste (Pangborn, 1960; Kamen et al., 1961; Bartoshuk, 1975, Lawless, 1979; Lawless, 1982; Van der Heijden et al., 1983; Gillan, 1983; Frank and Archambo, 1986; Kroeze, 1989; Kroeze, 1990; Calviño et al., 1990; Schifferstein and Frijters, 1990; Frank et al., 1993; Schifferstein, 1995; Stevens, 1995; Stevens and Traverzo, 1997; Kaneda et al., 2000; Prescott et al., 2001). The excellent review of taste-taste interactions given by Keast and Breslin (2002) led to the conclusion that in general, suppression may be found with strong stimuli, whereas cases of enhancement may be found mostly with weak, near threshold stimuli.

In another approach the oral perception of mixtures of cross modal sensory stimuli such as odour and taste mixtures was investigated (Lawless, 1977; Murphy et al., 1977; Murphy and Cain, 1980; Rozin, 1982; Frank and Byram, 1988; Calviño et al., 1990; Shaffer and Frank, 1990; Frank et al., 1993; Stevenson et al., 1999; Kaneda et al., 2000). The use of a specially developed instrument to combine taste with orthonasal instead of retronasal smell (Hornung and Enns, 1984; Enns and Hornung, 1985, 1988; Gilan,1983) might not show an interaction between taste and smell, since orthonasal sniffing has much weaker effects than retronasal stimulation in the mouth (Zoeteman, 1978). The general picture emerging from this literature is that the interaction effect is strongly dependent on the compounds used. Consonant odours and tastes seem to enhance the perceived taste, dissonant odours and tastes seem either to suppress the perceived taste or to show no effect at all.

Only a few authors investigated age-related taste-taste and odour-taste interaction effects. These authors reported no age-related effects, whereas Murphy (1985), in a study on the ability to identify blended foods while blindfolded, found that the average number of correct responses on the first attempt to identify was significantly higher in young than in old subjects. With feedback and practice, performance improved, but the age effect remained significant. When deprived of olfaction by wearing a nose clip, the young lost their superiority over the elderly.

The experimental questions addressed in the present study are whether the increase of one taste compound in a food, such as sodium chloride, influences the perception of the other tastes of the food, such as the sweetness, sourness, bitterness and umami taste. Furthermore, whether, when such an influence is noticeable, it is different for elderly and young or for men and women. Finally, the role of olfaction in this experiment will be investigated.

This study is part of a larger study in which taste perception with age has been studied with ten tastants, dissolved in water and in products and assessed by a fixed group of elderly and young subjects with or without wearing a nose clip (Mojet et al. 2001, 2003 and 2004a,b). The elderly had higher thresholds than the young did. While the relative perception (intensity discrimination) seemed to be remarkably resistant to the effects of ageing, the absolute perception (intensity rating) decreased with age for all tastants in water, whereas in product this was only the case for the salty and sweet tastants.

Threshold sensitivity did neither predict supra-threshold intensity perception, nor the optimally preferred concentration of the tastants. The latter was not different for the elderly and the young, whereas the former did differ with age for a number of tastants. Apart from the intensities of the taste qualities that were experimentally varied in the food, the intensities of the non-manipulated concentrations of other taste qualities were also assessed. Throughout this paper these taste qualities (other than the manipulated taste quality in the product) will be referred to as side-tastes.

Materials and Methods

Subjects

Twenty-one older subjects (age 60-75, 10 male, M=66.0, SD=3.6, and 11 female, M=64.6, SD=4.2) and 21 young subjects (age 19-33, 11 male, M=26.5, SD=3.6, and 10 female, M=23.2, SD=3.3) participated in the experiments. They had all taken part in several series of experiments, one on threshold sensitivity (Mojet et al., 2001), one on supra-threshold intensity (Mojet et al., 2003) and one on pleasantness of the same taste stimuli (Mojet et al., 2004). All subjects were Caucasian and met the following criteria: healthy, not on a diet, not living in a home for the elderly, not taking any prescribed medicine, non-smoking, no heavy alcohol users, not pregnant or lactating, not subject to food allergies, good dental hygiene, and not wearing dentures (as it was very difficult to recruit enough elderly persons without dentures, subjects with partial dentures were admitted but they were not allowed to wear these during testing).

Furthermore, since hearing was used as a matching modality for taste, all subjects had normal hearing as tested at 750 Hz (see Mojet et al., 2001 for detailed selection criteria). Subjects were recruited by advertisements in local newspapers and on bulletin boards in senior citizen centres. At the end of the experiments the subjects were paid for their participation.

Stimuli

Five taste qualities were investigated: saltiness, sweetness, sourness, bitterness and umami taste. For each taste quality, two representative compounds were chosen, which were administered at five concentrations in commercially available products. The compounds were grouped into two sets, each containing one compound for each of the five taste qualities. One set contained NaCl, sucrose, acetic acid, caffeine and MSG, the other set consisted of KCl, aspartame, citric acid, quinine HCl and IMP.

The tastants were dissolved in foods. These food products were ice tea in which the sweet taste was varied, chocolate drink in which the bitter taste was varied, mayonnaise in which the sour taste was varied, tomato soup in which the salty taste was varied, and bouillon in which the umami taste was varied. The products were versions of commercially available products (all Unilever products), which were varied by the omission or addition of the tastants to be tested. Five concentration levels of each tastant (ascending 0.2 log steps) were used in the test. An exception in the concentration levels was made for mayonnaise (ascending 0.1 log steps), since the total concentration difference could not be larger than 0.4 log for technical reasons.

Since the aim of the experiments was to study age differences in the perception of tastants in normal products rather than to investigate the effect of different tastants on a product, the tastants were embedded in products in which they do occur naturally in normal life and were not all varied in the same product. Furthermore, the second step in the range of five concentrations corresponded to the usual concentration of the compound in each selected product, except in the chocolate drink, where the customary concentration was equal to the first step. Using different products for different taste qualities helped also to better assess the generality of the age effects in a larger food context.

The compounds were mixed with the dry product beforehand. On the day of testing, the final products were prepared. However, the mayonnaise was prepared beforehand at the Unilever pilot plant at Vlaardingen. The subjects received 20 ml of each stimulus in disposable 50-ml plastic cups. All products were served at room temperature.

The following concentration ranges in (g/l) of the tastants were used: saltiness in tomato soup - sodium chloride 5.68 to 35.83 and potassium chloride 9.00 to 56.77; sweetness in ice tea - sucrose 53.95 to 340.38 and aspartame 0.15 to 0.92; umami taste in broth - MSG 1.58 to 9.95 and IMP 1.00 to 6.28; bitterness in chocolate drink -caffeine 0.63 to 3.98 and hydrochloric quinine 0.01 to 0.03; sourness in mayonnaise - acetic acid 0.27 to 0.67 and citric acid 0.02 to 0.05.

Five levels each of auditory (loudness), visual (size) and kinaesthetic/tactile (weight) stimuli were included to be eventually used as controls in cross-modal intensity matching. As auditory stimuli, 1.5 second bursts of a narrow band of noise centred at 750 Hz were recorded, with intensities varying from 45 to 85 dB in 10 dB steps. These sounds were delivered to the subjects through earphones. As kinaesthetic stimuli, five weights were constructed varying in 0.2 log steps from 33.7 to 212.6 grams and hidden in small black (film) containers of equal size which subjects lifted with the top of the forefinger by means of a ring on a string connected to the container. As visual stimuli, an irregular star figure was multiplied in ascending 0.2 log size steps.

Procedure

The first week of this particular experiment, the subjects assessed the stimuli without wearing a nose clip on three consecutive days, one session per day. The stimuli were presented one after the other. The sip-and-spit method was used, i.e. after tasting, the subjects rinsed their mouth with distilled water and expectorated. For practical reasons separate sessions were held for the elderly and the young. At the start of a session and before each new trial the subject rinsed with distilled water and expectorated. The subjects were instructed to eat a piece of cream cracker at the end of a series of samples of a given compound. In each session of an experiment, all ten compounds were presented once at five concentrations in five series, one for each taste quality. These taste stimuli were alternated with samples of three replications of auditory, visual and weight stimuli at five levels. This alternation prevented monotony and adaptation on the one hand and prolonged the inter-taste-stimulus interval up to two minutes on the other, diminishing the induction of fatigue. Before the experiment started the subjects were familiarised with those stimuli by presenting the lowest and highest in the range. Thus, the subjects assessed 50 taste stimuli and 45 cross-modal stimuli in one session. Each session lasted two hours. Between two taste quality series within a session there was a break of 5 minutes.

The order in which the taste qualities were presented differed over the three days, as did the presentation order of the stimuli within each series. In total, each taste stimulus was assessed three times and each cross-modal stimulus was assessed nine times per experiment. Since the major interest was in unconfounded differences between the two age groups, the presentation order of the compound concentrations and the cross-modal stimuli was the same for all subjects. Possible taste order effects were considered to be strongly reduced by the interspersing of the taste stimuli with the stimuli from the other sensory modalities.

All taste samples were assessed on their intensity of salt, sweet, sour, bitter and umami and on liking, whereas the cross-modal stimuli were rated on intensity only. Intensities were marked on a 9-point scale with the anchors ‘very weak’ to the left and ‘very strong’ to the right. For the taste stimuli, liking for the product was assessed on a 9-point pleasantness scale with the anchors ‘very little’ to the left and ‘very much’ to the right. Since the Dutch are raised not to admit to food dislike, this scale was considered more appropriate than a like – dislike scale. The second week was similar to the first, but this time the subjects assessed the stimuli while wearing a nose clip.

In this paper, the effects of concentration of the experimentally varied tastants on the other tastes (side-tastes) of the products are reported.

Statistical Analysis

Methods

The statistical analyses were conducted by means of SAS® and SAS/STAT® with data arithmetically averaged over the three replications. Different tastes were defined as side-taste for the products (e.g. sweet, sour, bitter and umami in tomato soup; sour, salty, bitter and umami in ice tea). Repeated Measures Analysis is applied separately per product and per experimentally varied tastant (e.g. tomato soup with NaCl and with KCl separately) with age, gender and age by gender as between subject factors and with nose clip and concentration as repeated within subject factors, to investigate the effect of these factors on the perceived side-tastes. Since the sphericity test show that the patterns in the covariance matrix of this experiment generally do not satisfy the Huynh-Feldt condition, the multivariate test results instead of the univariate test results are described, but for the concentration effect only in those cases where the repeated tests resulted in a significant linear or quadratic effect. An interpretation of the results, in terms of higher polynomials, would be rather meaningless.

Levels of significance

All effects that have a p-value of 0.05 or lower are reported as ‘significant’. Power Analysis shows that, with the number of subjects in our study, an effect with a magnitude of 1.3 standard deviations and a p-value of 0.10 still has a power of 0.90. Therefore, a selection of the more interesting effects with a p-value between 0.05 and 0.10 are reported additionally. These effects will be denoted as ‘trends’.

Cross-modal intensity matching

All intensity and liking data reported here are based on scores that were corrected by means of the Cross-Modal Intensity Matching (CMIM) method, as described in a previous paper from this group (Mojet et al., 2003). Auditory stimulation was selected to correct the present data for differences in scale usage since the sensitivity to low-frequency sounds (around 750 Hz) is normally not impaired with age and because an analysis of variance of the results for each of the five sound levels did not show any systematic age or gender variations. The matrix of the CMIM data consisted of 42 subjects, 27 replications per individual, and 5 different levels of loudness per replication. On average, the standard deviation per individual/level of loudness was fairly constant and in the order of 0.9, indicating that the standard error of an individual/level of loudness combination is in the order of 0.17 (0.9/√27). The correction steps were as follows. First, the individual average and the age group average were determined for each sound level. Then, the (individual minus group) averages (which also have a standard deviation of approx. 0.17) were regressed against the group averages using polynomial functions of the latter, starting with a polynomial of degree 0 (constant difference from group mean) and ending with a polynomial of degree 4 (complete fit of individual means). Subsequently, the lowest polynomial with a residual standard deviation of ca 0.17 was selected as the assessor's correction formula for each subject. Finally, each individual score on the scale was corrected by a value obtained from the individual's correction formula. All data to be reported here are based on scores that were corrected by means of this method.

Results

Overall age and gender differences

Before analysing the influence of concentration and nose clip on the perception of the side-tastes, first the between subject effects are considered. This exploration shows a number of significant between subject effects [all F's (1,38)]. The elderly perceived both the sourness and bitterness as side-tastes of NaCl [F = 21.45, P < 0.0001 and F = 8.44, P < 0.007 respectively] or KCl [F = 16.98, P < 0.0002 and F = 16.58, P < 0.0002] in tomato soup and of MSG [F = 8.81, P < 0.006 and F = 4.10, P < 0.05 respectively] or IMP [F = 7.89, P < 0.008 and F = 4.10, P < 0.05 respectively] in broth as stronger than the young did. They also perceived the bitterness as side-taste in the mayonnaise with either acetic acid [F = 4.99, P < 0.04] or citric acid [F = 8.07, P < 0.0.08] as stronger than did the young. However, they perceived the sourness in caffeine-flavoured chocolate drink as less intense [F = 4.36, P < 0.05].

In general, no significant gender effects were found for the side tastes, with the exception of the sweetness in KCl-flavoured tomato soup, where men rated the sweetness higher than women did [*F(*1,38) = 4.31, P < 0.05]. An age by gender effect was found for the bitterness perception of KCl-flavoured tomato soup, where the elderly men and women perceived the bitterness as stronger than the young, but where the elderly women did so to an extreme [$F(1,38) = 5.95$, $P < 0.02$]. A second age by gender effect was found for the sourness perception of caffeine-flavoured chocolate drink [$F(1,38) = 5.71$, $P < 0.03$]. Here, the young women perceived the sourness most strongly, followed by subsequently the young men, the older men, and the older women. Since only a few gender differences were found, the mean intensities of all rated taste qualities are given in Figures 6.1 and 6.2 per experimentally varied tastant for elderly and young only.

Influence of concentration of the varied tastant on the perception of the side-tastes

Is the perception of the side-tastes dependent on the concentration of the experimentally varied taste, and if so, do elderly and young or men and women differ in this respect? Apart from some differences due to the wearing of a nose clip, which will be discussed below, the general effects of the manipulation on the intensity of the side tastes (see Figure 6.1 and 6.2) show a strong similarity.

The increasing concentration of both salts, NaCl and KCl, induced a significant [all F's (4,35)] decrease in the sweetness of the tomato soup [$F = 9.31$, $P < 0.001$ and $F = 9.07$, $P < 0.0001$ respectively], but significant increases in bitterness [$F = 3.10$, $P < 0.03$ and $F = 6.91$, $P < 0.003$], sourness [$F = 8.70$, $P < 0.0001$ and $F = 2.31$, $P < 0.08$ (trend only)], and umami taste [$F = 2.69$, $P < 0.05$, KCl only]. The increases in sourness with increasing NaCl and in bitterness with increasing KCl are larger for the elderly than for the young [$F = 4.01$, $P < 0.009$ and $F = 4.72$, $P < 0.004$ respectively].

The increase in sucrose and aspartame concentration in ice tea resulted in significant decreases [all F's (4,35)] in bitterness [$F = 3.92$, $P < 0.01$ and $F = 6.59$, $P < 0.0005$ respectively], major decreases in sourness [$F = 48.06$, $P < 0.0001$ and $F = 30.67$, $P < 0.0001$ respectively], and a minor decrease in saltiness [sucrose only; $F = 2.94$, $P < 0.04$]. The decrease in bitterness with increasing aspartame was larger for the young than for the elderly [$F = 5.17$, $P < 0.003$].

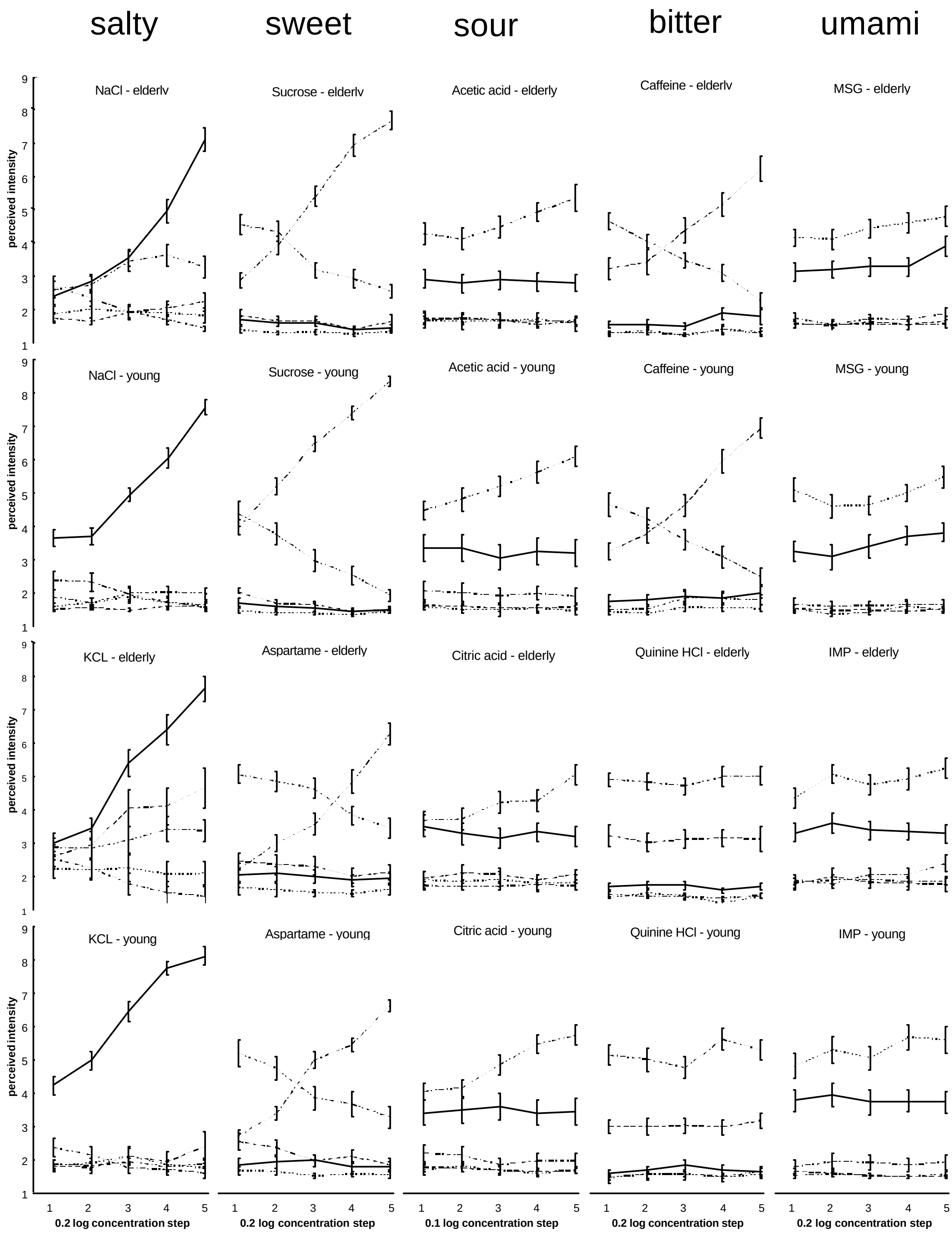

Figure 6.1 Perceived intensities of all taste qualities for elderly and young, while not wearing a nose clip. Saltiness is represented by solid lines, sweetness by lines of alternating stripes and dots, sourness by lines of stripes and double dots, bitterness by striped lines and the taste of umami by dotted lines.

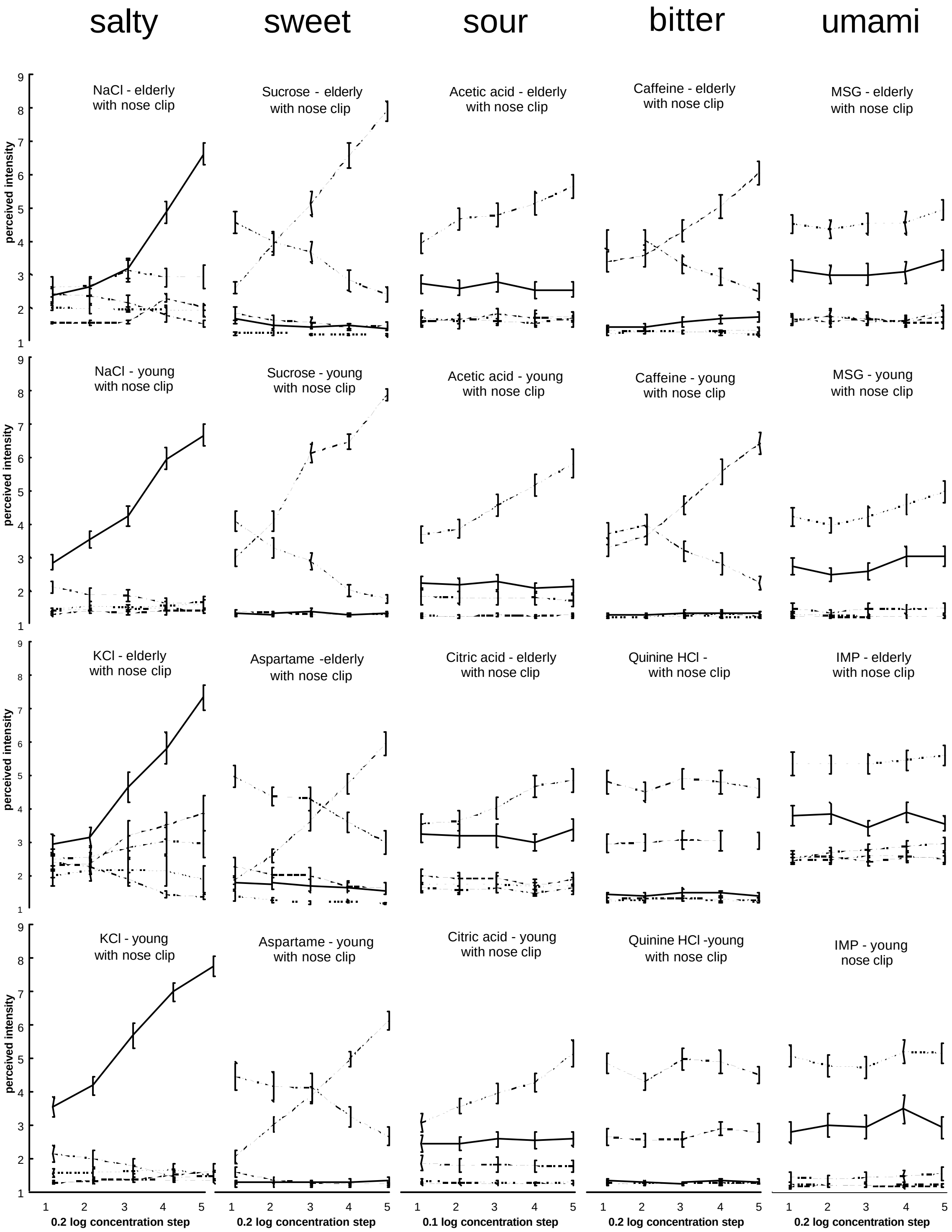

Figure 6.2 Perceived intensities of all taste qualities for elderly and young, while wearing a nose clip. Saltiness is represented by solid lines, sweetness by lines of alternating stripes and dots, sourness by lines of stripes and double dots, bitterness by striped lines and the taste of umami by dotted lines.

The increasing concentration of neither of the acids in mayonnaise had a significant influence on the perception of the side-tastes, and the slopes of the side-tastes also did not differ for the elderly and young.

An increase in caffeine and quinine provoked a decrease in sweetness of the chocolate drink, which was large with caffeine [$F = 55.44$, $P < 0.0001$] and less pronounced with quinine [$F = 3.93$, $P < 0.01$].

An increase in MSG concentration in broth is accompanied by an increase in saltiness [$F = 16.86$, $P < 0.0001$], whereas an increase in IMP led to a decrease in saltiness [$F = 4.18$, $P < 0.007$] and an increase in sweetness [$F = 4.23$, $P < 0.007$].

The elderly and young did not differ in the slopes of the side-tastes in mayonnaise, chocolate drink or broth. Men and women did not show significant differences in their slopes for any of the side tastes in any of the products.

Deprivation of olfactory stimulation

To investigate whether olfaction played a role in this experiment, the nose clip conditions (off and on) were compared. Significant differences were found in the perception of the side-tastes [all F's (1,38)]. Clipping the nose resulted in a decrease in sourness and bitterness of the tomato soup with NaCl [$F = 10.02$, $P < 0.003$ and $F = 6.32$, $P < 0.02$ respectively] or tomato soup with KCl [$F = 9.71$, $P < 0.004$ and $F = 12.96$, $P < 0.0009$ respectively]; reduced the saltiness, bitterness and umami taste of ice tea with sucrose [$F = 4.79$, $P < 0.04$, $F = 8.02$, $P < 0.008$ and $F = 6.64$, $P < 0.02$ respectively] or with aspartame [$F = 6.20$, $P < 0.04$, $F = 12.80$, $P < 0.001$ and $F = 9.20$, $P < 0.005$ respectively]; decreased the saltiness in mayonnaise with acetic or with citric acid [$F = 8.35$, $P < 0.007$ and $F = 3.97$, $P < 0.06$ (trend) respectively]; diminished the sourness and saltiness of chocolate drink with caffeine [$F = 7.42$, $P < 0.01$ and $F = 9.82$, $P < 0.004$ respectively] or with quinine [$F = 4.41$, $P < 0.05$ and $F = 10.76$, $P < 0.003$ respectively]; and reduced the saltiness of broth with MSG [$F = 8.39$, $P < 0.007$] or with IMP [$F = 5.61$, $P < 0.03$].

These reductions in perceived intensities are mainly due to higher intensity ratings given by the young in the 'nose clip off' condition than in the 'nose clip on' condition. T-tests showed that the differences between the 'nose clip off' and the 'nose clip on' condition only deviated significantly from zero for the elderly when tested over all tastants and all side-tastes [$T(20)=2.18$, $P < 0.04$]. This is also shown in the scatter plots of Figures 6.3a, b. The ratings of the elderly shown in Figure 6.3a are almost similar in the two nose clip conditions (on and off), which is shown by the close proximity of the ratings to the y = x line. The variance in the group of elderly is much larger than the variance in the group of young subjects, whose ratings are, compared to the elderly, more scattered over the left upper side of the plot. This indicates that the young make more use of their sense of smell when assessing the intensities in the 'nose clip off' condition than the elderly. In all forty cases (10 tastants, 4 side-tastes each, averaged over the five concentrations), the young gave lower ratings when wearing a nose clip than when not wearing a nose clip. Furthermore, in all cases but one, these differences between the 'nose clip on' condition and the 'nose clip off' condition, were larger than the differences found for the elderly (overall Sign test: $P <0.0001$). The only exception was found for the bitterness of tomato soup with KCl, where no significant difference between the elderly and the young was found, but where the elderly women perceived a stronger bitterness when they wore no nose clip than when they wore one. This difference between the two conditions was the only difference found for one of the age by gender groups that deviated significantly from zero [$T(10)=3.15$, $P < 0.02$].

Analysed per individual side-taste for each of the experimentally varied tastants, the interaction between nose clip and age reached significance [all F's (1,38)] in ten out of these forty cases.

Thus, different effects of the nose clip condition on the ratings of the elderly and young were found for the bitterness of ice tea, mayonnaise, and broth, but not of tomato soup. With the nose clip on, the extent to which the young gave lower ratings to the side-tastes than the elderly was larger than when they had no nose clip on. This age by nose clip interaction on bitterness was found for broth with MSG [$F = 7.26$, $P < 0.02$], for mayonnaise with acetic acid [$F = 5.47$, $P <$

0.03] or citric acid [F = 3.28, P < 0.08 (trend)], for ice tea with aspartame [F = 4.97, P < 0.04], or sucrose [F = 5.64, P < 0.03].

An interaction effect was also found in the ratings of the sweetness of broth with MSG [F = 6.18, P < 0.02], where, when wearing a nose clip, the elderly gave higher ratings than the young. Furthermore, wearing a nose clip had also a different effect on elderly and young in the assessment of the saltiness of mayonnaise with acetic acid [F = 4.47, P < 0.05] or citric acid [F = 4.98, P < 0.04] and of chocolate drink with caffeine [F = 6.08, P < 0.02]. With the nose clip off, the young gave higher ratings than the elderly did, whereas with the nose clip on the reverse was true. A similar interaction was found in the assessment of the sourness of chocolate drink with caffeine [F = 10.05, P < 0.03] or with quinine [F = 5.84, P < 0.03] where with the nose clip on, the young gave higher ratings than the elderly.

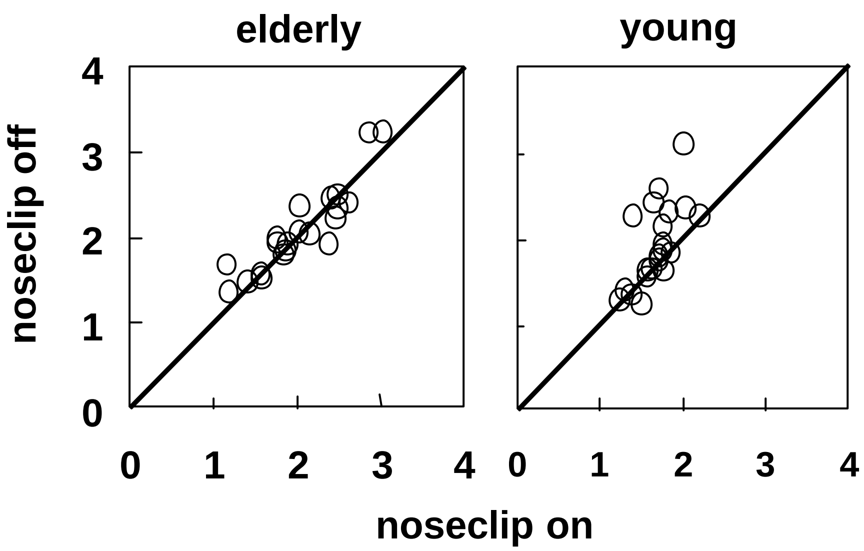

Figure 6.3 Scatter plots of the intensities of the side-tastes of the 5 products, assessed by elderly and young with or without a nose clip. The intensities are averaged per person over all concentrations and all side-tastes.

Deprivation of olfaction had no different effect on the ratings of men and women, or on those of the four age by gender groups.

In a few cases, wearing a nose clip had also an effect on the slopes of the side-tastes [all F's (1,38). The slope of the sweet and the slope of the sour taste of tomato soup were significantly flatter with increasing NaCl when subjects wore a nose clip [sweet: $F = 12.07$, $P < 0.002$ and sour: $F = 11.33$, $P < 0.002$]. Furthermore, the sweetness slope of chocolate drink with increasing caffeine was significantly flatter [$F = 8.67$, $P < 0.006$] when the assessment was made with the nose clipped. Wearing a nose clip also led to a flatter slope [$F = 3.08$, $P < 0.09$; trend only] of sweetness in chocolate drink with increasing quinine.

Discussion

Interactions

This first study over all taste qualities in the same group of elderly and young people shows that increasing the concentration of one dominant taste compound in a complex food matrix has different effects on the perceived intensities of the side-tastes of the food. In addition, these effects were similar for the two tastants within one taste quality. Since in this experiment, foods were chosen on the basis of their representativeness of salty, sweet, sour, bitter and umami foods in 'real life', different foods were used to investigate the effects of the manipulated tastants on the side-tastes, and as a result no mutual effects between the taste qualities in one system can be demonstrated.

Nevertheless, a generalisation of the taste-taste interaction effects over these different food types might help to further the insight in these complex interactions. Figure 6.4, which is a schematic overview of the results inspired by Keast and Breslin (2002), summarises this generalisation. They divide the taste-taste interaction effects found in the literature into three schemata's, one for low, one for medium and one for high intensity/concentrations. The perceived intensities of the experimentally varied tastants in the present study correspond mainly with their medium concentration scheme. It should be noted that in Figure 6.4 the arrows pointing away from a given taste quality are directly comparable since they are effects exerted in the same food matrix, whereas the arrows pointing towards a certain taste quality show how this quality is affected by changes of other taste qualities in different food matrices. In contrast to the findings presented by Keast and Breslin (2002), no effect of acids on any of the other taste qualities was found in the present experiment.

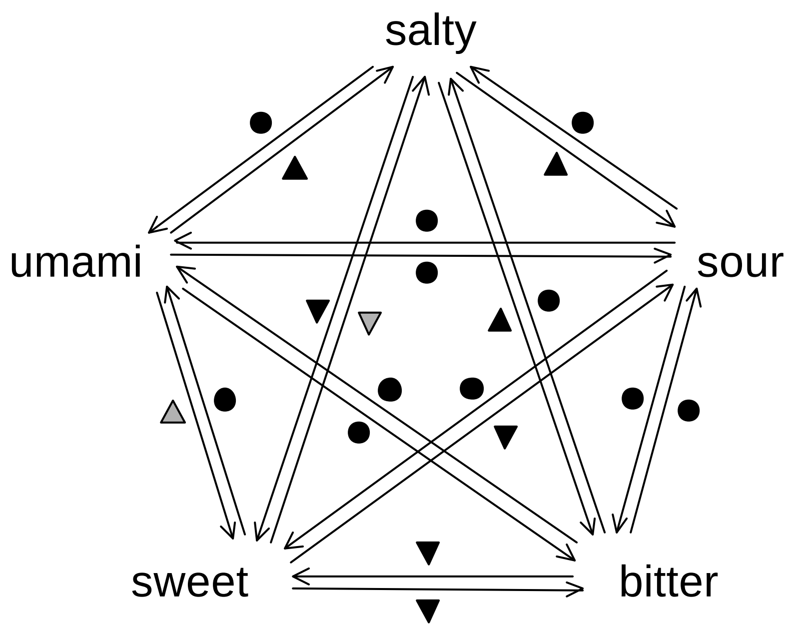

Figure 6.4 Pentagram of the taste-taste interactions in complex food matrices. Outgoing arrows show the influence of one taste quality on the other taste qualities in the same food. Incoming arrows represent influences of different taste qualities from different foods. Triangles indicate either an enhancement effect (when they point upwards) or a depressive effect (when they point downwards). Circles indicate a nil effect. Black symbols represent both tastants within a taste quality, grey symbols indicate that only one of the tastants exerts the effect.

This lack of suppression or enhancement effect might be due to the relatively limited concentration range in which the highest concentration was only 2.5 times larger than the lowest concentration. Another difference exists with regard to the influence of salts on bitterness. In their summary Keast and Breslin describe this influence as suppressive, irrespective of the used concentration, whereas in the present study an increase in bitterness was found for both salts. Finally, in the present study, neither an increase nor a decrease in sourness by bitter tastants, as Keast and Breslin (2002) described for the moderate and high concentrations respectively, was found. This could be due to the fact that the sourness perceptibility in the chocolate drink was very low to begin with, or it might be that the concentration range used here falls just between the moderate and high intensities for which Keast and Breslin (2002) describe opposite findings.

Umami perception was not influenced by any of the other taste qualities, which supports the findings of Bartoshuk (1975). She found that substances which show the least compression when added to themselves, like the umami tastants do (see Fig.6.1 and 6.2), also show the least suppression when other substances are added to them.

Slopes of the side-tastes with age

Taste-taste interaction effects have not been studied in elderly to our knowledge, whereas odour-taste interactions are reported by Enns and Hornung (1985) who found that, when using odorant/tastant pairs, the magnitude of suppression [overall intensity/(smell intensity + taste intensity)] was not affected by the age of the subjects. In the present experiment only in 3 (sourness with NaCl and MSG, bitterness with KCl) out of the 40 possible cases a steeper increase was found for the elderly than for the young and in only one case a more pronounced decrease in bitterness with increasing aspartame was found for the young. This suggests that the slopes of the perceived side-tastes are not systematically affected by age.

The concentrations of the varied tastants in this experiment lie in the same range as that which is found in normal every day food. One could argue that experiments with much higher concentrations bear little relevance for every day life and run the risk of introducing artefacts caused by the strong deviation from what subjects are used to.

Contribution of olfaction

No findings on the influence of the contribution of olfaction on taste-taste interactions have been reported in the literature. However, Murphy (1985) reported that, when deprived of olfaction the performance of young women, in a task where they had to identify blended foods, fell to the same level as that of elderly women. Obviously, when they did not wear a nose clip, the young women took more advantage of their sense of smell. Furthermore it suggests that a decline in olfactory sensitivity of the elderly women made them perform less well than the young in this task with both olfactory and taste cues.

Would the same phenomenon occur in the present experiment where the side-taste intensities had to be assessed? In line with a previous study (Mojet et al., 2003), the differences between the nose clip 'off' and nose clip 'on' condition were larger for the young than for the elderly in the present experiment. Since the overall difference between the with and without smell condition deviated not only significantly from zero for the young but also (significantly, but to a minor degree) for the elderly, it is clear that they too use their sense of smell, if to a lesser degree. As it was pointed out in a previous paper (Mojet et al., 2003) there are two possible ways in which smell could play a role. First, the tastants themselves might have a smell. To the knowledge of the present authors, this possibility, unlikely as it seems for most tastants with the exception of acetic acid, has never been tested seriously. In the second place, the presence of the tastants might interact with the olfactory perception of the medium in which they are presented. That this latter possibility exists when the tastants are presented in product is evident, since some of them (MSG and IMP) are known flavour enhancers but might this also be true in the case of water? It would suggest that water has a smell of its own which is changed by tastants. To clarify this point, further research has been carried out (Mojet and Köster, 2004, submitted) and its findings favour the idea that the tastants have a smell that is perceptible when they are dissolved in water.

Age differences in attentional taste differentiation

One interesting general finding has to be discussed here. Over all products and tastants, the elderly gave higher ratings to the perceived intensities of the side-tastes than did the young, whether their olfactory input was blocked (37 out of 40 cases) or was not blocked (29 out of 40 cases). This is remarkable, since previously it was found (Mojet et al., 2003) that the elderly rated the perceived intensities of the experimentally varied taste lower than the young in 9 out of 10 cases (Sign-test, $P < 0.02$) without wearing a nose clip, and in 6 out of 10 cases (n.s.) while wearing a nose clip. To show this difference in attention of the elderly and the young graphically, the ratio between the scores for the dominant taste and for the summated side-tastes are given in Figure 6.5 in percentages of all scores.

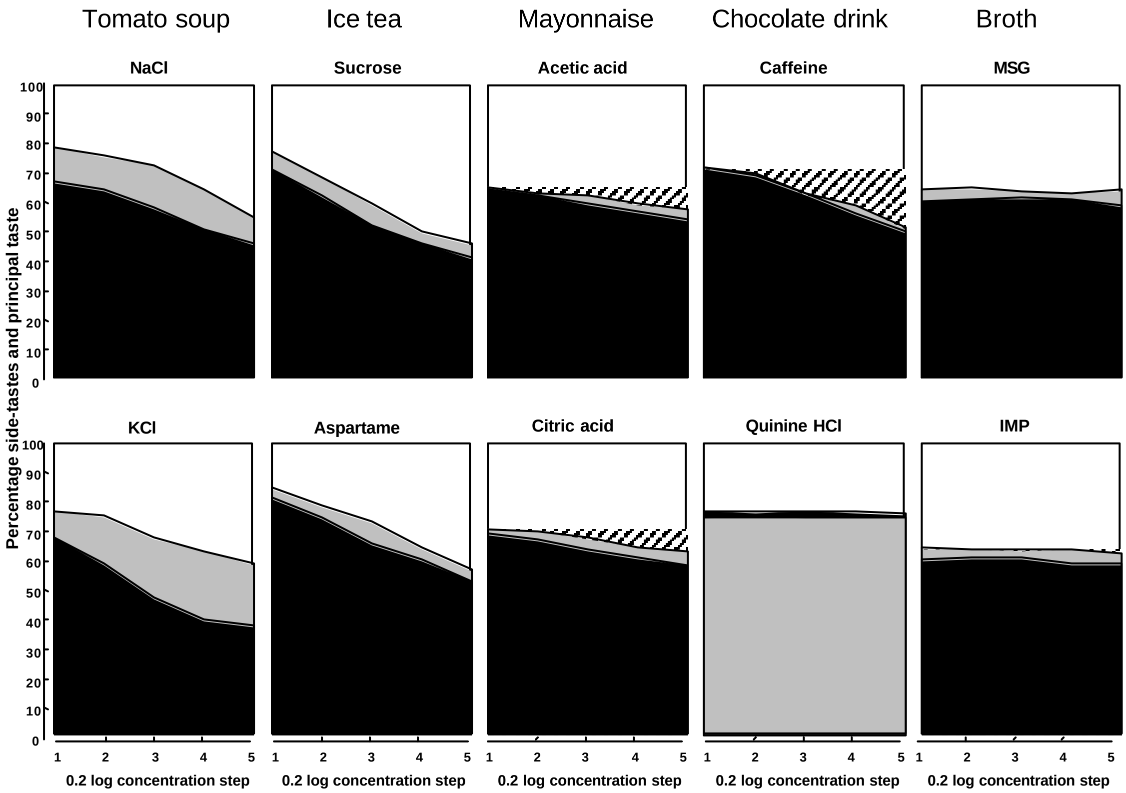

Figure 6.5 Percentages of the sum of intensity scores given to the dominant taste and to the combined side-tastes for elderly and young subjects. The percentages of scores given by young subjects to the combined side-tastes are represented by the black areas, while the grey or striped areas (including the black areas) show the percentages for the elderly (except for quinine, where the young attributed a higher percentage of their scores to the side-tastes than the young). The white areas represent the percentage of intensity scores given to the dominant taste for the elderly. For the young the white and striped areas represent the percentages given to the dominant taste (reversed for quinine).

For example, the percentage of all scores that is given to saltiness in tomato soup with NaCl increases from 21.3 % (concentration step 1) to 45.1 % (concentration step 5) for the elderly, and from 33.3 % to 54.4 % for the young, whereas per definition, the percentage given to the combined side-tastes decreases from 78.7 % to 54.9 % for the elderly and from 66.7% to 45.6 % for the young. It seems that the young gave more attention to the principal tastes, i.e. in their assessments, they differentiated more between the principal taste and the side tastes than did the elderly, who seemed to divide their attention to a larger degree over all perceptible tastes. This is especially so in the case of tomato soup. Whether this is because tomato soup is more complex than the other products used, or because the taste quality varied experimentally was salty, can not be concluded from this experiment. However, that the elderly devote more attention to the side-tastes was shown to some degree for all products with the exception of chocolate drink with quinine, where both the elderly and the young did spend a large amount of their attention to the side-tastes, and where the young consistently did so to a higher degree. Previously, Mojet et al. (2001) found that the elderly have less specified taste acuity than the young.

For both phenomena described above, which point in the same direction of a possible impairment in cognitive processes (Essed and Eling, 1986), the noise hypothesis might provide an explanation, either at a neural level, or at a psychological level. The neural noise hypothesis supposes that the signal to noise ratio is lowered by a decrease in intensity of the signal, by an increase in the level of spontaneously firing neurones, or both, and thus would make it more difficult for the elderly to differentiate between the requested taste quality and the other taste qualities. The perceptual noise hypothesis is characterised by a decrease in the ability to neglect irrelevant information. The irrelevant information could be considered as a type of noise, but on a psychological / perceptual level and not on a neural level (Stroop, 1935).

The present experiment reveals three points of interest for further research. Firstly, it can be concluded that increasing the concentration of the dominant taste in foods provokes significant positive or negative interaction effects on the perception of one or more other taste qualities of the product that are not age-related in most cases. Whether this influence is tastant or product specific, or both, is a subject for further research. Secondly, the fact that, especially in the young, olfaction plays a larger role in the assessment of taste intensity than has been hitherto assumed also has to be investigated further. Finally, the finding that the elderly divide their attention more over the different tastes in a product, whereas the young are more strongly focussed on the dominant taste, has not been reported previously and should be pursued in future research because of its possible gerontological implications.

Acknowledgement

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Chapter 7

Do tastants have a smell of their own?

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Abstract

The stimuli used in taste research are usually considered to be odourless. This was tested in two experiments with aqueous solutions of two representative compounds for each of five taste qualities including umami. In the first experiment elderly and young subjects rated the intensity and pleasantness of three concentrations of the stimuli, while wearing or not wearing a nose clip. Saliva production was also measured. Blocking olfaction only influenced salivation for umami. It reduced taste intensity ratings, but as found in an earlier experiment with the same compounds in food products, this effect was stronger in the young, who also liked the stimuli better wearing the nose clip. In the second experiment, another group of young people tried to detect the odours of the tastants when dissolved in three types of water. A majority of subjects could regularly detect seven of the ten tastants by olfaction and the extent to which they did correlated significantly with the reduction in taste intensity ratings for the different tastants found in the first experiment. We suggest that most tastants can be smelled and that this smell contributes to taste intensity ratings.

Introduction

The stimuli used in taste experiments are usually supposed to be non-odorous and to be perceived by the gustatory system only. Recently, some doubts about the veracity of this supposition were raised. Mojet et al. (2003) compared the taste intensity perception of elderly and young people. Subjects were exposed to concentrations of ten different taste stimuli embedded in food products (two per basic taste quality including umami), while their olfactory perception was or was not blocked by wearing a nose clip. The results showed that the young perceived the taste stimuli to be significantly more intense when they did not wear a nose clip than when they did wear one. Under the no nose clip condition the young also judged the stimuli to be more intense than did the elderly, but when a nose clip was worn, the young lost this advantage and judged the stimuli to be as intense as did the elderly under both conditions. Furthermore, there were clear indications that the young relied on more and other sensory information than taste alone when they judged the stimuli without a nose clip, whereas the elderly did not. Combined with the well documented finding that olfactory sensitivity decreases more rapidly with age than gustatory sensitivity (Murphy et al., 1991), this led the authors to the hypothesis that olfaction was more involved in taste perception than is usually assumed. Two alternative explanations were forwarded to explain these results. The first suggests that weak odours, produced by the tastants themselves, could be smelled by the young but not by the elderly in the no nose clip condition. The other suggests that the presence of the tastants interacted with the olfactory perception of the medium in which they were presented. Thus, the addition of non-odorous tastants to food products might intensify the odour of the products to a degree that could be noticed by the young, but not by the less sensitive elderly. That this latter possibility existed when the tastants were presented in product was evident, since a number of them (NaCl, KCl, MSG and IMP) are known flavour enhancers, but whether it would also be true when water was the solvent seemed less clear and even quite improbable. Therefore, the fact that the same subjects showed a comparable age difference in sensitivity when the same stimuli were dissolved in distilled water and judged without a nose clip seemed to plead in favour of the first explanation and against the second one. The fact that the age effect for acetic acid, which is known to have an odour at higher concentrations, was among the strongest, pointed perhaps in the same direction.

That taste and smell show additive intensity perception effects has been reported by several authors. Murphy et al. (1977) rated the perceived intensity of various concentrations of an odour (ethyl butyrate), a taste (sodium saccharin), and mixtures of the two. They investigated whether the perceived overall intensity of the odour-taste mixtures was equal to, greater than, or less than the intensities of the unmixed components. They found that the intensities of mixtures approximated simple additivity. In a similar study Murphy and Cain (1980) examined the perceived intensity of sucrose-citral and NaCl-citral mixtures. Again they found additivity in the intensity ratings. The authors also noted that taste/smell confusion took place in the assessment. Their subjects ascribed little odour magnitude to solutions containing only sodium saccharin or NaCl, but ascribed considerable taste magnitude to solutions containing only butyrate or citral. In a second experiment, when the subjects assessed the same samples with their nostrils closed, the taste intensity ratings for ethyl butyrate and citral solutions dropped significantly. Murphy et al. (1977, 1980) drew the conclusion that the retronal smell of ethyl butyrate and citral was perceived by the assessors as taste from the oral cavity and thereby added to the taste intensity. This could be interpreted as a form of interaction, in which odours affect taste perception. According to Rozin (1982), these taste-smell interactions/confusions in the oral cavity are due to the fact that olfaction is a dual sense, i.e. the same olfactory stimulus may seem to be qualitatively different when referred to the mouth or the outside world. “While subjects attribute little if any olfactory stimulation to relatively pure taste stimuli in the mouth, they attribute considerable taste to solutions of relatively pure odorants” (Rozin, 1982). Further support for this hypothesis has been provided by other studies on taste enhancement by odours. Although it seems that Hornung and Enns (1984) found contradicting results, their findings may point in the same direction. The authors used a specially developed device to deliver taste and orthonasal smell at the same time and reported that neither taste backgrounds altered the scaling of olfaction, nor olfactory backgrounds altered the scaling of taste. The combination of taste with orthonasal in stead of retronasal smell used by Hornung and Enns (1984), might not show the interaction between taste and smell, since orthonasal sniffing has much weaker effects than retronasal stimulation in the mouth (Zoeteman, 1978).

Other support comes from Frank and Byram (1988) who found that the sweetness of a sucrose-solution was enhanced by strawberry odour but not by peanut butter odour. With other taste-odour mixtures, even more complex interactions were observed (Shaffer and Frank, 1990). Stevenson et al. (1999) reported that specific odours could enhance or suppress the sweetness of sucrose solutions. Similar effects were found with sour tastes. Although in a number of these studies it was carefully verified that the odorants used in the mixtures were tasteless, none of the authors verified the lack of odour of the tastants. Thus, it might be possible that additive effects of the odour of the tastants played also an important role in the differences in taste intensity perception while wearing a nose clip or not (Mojet et al. 2003). In that case, age related loss of taste intensity might have to be explained mainly by loss of olfactory sensitivity in the elderly.

Unfortunately, in the experiment of Mojet et al. (2003) a condition in which the tastants dissolved in water were judged while the subjects wore a nose clip was not included and as a result it could not be verified whether, when a nose clip was worn, the differences between the elderly and the young in the intensity perception of the tastants disappeared in the same way when the tastants were dissolved in water as when they were dissolved in product.

In the present experiments this gap is filled and a ”with nose clip” condition is compared with a “no nose clip” condition for all ten tastants dissolved in water with new groups of elderly and young people. Apart from the intensity, the pleasantness of the stimuli and the saliva production caused by them are also measured. This was intended to check whether intensity differences between the two nose clip conditions are related to irritation and unpleasant feelings about the wearing of the nose clip and to get an impression of the possible role of saliva production in making the intensity judgements.

It has been shown that variations in salivary flow rates may explain individual differences in taste sensitivity (Christensen 1986, Spielman, 1990, Guinard et al. 1998, Neyraud et al. 2003). Simple dilution by the 99% water in saliva, changing the pH of acid tastants by buffering, and concentration of very dilute tastants by addition of saliva components such as salivary sodium are described as the mechanisms involved. That elderly people suffer more often from a dry mouth syndrome than do young people is well known (Bradley and Beidler 2003). Thus, differences in taste intensity between different age groups might also be explained by reduction in saliva production with age, although reports concerning the relationship between ageing and salivary flow rates are conflicting (Pederson et al., 2002). The highest saliva stimulation is obtained with sour taste, followed by salty, sweet and bitter (Dawes and Watanabe, 1987). Furthermore, salivary production increases with increasing concentration and amount of a separate taste stimulus (Froehlich, Pangborn and Whitake, 1987; Watanabe and Dawes, 1988; Bardow et al., 2001).

Finally, in a second experiment, the possibility of orthonasal olfactory stimulation by all ten tastants dissolved in water has been studied directly in young subjects. To check whether possible odour effects found might be due to interactions of the tastants with possible water odours, each of these tastants was dissolved in three different types of water. The waters chosen were: demineralised water, which is used in many other studies, double distilled water, which is the purest water commercially available and Evian water, which is an internationally available natural source water that contains many minerals and spores of other substances.

Experiment 1

Materials and Methods

Subjects

Nineteen older subjects (age 60-83, 10 male, M=69.0, SD=6.8, and 9 female, M=64.8, SD=2.9) and 20 young subjects (age 18-30, 10 male, M=23.5, SD=3.9, and 10 female, M=21.3, SD=2.5) participated in the first experiment. All subjects were Caucasian and met the following criteria: healthy, not on a diet, not living in a home for the elderly, not taking any prescribed medicine, non-smoking, no heavy alcohol users, not pregnant or lactating, not subject to food allergies, good dental hygiene, and not wearing dentures (one subject had dentures but did not wear these while tasting the stimuli. Subjects were selected on a volunteer basis in response to advertisements in local newspapers and on bulletin boards in senior citizen centres. At the end of the experiments the subjects were paid for their participation. Of the 40 subjects that were recruited one elderly subject was left out of the analyses since she clearly did not understand the task.

Stimuli

The saltiness, sweetness, sourness, bitterness and the perception of umami taste were investigated. Each compound was presented in three supra-threshold concentrations (0.4 log step differences). The range of concentrations was similar to the range of concentrations used in a previous experiment (Mojet et al. 2003). In that experiment the concentrations in water had been matched to the intensities of the same taste qualities in food products. This resulted in ranges starting at: 3.58 g/l for sodium chloride (NaCl) and 5.68 g/l for potassium chloride (KCl), 8.55 g/l for sucrose and 0.06 g/l for aspartame, 0.63 g/l for acetic acid and 1.26 g/l for citric acid, 0.16 g/l for caffeine and 1.29 mg/l for quinine hydrochloride, 1.99 g/l for monosodium glutamate (MSG) and 1.26 g/l for inosine-5'-mono-phosphate (IMP). The compounds were dissolved in distilled water and stored below 4 °C. They were presented on the following two days after acclimatisation to room temperature. The subjects received 5 ml in a disposable 30-ml plastic cup with lid.

Procedure

Separate sessions were held for the elderly and the young for practical reasons, and each age group was split into two groups (see Table 7.1). While half of the elderly and half of the young subjects started to assess the stimuli in a session while wearing a nose clip and subsequently while not wearing a nose clip, the others did so in the reversed order. The sessions were held on two consecutive days.

Table 7.1 Subject groups with their order of assessment

Group	1	2	3	4
age	elderly	young	elderly	young
female	5	5	5	5
male	5	5	5	5
day 1	noseclip off	noseclip off	noseclip on	noseclip on
	noseclip on	noseclip on	noseclip off	noseclip off
day 2	noseclip on	noseclip on	noseclip off	noseclip off
	noseclip off	noseclip off	noseclip on	noseclip on

All subjects received the taste qualities in the same fixed order per session. In the first series of session 1 and session 2, the order was sweet, sour, salty, bitter and umami, and in the second series the order was salty, sour, bitter, sweet and umami. Umami was always given last to avoid the risk that these compounds might cause an enhancement of the perception of a subsequent taste stimulus.

The order of the two tastants within one taste quality was held constant. For sweet the order was sucrose-aspartame, for salty sodium chloride-potassium chloride, for sour acetic acid–citric acid, for bitter caffeine-quinine hydrochloride, and for umami MSG–IMP. The three concentrations of each tastant were randomised per session series.

Summarising, the subjects had to taste 5 taste qualities in a row, 6 stimuli per taste quality, 3 concentrations of compound A, and three concentrations of compound B. In addition, each series of one taste quality was preceded by a rinsing of the mouth with 5 ml distilled water, and was completed by a rinsing of the mouth with 10 ml distilled water. All stimuli, water and tastants, had to be swirled through the mouth for 5 seconds and to be spat out into the cups and covered carefully by the same lids. This time span of 5 seconds was chosen for two reasons. Firstly, because the flow rate is highest at the beginning and then drops by the second to about half of the initial rate in approximately 11 seconds, due to a rapid adaptation. Secondly, to prevent the subjects of becoming fatigued. The inter stimulus interval of 45 seconds and the tasting time of 5 seconds were indicated by a tone signal. The tastants were rated on a 9-point intensity scale, ranging from very weak to very strong, and were also rated on a 9-point pleasantness scale, ranging from very unpleasant to very pleasant. All samples (both for the tastant and the water stimuli) were weighed immediately after each session trial to allow saliva production to be assessed.

Statistical Analysis

Methods

The statistical analyses were conducted by means of SAS®. Data were averaged arithmetically over the two replications. After checking for normal distribution, multivariate repeated measures analysis was applied to investigate the effect of age and concentration on intensity perception, on liking, and on saliva weight. The relationships between intensity, liking and saliva weight were investigated with correlation analysis. Furthermore, the effect of blocking the olfactory input on the intensity perception was compared for this experiment and for a previous one, which was carried out with the same tastants (Mojet et al., 2003).

Levels of significance

All effects that have a p-value of 0.05 or lower are reported as 'significant'. Power Analysis shows that, with the number of subjects in our study, an effect with a magnitude of 1.3 standard deviations and a p-value of 0.10 still has a power of 0.90. Therefore, a selection of the more interesting effects with a p-value between 0.05 and 0.10 are also reported. These effects will be denoted as 'trends'.

Results

Intensity perception

An overview of the results obtained under the without and under the with nose clip conditions is given in Figure 7.1 for young and elderly men and women separately. Before describing the effect of blocking olfactory input, which is the primary objective of this experiment, some general findings on the intensity perception of the tastants in water by young and older subjects will be briefly pointed out. Firstly, it is clear that the influence of the increase in concentration by 0.4 log concentration steps was different for the different taste qualities, and sometimes even for the different compounds within a taste quality.

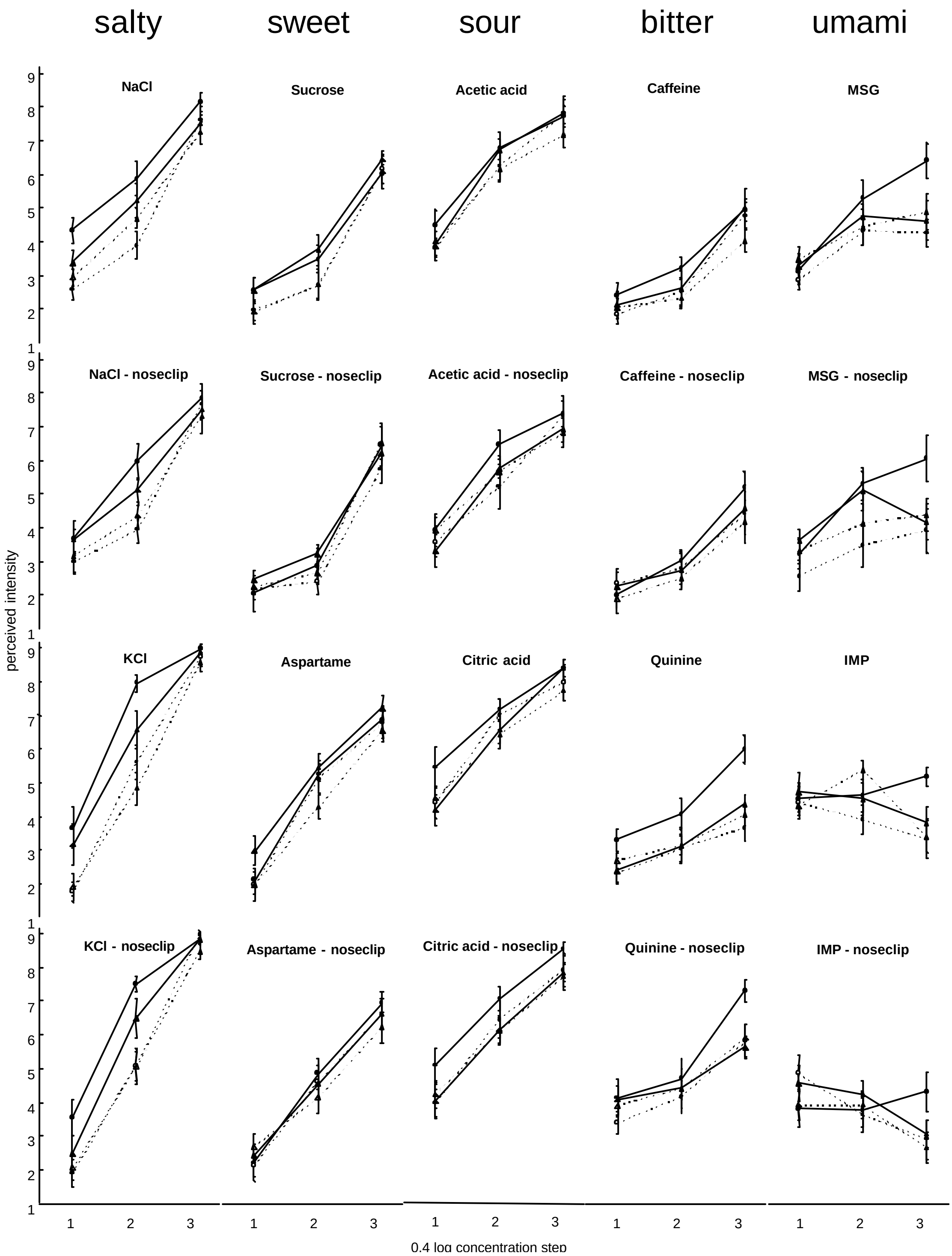

Figure 7.1 Intensity ratings (mean ± SE) for the ten tastants dissolved in water and assessed while wearing a nose clip or not by elderly and young male and female subjects. Elderly subjects are represented by dotted lines and open symbols, young subjects by solid lines and filled symbols. Men are indicated by triangles and women by circles.

In some cases (NaCl and KCl; sucrose and aspartame), these differences can perhaps be ascribed to insufficient intensity matching and to the different position the concentrations have in the dynamic range of perceived intensities (floor effects for NaCl, sucrose, caffeine and quinine HCl, ceiling effects for KCl and acetic acid), but for the umami taste qualities (MSG and especially IMP) more erratic and inexplicable relationships between concentration and intensity seem to prevail. Secondly, it should be noted that analysed over all tastants, no significant age and gender effects or age by gender interactions on intensity are found, although the elderly rated the saltiness of sodium chloride [$F(1,35) = 6.76$, $P < 0.02$] and potassium chloride [$F(1,35) = 18.57$, $P < 0.0001$] in water lower than did the young.

The intensities perceived by the group of young women are among the highest in almost all cases for salty, sour, bitter and for the highest concentrations of umami, but not for sweet, whereas the elderly usually perceive the tastants as less intense than the young (see Figure 7.1).

The nose clip effect on intensity

Since in the repeated measures analysis of variance a main effect of wearing a nose clip was found [$F(1,35) = 10.21$, $P < 0.003$], the results of a further analysis of the differences in the intensities of the tastants perceived under the conditions without and with a nose clip are given in Figure 7.2.a. Shown are the group means of the differences between the nose clip conditions, averaged per person over the three concentrations. As can be seen from this figure, in the majority of the cases, older subjects perceive the tastants as less different under the two conditions than do young subjects. In fact, for the elderly only the differences found for acetic acid [$T(18) = 3.81$; $P < 0.002$) and for MSG [$T(18) = 2.22$; $P < 0.04$) are significantly different from zero and the difference for IMP shows a trend [$T(18) = 2.03$; $P < 0.06$] in the same direction. Measured over all tastants, no significant deviation from zero is found for the elderly [difference = 0.11; $T(18) = 1.35$; $P < 0.20$] and a separate analysis for each of the three concentration levels over all tastants shows only a significant difference from zero [$T(18) = 2.37$; $P = 0.03$] for the middle concentration.

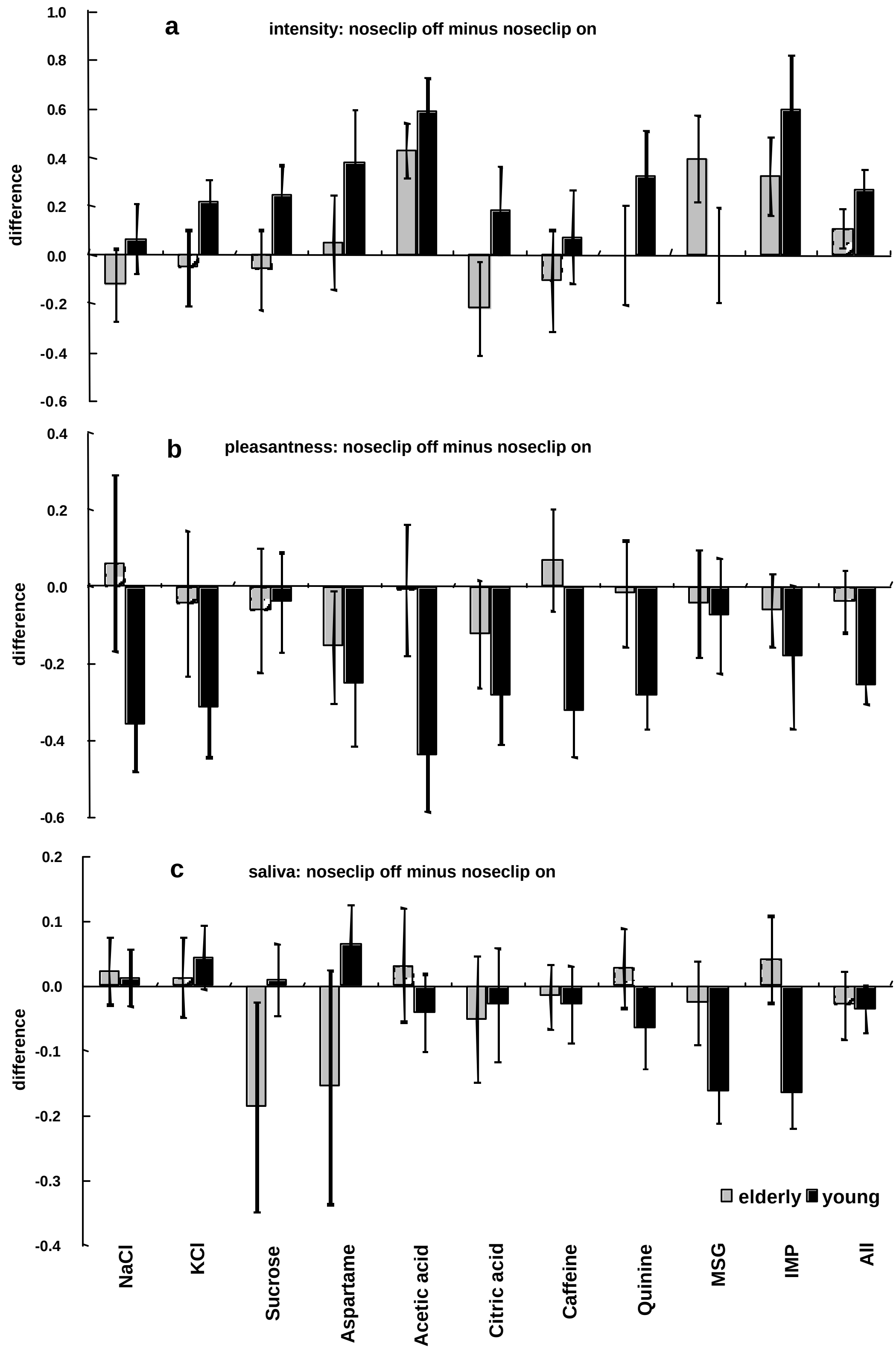

Figure 7.2 Differences (mean ± SE) between the nose clip off and nose clip on condition for elderly and young subjects assessing the ten tastants on intensity (**a**), pleasantness (**b**), and amount of saliva (**c**). Positive differences mean higher ratings of intensity / pleasantness or larger amounts of saliva were obtained in the nose clip off than in the nose clip on condition. Negative differences mean that the reverse was true. Elderly are represented by grey bars and young by filled black bars.

For the young, the mean difference over all tastants deviates significantly [difference = 2.69; T(19) = 3.25; P < 0.005] from zero and such significant differences are also found for the data over all compounds at each of the three concentration levels used [lowest concentration: difference = 0.23; T(19) = 2.15; P < 0.05; middle concentration: difference = 0.31; T(19) = 2.98; P < 0.008; highest concentration: difference = 0.27; T(19) = 3.10; P < 0.006]. Furthermore, in the case of the individual compounds, significant differences from zero are found for KCl [T(19) = 2.33; P < 0.04], sucrose [T(19) = 2.12; P < 0.05], acetic acid [T(19) = 4.37; P < 0.0003] and IMP [T(19) = 2.71; P < 0.02], while for aspartame [T (19) = 1.81; P < 0.09] and quinine [T(19) = 1.76; P < 0.10] trends in the same direction are found. It should be noted that all these significant differences and trends are positive, indicating that the intensity of the tastants is reduced by wearing a nose clip. That this reduction is larger for the young than for the elderly means that, by putting a nose clip on, the difference in intensity perception between the two groups is reduced by about 70 % (57.6% in men and 82.3% in women).

Pleasantness

In order to check whether the unpleasant feeling of wearing a nose clip might have negative effects on the appreciation for the stimuli, liking for the stimuli was measured under both the without nose clip and the with nose clip condition. In Figure 7.2.b the differences in appreciation between the two nose clip conditions are shown for each of the tastants and for all tastants pooled. The elderly appreciate the individual tastants about equally well under both conditions and non of the differences found for them do deviate significantly from zero. Overall, the young do appreciate the tastants less with the nose clip off than with the nose clip on [difference = -0.26, T(19) = -5.22, P < 0.0001] and for NaCl [T(19) = -2.92, P < 0.009], KCl [T(19) = -2.48, P < 0.03], acetic acid [T(19) = -3.06, P < 0.007], citric acid [T(19) = -2.21, P < 0.04], caffeine [T(19) = -2.75, P < 0.02] and quinine HCl [T(19) = -3.19, P < 0.005] this is also the case. No differences in appreciation are found for both sweet and both umami tastants. Furthermore, it is clear that wearing a nose clip improves the appreciation in the young, and that it reduces the gap in appreciation between the elderly and the young by 69.6 % (mean appreciation without nose clip elderly = 4.19, young = 3.88; with nose clip elderly = 4.23; young = 4.13). In fact, putting on a nose clip did not lead to lower appreciation of the tastants in any of the two age groups, indicating that possible irritation by it had no ill-effects on the results.

Saliva

The basic data on the saliva production in the two age groups are given in Figure 7.3. It shows that saliva production is in all cases higher in the young than in the elderly and in many cases the elderly obtain negative results, which might indicate that they suffer from a dry mouth and do not clear their mouth completely. This is a systematic overall difference with the young, because the correlations between the amounts of saliva produced by the elderly and the young in response to the different concentrations of the different taste stimuli are R = 0.950 for the without nose clip and R = 0.953 for the with nose clip

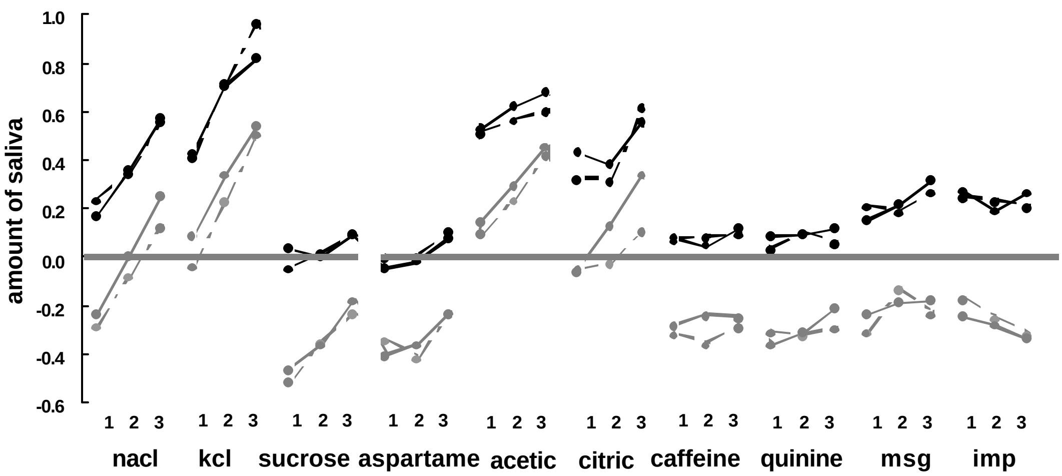

Figure 7.3. Amount of saliva for the three concentrations of each of the ten tastants for elderly (black) and young (grey) subjects in the nose-clip on (solid lines) and nose-clip off (broken lines) condition. The amount of saliva is the difference between the weight of the cup before and after tasting, averaged over persons, and is expressed in g/l.

condition. This indicates that the salivation patterns to the different stimuli of the two groups are almost identical and that, with regard to the quantity of saliva produced, the groups differ in the same way for all tastants and even for all levels of concentration of the tastants.

Furthermore, it is clear that the amounts of saliva produced are positively related to the concentrations of the tastants for the salty compounds NaCl [$F(2,34) = 48.31$, $P < 0.0001$] and KCl [$F(2,34) = 55.01$, $P < 0.000$] , for the sweet compounds sucrose [$F(2,34) = 15.84$, $P < 0.0001$] and aspartame [$F(2,34) = 19.05$, $P < 0.0001$], for the sour compounds acetic acid [$F(2,34) = 9.34$, $P < 0.0007$] and citric acid [$F(2,34) = 24.28$, $P < 0.0001$], and to a certain extent for MSG [$F(2,34) = 7.92$, $P < 0.002$] , but that this is not the case for the bitter compounds. However, for IMP a trend towards a negative relationship [$F(2,34) = 2.86$, $P < 0.08$] between the presented concentration and the saliva production is found. This latter finding is in line with the decline of the taste intensity with increasing concentration for this compound, as is described earlier in this section and shown in Fig. 7.2a. An interaction of concentration by age was found for sucrose [$F(2,340 = 3.35$, $P < 0.05)$] where the saliva production of the elderly rose faster with the concentration of the tastant than that of the young, and for MSG [$F(2,340 = 3.30$, $P < 0.05)$] where the reverse was true and the change in saliva production was very small for the elderly subjects.

The differences between the two nose clip conditions in saliva production by the elderly and the young, averaged over the three concentrations are given per product in Figure 7.2c. For the elderly, none of these differences deviated significantly from zero. In some cases such as for the sweet tastants, the standard errors of the mean of the elderly were extremely large, indicating considerable individual variation in salivary production between members of the group for these tastants. For the young there were also no differences that significantly differed from zero, with the notable exception of the results for the two umami compounds. Both MSG [$T(19) = -3.22$; $P < 0.005$] and IMP [$T(19) = -3.18$; $P < 0.005$] invoked a larger saliva production in young subjects when they had their noses blocked.

It can be concluded that possible odorous effects of the classical taste stimuli (sweet, salty, sour and bitter) do not affect salivary function, but that this may be an aspect in which umami differs from the other tastants.

Correlations

A correlation analysis was carried out to check whether the three types of data (intensity judgements, pleasantness judgements and saliva production) were related to each other. The correlations were calculated per age group over the individual responses of the subjects in each of the three tasks and calculated for all tastants pooled and for the separate tastants under each of the two nose clip conditions. For the elderly the only two significant correlations found are the relationship between intensity and saliva production in response to NaCl under respectively the with ($R = 0.57$, $P < 0.01$) and without ($R = 0.50$, $P < 0.05$) nose clip conditions.

For the young quite substantial negative correlations (all P's <0.01, unless mentioned otherwise) between intensity and liking were found under both nose clip conditions for the sour (without nose clip $R = -0.76$ and -0.81; with nose clip $R = -0.83$ and -0.74 for respectively acetic and citric acid) and bitter stimuli (without nose clip $R = -0.73$ and -0.71; with nose clip $R = -0.58$ and -0.62 for respectively caffeine and quinine HCl) as well as for the salty stimuli under the nose clip "on" condition (NaCl: R =.-0.69; KCl: R =.-0.55, $P < 0.02$) and to a lesser degree for the umami stimuli under the nose clip "off" condition (MSG: $R = -0.50$; $P <0.05$; IMP: $R = -0.66$, $P < 0.01$). That all correlations found between intensity and liking are negative is not surprising, because it is known that the dislike for unpleasant stimuli grows monotonically with concentration, whereas liking for pleasant stimuli usually grows to a maximum and then declines at higher intensities. It is therefore not surprising that no correlations are found for the sweet compounds. Inspection of the average liking of the different concentrations of aspartame showed indeed that the middle concentration was liked best by both age groups, but for sucrose a monotonically rising function with rising concentration was obtained and the lack of significant correlation could therefore not be explained in the same way.

For the young the only significant correlation between intensity and saliva production was found for acetic acid under the no nose clip condition ($R = 0.56$, $P < 0.01$). Negative correlations between liking and saliva production were found for both umami compounds when the nose of the young subjects was blocked (MSG: $R = -0.49$; IMP: $R = 0.46$, both P's < 0.05).

When analysed over the individual average responses to the ten tastants, negative correlations between intensity and liking were found for the young under both nose clip conditions (nose clip on: $R= -0.66$; nose clip off: $R = -0.63$, both $P < 0.01$).

Preliminary conclusions

In earlier research (Mojet et al., 2003) it was demonstrated that wearing a nose clip reduced the difference in taste intensity perception between elderly and young for tastants in food products. The results of the elderly remained almost unchanged, but the young lost their advantage over the elderly when their noses were blocked.

The present experiment shows that a similar reduction (by 70%) of the difference between elderly and young takes place when the pure tastants are dissolved in distilled water. Since it is well known that odour sensitivity deteriorates to a much larger extent with age than does taste sensitivity, and since the nose clip excludes or at least greatly reduces the possibility of olfactory stimulation, these results strongly suggest that the so-called differences in “taste intensity” perception between elderly and young are predominantly due to differences in sensitivity to the smell rather than to differences in sensitivity to the taste of the compounds. To accept the hypothesis that the tastants themselves have a smell, it is nevertheless necessary to prove this directly. At the same time it is necessary to show that the effects are not due to changes in the olfactory quality of the solvent caused by cross-modal interaction with the tastant. This possibility was mentioned in the earlier study (Mojet et al. 2003) where the tastants were dissolved in normal food products. Although it was considered highly unlikely that the water used in the earlier and the present experiment had an odour which was sufficiently strong to explain the difference in reported “taste” intensity between the elderly and the young, the precaution was taken to use and compare the results obtained with three different waters in the second experiment in which the odours of tastant solutions were orthonasally tested.

Orthonasal testing of the olfactory properties of the tastants in water was chosen because it is easier to accomplish, avoids the risk of contamination by accidental taste stimulation in the mouth and because it is the most conservative measurement, since it has been shown (Zoeteman, 1978) that (mal)odorous compounds dissolved in water are detected retronasally as stronger and at much lower concentrations than when presented orthonasally. Taking water in the mouth is therefore a standard procedure in the water industry to test for the absence of off-odours. This suggests that if the odours of the tastants in water are already discernible by orthonasal olfaction, their retronasal effects will be much stronger. In order to avoid falsification of the results by possible minute off-odours of the water itself – quantities measured in parts per trillion have been known to produce effects – the tests are executed with three types of water, covering the scope of the waters usually used in taste research.

Experiment 2

Materials and Methods

Subjects

Forty-one subjects (13 men, age 28.2 ± 5.7; 28 women, age 30.8 ± 5.6) took part in the experiment. They were tested in four groups of about ten persons. All subjects were healthy and naïve with regard to the purpose of the experiment. They were recruited to judge water on the presence of possible odour contamination. At the end of the experiment they were paid for their participation.

Stimuli

For all ten tastants the highest concentration used in experiment 1 was prepared in demineralised water, in double distilled water and in commercially available Evian water respectively. The samples were prepared on the evening before the experiment and kept at room temperature overnight. The next day 50 ml of each of the 30 solutions was transferred to a coded 150 ml plastic cup with an attached lid. Each of these stimuli was presented on a tray together with three similarly coded (random three digit numbers), but otherwise identical cups containing only 50 ml of the same water as was used in the composition of the taste stimulus.

The position of the target stimulus and the blanks was chosen at random with the restriction that over the three series all four positions of the target occurred about equally often. A separate randomised presentation order of the ten different stimuli was used in each of the three series (one series per type of water).

The order of the series was balanced over the groups. Each of the series was first in one group, second in another group and third in the third group. The fourth group started with the double distilled water, then received the Evian and ended with the demineralised water series.

Procedure

At the beginning of the session the subjects were seated independently around a set of large tables. Each subject sat in front of a tray with four coded cups (one stimulus and three blanks). In a four alternative forced choice paradigm (4AFC) the subjects were asked to indicate which of the four cups smelled differently from the other three. They were told that often the task would be very difficult, but that they had to make a choice, even if they felt that it was only their best guess. At a sign from the experimenter, the subjects opened the cups, smelled the samples, noted their decision by crossing out a number on the response sheet, closed the cups again and passed the tray in the direction of their neighbour, who picked it up and waited for the next sign of the experimenter (interval between signs 60 seconds). This procedure was carried out ten times and followed by a pause of 5 minutes during which the stimulus sets and response sheets for the next series were distributed. The total time for completing the three series of the experiment was 45 minutes (including instruction).

Statistical analysis

Methods

For each taste stimulus the number of correct odour responses was calculated over the 41 subjects. This was expressed as a percentage and corrected for guessing by the following calculation: Percentage corrected = [(Percentage observed – Percentage expected by chance) / (100 – Percentage expected by chance)] x 100. Calculation of the significance of the differences from chance guessing was done by Chi-square calculations on the numbers of correct and incorrect responses (Siegel and Castellan, 1988) in each of the series. Chi-square was also used to verify whether the numbers of correct responses found for the three waters differed and to verify whether the numbers of correct responses differed between the ten tastants used.

Since Chi-square(df 1) reaches a P-value of 0.05 at 3.84 and a P-value of 0.10 at 2.71, a number of at least 12 out of 30 responses correct in the one out of four forced choice task (Chi-square(1) = 3.6, $P < 0.06$) is indicated as significant in the description of this experiment. Effects with Chi-squares between 3.6 and 2.71 ($P < 0.10$) will be denoted as ‘trends’ or ‘tendencies’.

Results

General

First the percentages correct responses to the stimuli were compared for men and women over all ten tastants and the three waters together. Men (37.2 %) performed overall somewhat better [Chi-square(1) = 4.398, $P < 0.05$] than women (31.0%), and this was mainly due to the lesser performance of the women in the detection of quinine [men 33.3%, women 14.4%; Chi-square(1) =

4.849, $P < 0.05$]. Although in total the men outperformed the women in seven out of the ten cases, none of the other differences were significant. Since the group of men was small (N = 13) and probably not representative of the male population, it was decided not to take too much notice of these possibly rather accidental gender differences and to pool the data of women and men in the further analyses. A correlation coefficient of R = -.0019 between age and performance showed that age played no role in odour detection performance within the group.

The influence of the waters

Overall, no significant difference was found in the total numbers of correct responses (demineralised water 132, double distilled water 147, Evian 126, n = 410) to the tastants when dissolved in the different waters [Chi-square(2) = 2.036, n.s.].

When the differences between the waters were tested for the individual tastants, there were also no significant differences, except in the case of IMP [demineralised water: 14, double distilled water: 24, Evian: 6, n = 41; Chi-square(1) = 12.29, $P < 0.001$] whereas for MSG a similarly skewed but not significantly different distribution in the numbers of correct responses per water was found.

When the results of the two compounds for each taste quality are combined, umami is also the only taste quality where the use of different waters leads to different results [demineralised water: 27, double distilled water: 35, Evian: 11; Chi-square(2) = 12.29, $P < 0.001$]. This suggests that the use of double distilled water increases [Chi-square(1) = 13.67, $P < 0.001$] and the use of Evian water reduces [Chi-square(1) = 5.94, $P < 0.02$] the chance that the presence of umami odour is detected orthonasally.

Odour detection performance

The percentages odour detection after correction for chance guessing are given in Figure 7.4 for the whole group (all subjects) and for the subjects that performed better than chance, because they had a correct score of twelve [Chi-square(1)= 3.6, $P < 0.06$] or more out of thirty responses (12+ subjects).

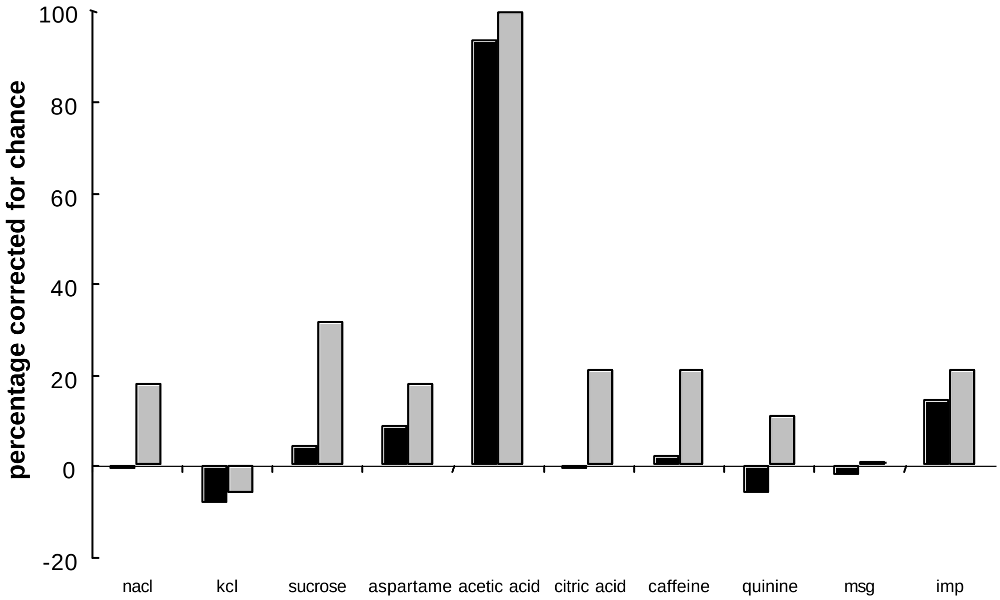

Figure 7.4 Percentage detection corrected for chance for the ten tastants for all subjects (n=41) and for the subjects who had a correct score of twelve or more out of thirty responses (so-called 12+ subjects, n=13). All subjects are represented by filled black bars and the subjects who did better than chance (12+ subjects) by grey bars.

The total group performs significantly better than chance in detecting the odours of acetic acid which is detected in 93.5 % [Chi square(1)= 322.56, $P < 0.001$], and IMP which is detected in 14.4%. [Chi-square(1) = 14.36, $P < 0.02$]. For the odour of aspartame a detection trend is found at 8.9% [Chi-square(1) = 2.94, $P < 0.10$].

When the data of the 12+ subjects are considered, only the odours of three tastants (KCl, quinine and MSG) are *not* detected significantly more than could be expected by chance. NaCl and aspartame are both detected in 18.0 % [Chi-square(1) = 3.77, $P < 0.06$], citric acid, caffeine and IMP in 21.4% [Chi-square(1) = 5.34, $P < 0.03$], sucrose in 31.6% [Chi-square(1) = 14.33, $P < 0.01$] and acetic acid in 100 % [Chi-square(1) = 117, $P < 0.001$]. This means that around 31% of the subjects orthonasally perceive the odours of seven out of ten tastants dissolved in water at room temperature in at least 18% of the times they are presented to them.

Of course it is not surprising that a selection of the subjects based on their superior response performance shows indeed a better performance, but an analysis of the differences in percentages corrected between the total group and the 12+ subjects shows that these differences are not evenly distributed over the ten tastants [Chi-square(9) = 51.45, P < 0.01] and this is also the case when the result of acetic acid, which left very little room for difference between the groups, is left out [Chi-square(8) = 45.14, P < 0.01]. This means that the differences between the total group and the 12+ group are, at least to a substantial part, due to the specific sensitivities of the 12+ group and not just to mere better luck in chance guessing.

Preliminary conclusions from experiment 2

The fact that seven of the ten tastants used can be detected by orthonasal olfaction and that this detection is independent of the water used for four of the five taste qualities strongly suggests that a number of tastants themselves have an odour and that the effects are not due to enhancement of the odour of the solvent. That the odour of umami was better perceived when dissolved in double distilled water might perhaps be an indication of such an enhancement, but that would suppose that the double distilled water had more of a different odour than the Evian in which the umami was perceived less well. A simple check with a small group of experts did not show any detectable odour difference between these waters in triangle tests.

Discussion

Effects of olfactory deprivation

As pointed out in the introduction, these experiments were set up to see whether similar effects of blocking olfactory cues by wearing a nose clip on the taste intensity of older and young subjects would be found when the tastants were dissolved in water as when they were dissolved in food products (Mojet et al. 2003, 2004b). Secondly, the experiments aimed at verifying whether such effects were due to odours given of by the tastants themselves or by interactive changes in the odours of the solvent (food product or water) caused by the presence of the tastants, some of which are known flavour enhancers (MSG and IMP).

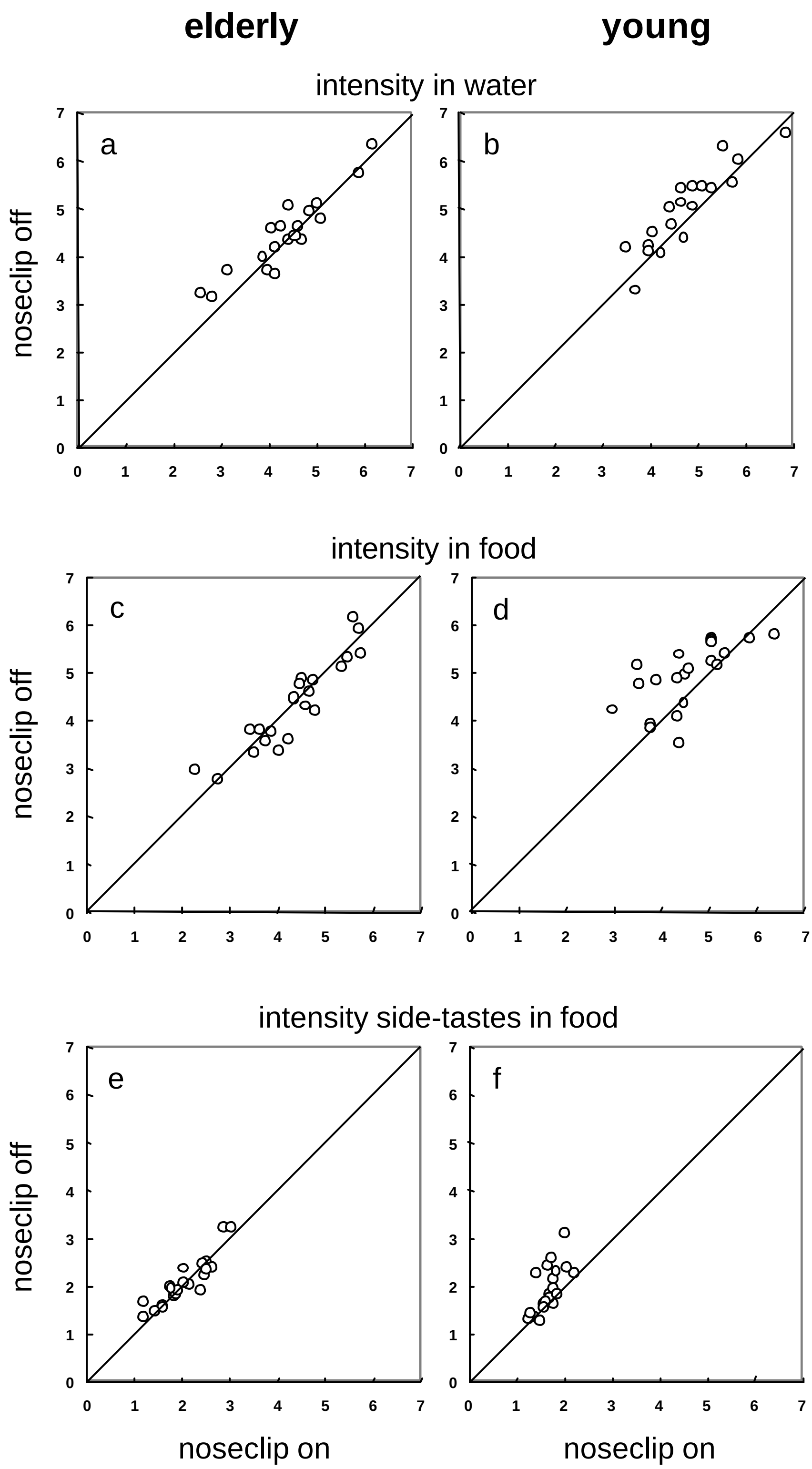

Figure 7.5 The effect of olfactory deprivation on the perceived intensities for elderly and young subjects. Figures **a** and **b** show the intensities in water of the present study. Figures **c** and **d** show the intensities of the experimentally varied tastants in food of a previous study (Mojet et al., 2003). Figures **e** and **f** show the intensities of the side-tastes in food of a previous study (Mojet et al., 2004b).

The answer to the first question is illustrated in Figure 7.5.a-f, where the results of the experiments are compared for young and older subjects in the scatter plots of the correlation between the nose clip-off and the nose clip-on condition. The story these figures tell is simple. For the young the pattern of differences in taste intensity perception under the two nose clip conditions is indeed quite similar over the experiments, although the effects are substantially more pronounced when the tastants are dissolved in product. Most data points are found above the diagonal line, indicating that for most subjects the taste intensities are enhanced by olfactory cues. The elderly show the same effect, although to a lesser degree, when the tastants are judged in water, but when they are presented in product, the taste intensity judgements of the elderly do not seem to be influenced systematically by the nose clip on or off conditions. The difference between the nose clip effects in water and in product may of course be due to a lesser olfactory sensitivity of the elderly in the "product group", but it may also be explained by assuming that the elderly find it easier to summate the odour and the taste intensity of the same tastant when they are perceived unmixed with other odours as in water, but that they cannot do so when the odour of the tastant is part of a complex mix that does not seem to be specifically related to the tastant in question. Mojet et al. (2004b) found that these same elderly systematically rated the intensities of the side-tastes in the product higher than the young did, whereas they rated the intensity of the dominant and experimentally varied taste lower than the young. To explain this phenomenon, Mojet et al. (2004b) invoked a signal-to-noise ratio hypothesis and supposed that the elderly exhibit a lowered attentional differentiation because they were less capable of separating sensory inputs. A similar phenomenon is known as the "cocktail party syndrome" in audition and speech perception. In rooms where many people are talking, elderly people often have great difficulty listening specifically to the person who is talking directly to them. Similarly in the water condition, the odours of the tastants are congruent with the taste and stand out against a blank background whereas in the product context they are swamped by other odours. That it is unlikely that the group of subjects who judged the tastants in product ("product" group) was really much less sensitive than the subjects who judged the tastants in water ("water" group) is illustrated when the effects of wearing a nose clip on the liking for the stimuli are compared (see Figure 7.6). Here it becomes clear that wearing a nose clip does have an effect on the liking of the elderly in the "product" group and not on that of the elderly in the "water" group. Although this shows that the elderly in the "product" group were not insensitive to odours, it also shows – strangely enough – that they liked the products better when they had their nose clip on. Similarly, the young in the present experiment liked the tastants in water better when they did wear a nose clip than when they did not wear one (see also Figure 7.2.b). That the odours of the tastants could contribute to the general dislike of the young for the tastants dissolved in water is quite understandable, but that the elderly would rather not smell the products is less easy to explain.

Whatever the answer to these riddles is, it is clear that olfactory information plays a role in taste intensity perception and that these effects are stronger in the young than in the elderly.

These findings and the fact that wearing a nose clip narrows the gap between the elderly and the young by about 70 % for both intensity perception and liking are in good agreement with the well documented fact that, compared to the other senses, the olfactory sense declines rather rapidly with age (Murphy, 1986; Doty, 1990; Doty and Laing, 2003). The second question mentioned at the beginning of this discussion is whether the effects are due to odours given off by the tastants themselves or to interactions between the tastants and the odours of the solvent. The experiment where different waters were used was designed to provide an answer to this question. It is clear that even with orthonasal olfaction the odours of the majority of the tastants can be detected by almost a third of the young subjects in about twenty or more percent of the cases. Since retronasal stimulation by off-odours of water in the mouth has much stronger effects than orthonasal sniffing (Zoeteman, 1978) it can be safely assumed that a larger group of the young in the first experiment detected the odours of the tastants in a larger percentage of the presentations. In fact it is possible to compare the reduction in intensity perception caused by the wearing of a nose clip for the ten tastants in the young group of experiment 1, with the amount of orthonasal detection of the tastants odours in experiment 2 (only young subjects). A correlation of R = 0.645 [T(8) = 2.71, P < 0.05) between these two data sets is found, indicating that about 41% of the variance of the difference between the two nose clip conditions found for the different tastants in experiment 1 could be explained by variations in the orthonasal odour delectability of the tastants in experiment 2, notwithstanding the fact that two different groups of subjects were used. Thus, it might be that the retronasal perception of the odours of the tastants alone is responsible for the differences between the two nose clip conditions in both age groups and that the difference between the two age groups in the extent of the nose clip effect is caused by the decline of the olfactory sensitivity of the elderly for these odours.

However, as indicated above, it should be realised that in young subjects the nose clip effects are stronger (see figure 7.5a-d) when the tastants - and especially the dominant and varied tastants - are dissolved in product than when they are dissolved in water, whereas in the elderly this is not the case and the effects of nose clip are negligible.

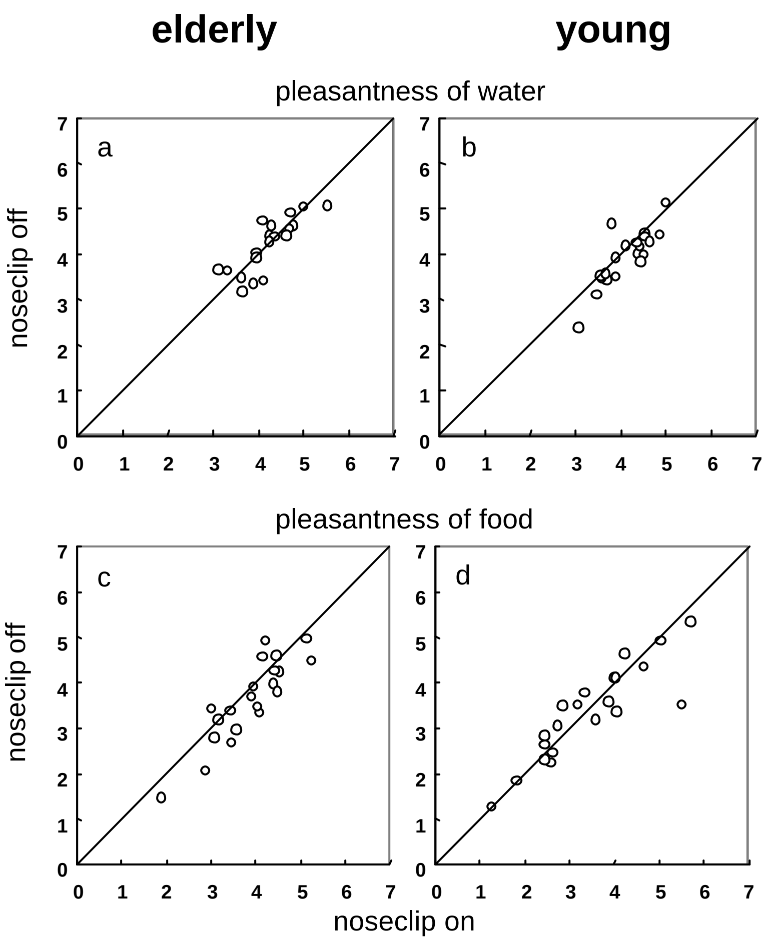

Figure 7.6 The effect of olfactory deprivation on the pleasantness of water solutions (**a** and **b**) and of food (**c** and **d**) for elderly and young subjects

This again seems to confirm that the effects are due to the odour of the tastants themselves for which the young are more sensitive than the elderly. Nevertheless it indicates at the same time that the presence of the odours of the product itself may interact with and have an enhancing effect on these added tastants. The fact that this only occurs for the young, who indeed perceive them as odorous, seems to suggest that this is in the first place an odour-odour interaction, the effect of which is then subsequently interpreted as a taste enhancement. Such an interpretation in terms of taste enhancement by odour is well in line with the literature on odour-taste enhancement described in the introduction (Frank and Byram, 1988; Frank et al., 1993; Stevenson et al., 1999).

Sensitivity to the odour of the different tastants

In the first experiment, even the elderly are on average sensitive enough to perceive the odours of acetic acid and MSG when dissolved in water (see fig. 7.2.a). The young seem to be less sensitive to the odour of MSG, but show significant effects of olfactory blocking for the odours of KCl, sucrose, acetic acid , IMP and marginally significant ones for those of aspartame and quinine. The only tastants for which no intensity effects of olfactory blockage were found when they were dissolved in water are NaCl, citric acid and caffeine, but for all three of these and for the other salty, sour and bitter tastants, the young show a positive shift in liking when their noses are blocked, indicating that olfactory cues do play a role with these tastants as well.

In general, such differential effects as a result of nose clip condition are not found in the saliva production of the two age groups. Although averaged over all tastants the young produce more saliva than the elderly, putting on a nose clip does not significantly change these amounts in either group for any of the salty, sweet, sour and bitter tastants (see fig. 7.3). For the elderly this is also true for umami, but for the young blocking the nose significantly increases the flow of saliva at stimulation with both MSG and IMP. It can be concluded that the production of saliva, which itself contains MSG (about 3.3 g/l according to Yamaguchi et al. (1987), i.e. about a quarter of the highest 12.59 g/l stimulus and 1.5 times the lowest 1.99 g/l stimulus in this experiment) is decreased by the smell of the umami tastants. This is an interesting finding, because MSG is one of the two tastants that could not be detected by orthonasal olfaction even by the most sensitive (12+ group in fig. 7.4) of the young people in the second experiment and because MSG is the only tastant that by the elderly, but not by the young is perceived as more intense without than with a nose clip. This might suggest that the higher general saliva production of the young (independent of stimulation) leads to a higher general adaptation level for MSG, which makes it more difficult for them to detect its odour when stimulated with it, than for the elderly.

In conclusion, it can be said that contrary to what is commonly assumed, all so-called "pure tastants" used here - and in many experiments by others - are also olfactory stimuli and that most of the age-related "taste" differences found are probably predominantly based on differences in olfactory sensitivity. This leads to the intriguing question what is smelled and how it is smelled? That acetic acid is volatile enough to be smelled at even rather low concentrations is well known, but what about most of the other compounds? Is it possible that substances with no measurable vapour pressure still stimulate the nose? Or should the conclusion be that, even with the pure reagent grade stimuli used in these experiments, the odours are due to impurities? Although it seems unlikely, this can not be excluded and if it is true it will have affected the results of other investigators, who sometimes took less precautions, at least to the same degree. It is clear that further research is needed to find answers to these questions, but that olfaction plays a larger role in taste perception than has been assumed in the past.

Acknowledgement

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Chapter 8

General discussion

Age

The main aim of the studies presented in this thesis was to investigate possible differences between taste perception of elderly and young people. Several changes with age are found. First, age has a deteriorating effect on taste perception, which is already noticeable in the young-old group of elderly. This effect is generic in nature, i.e. the perception of all tastants is affected, and is evident when tastants are dissolved in water or in product. In both cases, more than 90% of the total variance attributable to age is due to age alone and less than 6% to the fact that elderly and young differ in the perception of the different taste qualities (chapter 3 and 4). Secondly, the differentiation between the different taste qualities is less distinct for the elderly than for the young (chapter 3 and 6). Both findings point in the direction of more general explanations, such as three noise hypotheses mentioned in the introduction of this thesis. First, a diminished signal or an increase in neural noise caused by a decline in functioning or by a loss in brain cells with age have been put forward to explain this phenomenon (Salthouse and Lichty, 1985). Second, there may be a problem with selective attention: the ability to neglect irrelevant information may be impaired. The irrelevant information may be considered as noise at a psychological/ perceptual level rather than at a neural level (Stroop, 1935; Rabbitt, 1965; Farkas and Hoyer, 1980; Wright and Elias, 1979). Third, the proximal noise hypothesis may explain the second finding. This hypothesis suggests an inappropriate lateral inhibition, due to a reduction of the resolution in the CNS stimulus configuration and resulting in diffusion. Further taste research, in which the change in signal-to-noise ratio with age is investigated, is needed.

The brain atrophies with age, i.e. there is a decrease in brain volume, particularly in the frontal cortex (Raz, 2000). Although this shrinking of the brain seems to be moderate in the mediotemporal areas, the taste cortex might also be affected. There is evidence that, while performing cognitive tasks, less specificity or differentiation in brain recruitment occurs in the elderly compared to the young (Park et al., 2001).

The number of brain sites recruited to perform a task increases with age or is different from the sites used by young adults. Three types of this so-called dedifferentiation have been classified: a contralateral (homologous) recruitment, an unique recruitment (non-homologous recruitment of additional brain areas), and a substitution (different structures show activation), which involves a difficulty in engaging specialised neural mechanisms. So far, it is not clear, whether this dedifferentiation with age also occurs for sensory tasks. Neuro-imaging research might throw light on this issue. In addition, Kempermann et al. (1998) have demonstrated growth of new neurons in response to complex environments in aged rats, suggesting that stimulating experiences may result in functional reorganisation of the brain. The learning effect of practice in the threshold measurements (chapter 3) might be seen in the same light. The optimistic view on ageing, expressed in the proverb “use it or lose it”, seems to be supported by this finding.

While in the taste experiments described here, absolute perception was affected by age, relative perception was not (chapter 4a). This suggests that enough signals are transported to discriminate concentration differences.

Nevertheless, possible explanations for age-related changes in taste perception can also be sought at the periphery. There might be a diminished accessibility of the taste buds resulting from a decrease in the number of them, or from a diminished saliva production with age, or from both. Another explanation would be the decrease in the number of taste receptor cells with age, which accounts for a lowered action potential firing rate in the higher regions. It is also possible that the action potentials are not altered, but that the thresholds in the cranial nerves are increased.

Differences in the use of psychological measuring scales between the elderly and young might also be an explanation of the differences between the elderly and young, but this possibility has been excluded beforehand throughout these experiments by the use of the cross modal intensity matching method to correct for such differences.

Taste

Locus of most accurate coding

The experiments with elderly and young subjects also throw some light on taste perception in general, which would not have been the case when the experiments were carried out with young adults only. Although the changes with age are mainly generic in nature, it is remarkable that the taste qualities which are most important for human beings, seen in the light of evolution, are most consistently affected by age. When tastants were dissolved in water, an age effect was found for all tastants. This effect of age remained significant for salty and sweet tastants when tastants were comprised in products (chapter 3 and 4b). This finding might relate to the findings of Scott and Plata-Salaman (1999), who found that about 73% of the neural resources in the primate insular-opercular (primary) taste cortex were devoted to the detection of the sweet (about 34%) and salty (about 38%) stimuli, whereas about 22% of the neurons were tuned to bitter (quinine) while only about 5% were oriented toward the detection of acids. It is expected that this clustering with sharp distinctions between the neurons responding to four prototypical tastants will be rather similar to the organisation in the human primary cortex, since primates are most closely related to humans. Rolls and Scott (2003) performed a not quite understandable quantitative comparison of macaque neurophysiology and human psychophysics and they reported a high positive correlation (0.91) between a similarity plot derived from descriptions of the same stimulus pairs of NaCl, glucose, quinine and HCl on the one hand and the similarities between patterns elicited by the same two stimuli in macaque cortex on the other. They concluded that the most accurate analysis of perceived taste quality is likely to take place in the primary taste cortex. Furthermore, the umami taste of proteins was shown to be approximately as well represented in terms of mean evoked neural activity and the number of cells with best responses to it, as the other four stimuli (Baylis and Rolls, 1991; Rolls, 2000). Further integrated investigations are needed to connect behavioural and neurophysiological responses.

Role of smell

Probably the most interesting and unexpected finding of this thesis is that smell seems to play a crucial role in taste perception. When the olfactory input is blocked about 70% of the age differences in taste perception disappeared (chapter 4 and 7). This means that, when rating intensities of tastants dissolved in water or in product, only about 30% of the differences between elderly and young are attributable to taste alone. Since taste and smell sensations are so intimately related and accompanied by other sensations, such as mouthfeel, temperature and spiciness, it might not be a bad idea to investigate age related changes in taste perception with a multimodal-multimethod (e.g. psychophysical and fMRI) approach, including all oral sensations in the investigation.

Affective response to taste

The most preferred concentration of tastants in product was not different for elderly and young, despite the differences in perceived intensity (chapter 5). One of the often heard hypotheses is that people habituate to a diminished perception, since the normal deterioration with age starts in their thirties and continues to decline through the years. An alternative hypothesis would be that due to the changed signal-to-noise ratio, the elderly have a more diffuse concept (Gestalt) of the product, which means that for them more products with small variations will fall into their concept, whereas the young will have a more limited and distinct concept. But if this were true, one would expect to find flatter pleasantness slopes for the elderly than for the young, which is not the case.

Another hypothesis might be that perception and (un)pleasantness are processed in different areas of the brain. Support for this might be found in the findings of Reilly and Pritchard (1995), who reported that thalamic taste relay nucleus lesions in macaques caused only minor changes in acceptability, while thalamic taste cells in rodents show monotonically increasing responses with stimulus concentration and differential activity to a full range of taste qualities (Scott and Erickson, 1971). This latter hypothesis might also explain that in this thesis taste sensitivity and the optimally preferred concentration of tastants in every day products were unrelated.

Summary

Chapter 1

In this introductory chapter the increase of the ageing population is briefly described. The world population of elderly is rapidly growing. The average life span is expected to extend another 10 years by 2050. As a consequence there is a growing need to understand the changes that occur with ageing.
The next section is devoted to age-related changes connected with eating and drinking behaviour, such as changes in gastrointestinal function. In the oral cavity, saliva production is diminished, saliva composition is changed, the chewing efficiency is reduced, and the number of taste buds is decreased. Ageing has also an effect on the speed of cognitive processes. A basic question in research on ageing is whether this slowing down process is generic or specific in nature. To date it seems best to assume that controlled information processing, which requires attention and processing capacity slows down with age, but that automatic processing, which does not require attention or effort, is retained. Several noise hypotheses to explain the slowing down process are described. Three hypotheses try to explain this phenomenon as a decreased signal-to-noise ratio at the input level. Two hypotheses assume increased noise in the retrieval process.
Subsequently, the changes with age in sensory perception are described. In vision, focussing becomes more difficult and there is often less depth perception, less tolerance for glare, and distinguishing colours may become more difficult. In the ear, age may affect hearing as well as balance. The elderly may have reduced sensations of pain, vibration, cold, heat, pressure and touch. Changes in taste and smell are described in detail in chapters 5-9. In this chapter it is stated that the sense of smell is more prone to losses with age than the sense of taste. The commonly believed assumption that loss in taste and smell perception eventually will lead to an impoverished health and well-being is discussed. It is concluded that there is a lack of evidence to support this assumption.
The following section is devoted to the common interpretation of “taste” as the combined sensation of taste proper, smell, temperature, texture and pain is

explained first. Although in current taste research often four or five taste qualities are used, debate is still going on whether or not the primary five taste qualities sweet, salty, sour, bitter, and umami describe all taste qualities, and the taste system is described. The peripheral taste system is subserved by three types of papillae, spread over the surface of the tongue: fungiform, foliate and circumvallate papillae. These papillae contain taste buds, which in turn comprise the taste receptor cells. More than 90% of the receptor cells respond to two or more taste qualities. This means that even the primary cell in the taste process is relatively broadly tuned to different types of chemical stimuli.

Furthermore, the mechanisms by which the initial transduction processes at the receptor side are initiated, are briefly described for the different taste qualities. Once transformed, the flow of information runs from the taste buds to the primary gustatory axons, and then proceeds into the brain stem, up to the thalamus, which projects to the cerebral cortex. Branches of three cranial nerves, the facial nerve (CN VII), the glossopharyngeal nerve (CN IX) and the vagus nerve (CN X), innervate the papillae, depending on their location.

Next, two concepts are described that has been invoked to explain how the brain is capable of differentiating between subtle differences in taste. These are the labelled line hypothesis, in which each taste quality is encoded by separate taste fibres, and the across-fibre pattern or population coding hypothesis, in which the response pattern of a large number of broadly tuned neurons is used to specify the characteristics of a particular stimulus.

The last section of this introductory chapter outlines both the objective of this thesis and its structure. Contradicting findings in taste research with elderly and young people showed the need to investigate age-related loss in taste acuity at threshold and supra-threshold level, under very well controlled, “ecologically” valid circumstances and with tastants representing all taste qualities in “every day life” foods, in the same groups of elderly and young subjects. Only by such an extensive study, which hitherto had never been undertaken, the question whether a possible loss is generic or specific in nature could be investigated. Furthermore, the role of the perceptual context, the relation between (supra-)

threshold intensity and pleasantness, and the influence of olfactory deprivation are questioned.

Chapter 2

The materials and methods used in the experiments throughout this thesis are described in general terms in this third chapter. First, the characteristics of the subjects are discussed. The age ranges chosen for the groups of elderly and young subjects are in line with the age ranges used by most other researchers. An about equal number of men and women, which were free living, healthy and with an auditory threshold below 30 dB for ~750 HZ sound were recruited. Since people who are classified as super-tasters for 6-*n*-propylthiouracil (PROP) are genetically more sensitive to bitterness of several compounds, the subjects were submitted to a test in which their sensitivity to PROP was determined. The results of the first PROP-tests did not show any relationship of PROP sensitivity status with threshold or supra-threshold sensitivity for any of the ten tastants. In the second PROP-test, three different scaling methods were used. The results of the three methods did not show any significant interrelationship. It is concluded that the optimal scaling method for PROP-sensitivity testing has not been designed yet.
Next, the choice of stimuli is discussed. To be able to investigate the specificity of possible taste losses, ten tastants, two to represent each of the five taste qualities were used in all experiments. The choice of the combinations of tastants and product types, which were used as the matrices in which they were varied, is accounted for. Finally, the different procedures used in the experiments are described.

Chapter 3

In this chapter, detection thresholds for NaCl, KCl, sucrose, aspartame, acetic acid, citric acid, caffeine, quinine HCl, Mono Sodium Glutamate (MSG) and Inosine 5'-MonoPhosphate (IMP) were assessed in 21 young (19-33) and 21 elderly (60-75) persons by taking the average of six ascending two-alternative forced choice tests. A significant overall effect was found for age, but not for gender. However, an interaction effect of age and gender was found. The older men were less sensitive than the young men and women for acetic acid, sucrose, citric acid, sodium and potassium chloride and IMP. To detect the compound dissolved in water they needed a 1.32 (aspartame) to 5.70 times (IMP) higher concentration than the younger subjects. The age effect found could be attributed predominantly to a generic taste loss. A significant decline in thresholds with replication was shown, i.e. a facilitating effect of practice was found. The elderly had a less specified taste acuity than the young, a phenomenon for which the noise hypothesis provides an explanation, either at a neural level, a psychological level, or both.

Chapter 4

The influence of ageing on supra-threshold intensity perception of the same tastants as in chapter 5, dissolved in water and in ‘regular’ product was studied in the same groups of elderly and young subjects. The results show that while the relative perception (intensity discrimination) seems to be remarkably resistant to the effect of ageing, the absolute perception (intensity rating) decreased with age for all tastants in water, but only for the salty and sweet tastants in product. The age effects found were almost exclusively generic and never compound-specific within a taste.

When the subjects assessed the products while wearing a nose clip, the young lost their advantage over the elderly while the ratings of the elderly remained the same as in the condition without a nose clip. Only the perception of salty tastants remained diminished with age. This strongly suggests that the young make use of their sense of smell in rating taste intensities, in contrast to the elderly, who, due to a deterioration in olfactory acuity, are less able to do so.

The slopes of the psychophysical functions were flatter in the elderly than in the young for the sweet, bitter and umami tastants in water, and for the sour tastants in product only.

This study indicates that the relevance of determining intensities of tastants dissolved in water for the ‘real life’ perception of taste in complex food is rather limited.

Chapter 5

In this chapter, the relationships between threshold sensitivity and supra-threshold intensity to the same ten tastants as in chapters 5 and 6, and the pleasantness of these stimuli in products, were studied in the same subjects. For the young, threshold sensitivity was unrelated to supra-threshold intensity for all tastants and in all experimental conditions. For the elderly, in a few cases a relationship was found between threshold sensitivity and supra-threshold intensity, but only when subjects wore a nose clip. The optimally preferred concentration did not differ between the elderly and the young when the products were tasted without a nose clip, except for both sweet tastants, where elderly men showed a higher optimally preferred concentration than did the young. The optimally preferred concentration did not depend on the pleasantness of the foods and was unrelated to threshold sensitivity, but did show a negative correlation with the supra-threshold intensity of sucrose, aspartame and citric acid for the elderly and of NaCl, sucrose and caffeine for the young. It was concluded that this study does not support the assumption that age-related loss of taste sensitivity will inevitably lead to a preference for taste-enhanced foods.

Chapter 6

The influence of the experimentally varied concentration of taste qualities on the other taste qualities perceptible in the same foods as in chapters 5, 6 and 7 is described in this chapter. An increase in concentration of one of the tastants in a ‘real food’ may not only affect the perception of the taste quality of that manipulated tastant, but also that of the other perceivable taste qualities. The effect of concentration increase of sodium or potassium chloride in tomato soup,

sucrose or aspartame in ice tea, acetic or citric acid in mayonnaise, caffeine or quinine HCl in chocolate drink, and monosodium glutamate (MSG) or inosine 5'-monophosphate (IMP) in broth on the other perceivable taste qualities in these foods was studied in the same elderly and young subjects as before. The results showed that for each of these tastants, except for the two acids, increasing the concentration provoked significant positive or negative interaction effects, i.e. an enhancement or suppression, in the perception of one or more other taste qualities of the product. Especially in the young, olfaction plays a larger role in the assessment of taste intensity than has been hitherto assumed. Finally, the finding that the elderly divide their attention more over the different tastes in a product, whereas the young focus more strongly on the dominant taste, has not been reported previously and should be pursued in future research because of its possible gerontological implications.
It is concluded that the noise hypothesis might explain these latter results.

Chapter 7

In this chapter the role of olfaction in taste research is investigated. The stimuli used in taste research are usually considered to be odourless. This was tested in two experiments with watery solutions of two representative compounds for each of five taste qualities including umami, i.e. the same ten tastants as in the previous experiments.
In the first experiment elderly and young subjects rated the intensity and pleasantness of three concentrations of the stimuli, while wearing or not wearing a nose clip. Saliva production was also measured. Blocking olfaction only influenced salivation for umami. It reduced taste intensity ratings, but as in the earlier experiments with the same compounds in food products, this effect was stronger in the young, who also liked the stimuli better while wearing the nose clip.
In the second experiment, another group of young people tried to detect the odours of the tastants when dissolved in three types of water, while smelling orthonasally. A majority of subjects could regularly detect seven of the ten

tastants by olfaction and the extent to which they did correlated significantly with the reduction in taste intensity ratings for the different tastants due to the wearing of a nose clip found in the first experiment. It is suggested that most tastants can be smelled and that this smell contributes to taste intensity ratings.

Chapter 8

In chapter 8 it was concluded that the affect of age on taste perception is generic in nature, since more than 90% of the total variance attributable to age is due to age alone and less than 6% is do to differences in de perception of the different tastants. In addition is was concluded that the differentiation between the tastants is less distinct for the elderly than for the young. Both findings point in the direction of more general explanations. Three of them might be noise hypotheses, which might explain both findings. First, a diminished signal or an increase in neural noise caused by a decline in functioning or by a loss in brain cells with age have been put forward to explain these phenomena. Second, there may be a problem with selective attention: the ability to neglect irrelevant information may be decreased. The irrelevant information may be considered as a type of noise, but at a psychological/perceptual level rather than at a neural level. Third, the proximal noise hypothesis, which suggests an inappropriate lateral inhibition, due to a reduction of the resolution in the CNS stimulus configuration and resulting in diffusion, might be an additional noise hypothesis to explain the second finding.

From a different point of view, there is evidence that, while performing cognitive tasks, less specificity or differentiation in brain recruitment has been found for the elderly compared the young (Park et al., 2001). The number of brain sites recruited to perform a task increases with age or is different from the sites used by young adults. Three types of this so-called dedifferentiation have been classified: a contralateral (homologous) recruitment, a unique recruitment (non-homologous recruitment of additional brain areas), and a substitution (different structures show activation), which involves a difficulty in engaging specialised neural mechanisms. So far, it is not clear, whether this dedifferentiation with age also occurs for sensory tasks. Neuroimaging research might throw more light on this issue.

Nevertheless, possible explanations for age-related changes in taste perception can also be sought at the periphery. There might be a diminished accessibility of the taste buds resulting from a decrease in the number of them, or from a diminished saliva production with age, or from both.

In this chapter it is suggested that the results from the experiments in the thesis might relate to the findings of Scott and Plata-Salaman (1999), who found in the primate insular-opercular (primary) taste cortex that about 73% of its neural resources were devoted to the detection of the sweet (about 38%) and salty (about 34%) stimuli, whereas about 22% of the neurons were tuned to bitter (quinine) while only about 5% were oriented toward the detection of acids. These authors concluded that the most accurate analysis of perceived taste quality is likely to take place in the primary taste cortex.

Probably the most interesting and unexpected finding of this thesis is that smell seems to play a crucial role in taste perception. When the olfactory input is blocked, about 70% of the age differences in taste perception disappeared.

The finding that the optimally preferred concentration of tastants in products did not differ for elderly and young people, might be related to the findings of Reilly and Pritchard (1995), who reported that thalamic taste relay nucleus lesions in macaques caused only minor changes in acceptability. The hypothesis that perception and hedonic responses might be processed in different regions of the brain might also be used to explain why in this thesis taste sensitivity and the optimally preferred concentration of tastants in every day products were unrelated.

Samenvatting

Summary in Dutch

Hoofdstuk 1

In dit inleidende hoofdstuk wordt eerst kort de aanleiding voor dit proefschrift beschreven. De wereldbevolking groeit snel. Men verwacht dat in 2050 de gemiddelde levensduur met nog eens 10 jaar verlengd zal zijn. Het gevolg hiervan zal een toenemende behoefte zijn om de veranderingen die gepaard gaan met de veroudering te begrijpen.

In het volgende deel worden de verouderingsverschijnselen, die gerelateerd zijn aan het eet- en drinkgedrag en veranderingen in het spijsverteringskanaal beschreven. In de mondholte is bijvoorbeeld de speekselproductie verminderd, is de speekselsamenstelling veranderd, is de kauwefficiëntie verminderd en is het aantal smaakknoppen afgenomen. Veroudering heeft ook een effect op de snelheid van cognitieve processen. Een belangrijke vraag in gerontologisch onderzoek is of de verlangzaming generiek of specifiek van aard is. Vooralsnog lijkt het het beste om aan te nemen dat gecontroleerde informatieverwerking, die aandacht en verwerkingscapaciteit vergt, verlangzaamt met het ouder worden, maar dat de automatische verwerking, die geen aandacht of inspanning vergt, behouden blijft. Verschillende ruishypothesen worden genoemd om het proces van verlangzaming te verklaren. Drie daarvan proberen het te verklaren in termen van een verlaagde signaal-ruis-verhouding aan de kant waar het signaal binnenkomt. Twee hypothesen veronderstellen een toegenomen ruis in de fase van het zich herinneren.

Vervolgens worden de veranderingen in de sensorische waarneming beschreven. Bij het zien wordt het scherp stellen moeilijker en is de waarneming van diepte, de tolerantie voor schittering en het onderscheiden van kleuren vaak afgenomen. In het oor kan het ouder worden zowel het gehoor als het evenwicht beïnvloeden. De ouderen kunnen ook gereduceerde gewaarwording hebben van pijn, trilling, koude, hitte, druk en tastzin. In dit hoofdstuk wordt gesteld dat de reukzin gevoeliger is voor achteruitgang met het ouder worden dan de smaakzin. De algemeen aanvaarde veronderstelling dat een achteruitgang in reuk en smaak uiteindelijk zal leiden tot een verslechterde

gezondheid en welbevinden wordt bediscussieerd. Geconcludeerd wordt dat het aan voldoende bewijskrachtige steun voor deze veronderstelling ontbreekt.
Het volgende deel is gewijd aan de interpretatie is van “smaak” in zijn algemeen gebruikte betekenis van een gecombineerde gewaarwording van smaak (in strikte zin), reuk, textuur en pijn. Hoewel in het huidige smaakonderzoek vaak vier of vijf smaakkwaliteiten worden gebruikt, is men het er nog niet over eens of de vijf basissmaken zoet, zout, zuur, bitter en umami wel alle smaakkwaliteiten beschrijven. Daarna wordt het smaaksysteem beschreven. Het perifere smaaksysteem maakt gebruikt van drie soorten papillen, die verspreid liggen over de tong: de paddestoelvormige, de bladvormige en de omwalde papillen. Deze papillen bevatten smaakknoppen, die op hun beurt weer smaak-receptorcellen bevatten. Meer dan 90% van de receptorcellen reageren op twee of meer smaakkwaliteiten. Dit betekent dat zelfs de eerste cel in het smaakproces al afgestemd is op een relatief breed spectrum van chemische prikkels.
Vervolgens worden de mechanismen, waardoor het initiële transductieproces in gang wordt gezet aan de kant van de receptor kort beschreven voor de verschillende smaken. Na de omzetting van chemische signalen loopt de informatiestroom van de smaakknoppen naar de eerste axonen in het smaaksysteem en gaat vervolgens naar de hersenstam en bereikt vandaar de thalamus, die de informatie naar de hersenschors projecteert. Afhankelijk van hun locatie worden de papillen door bepaalde aftakkingen van drie hersenzenuwbanen: de facialis (VII), de glossopharyngeus (IX) en vagus zenuw (X) geïnnerveerd.
Hierna worden twee concepten besproken, die verklaren hoe het brein in staat is te differentiëren tussen subtiele verschillen in smaak. Dit zijn de labelled-line hypothese, waarin de verschillende smaakkwaliteiten gecodeerd worden door activiteit in afzonderlijke smaakvezels en het across-fibre pattern of population coding concept, dat er juist van uitgaat dat een response patroon van een groot aantal breed afgestemde neuronen wordt gebruikt om de karakteristieken van een bepaalde stimulus te specificeren.

Het laatste deel van dit inleidende hoofdstuk beschrijft zowel de motivatie voor als de structuur van dit proefschrift. Tegengestelde bevindingen in het smaakonderzoek met ouderen en jongeren sporen er toe aan om leeftijdsgerelateerd verlies in smaakgevoeligheid op drempelniveau en bovendrempelig niveau te onderzoeken onder goed gecontroleerde “ecologisch valide” omstandigheden en met smaakstoffen die alle smaakkwaliteiten in ons dagelijks voedsel in dezelfde groep ouderen en jongeren. Dit is tot nu toe nog nooit eerder onderzocht en alleen een dergelijke aanpak kan een antwoord geven op de vraag of een mogelijk verlies dat optreedt bij toenemende leeftijd generiek of specifiek is. Bovendien worden de invloed van de perceptuele context, de relatie tussen intensiteit op (boven)drempel niveau en de invloed van het afsluiten van olfactorische prikkeling onderzocht.

Hoofdstuk 2

De materialen en methoden die gebruikt zijn in de experimenten van dit proefschrift worden in algemene termen beschreven in dit derde hoofdstuk.
Ten eerste worden de kenmerken van de proefpersonen beschreven. Het leeftijdsbereik, dat gekozen is voor de groep van ouderen en van jongeren komt overeen met de leeftijden die de meeste andere onderzoekers hebben gebruikt.
De werving van de proefpersonen was gericht op een gelijk aantal mannen en vrouwen, die zelfstandig wonen, gezond zijn en een geluidsdrempel hebben dat bij ~750 Hz niet hoger is dan 30 dB. De proefpersonen werden onderworpen aan een test waarin hun gevoeligheid voor 6-*n*-propylthiouracil (PROP) werd vastgesteld. Mensen die in deze test als super-taster voor PROP worden gekwalificeerd zijn genetisch gezien gevoeliger voor de bitterheid van verschillende andere stoffen. De resultaten van de eerste PROP-test lieten voor geen enkele van de tien smaakstoffen een verband zien met de drempel- of de bovendrempelige gevoeligheid. In de tweede PROP-test werden drie schaalmethoden gebruikt. De resultaten van deze drie methoden lieten onderling geen enkel significante relatie zien. De conclusie is dat de optimale schaalmethode voor het testen van PROP-gevoeligheid nog niet is gevonden.

Vervolgens wordt de keuze van de stimuli bediscussieerd. Om de specificiteit van mogelijk smaakverlies te kunnen onderzoeken worden tien smaakstoffen, twee vertegenwoordigende stoffen voor ieder van de vijf smaakkwaliteiten, gebruikt in alle experimenten. De keuze van de combinaties van smaakstoffen en producten waarin ze worden opgenomen wordt beargumenteerd. Verder worden de procedures beschreven, die in de experimenten zijn gevolgd.

Hoofdstuk 3

In dit hoofdstuk worden de detectiedrempels voor natrium- en kaliumchloride, suiker, aspartaam, azijnzuur, citroenzuur, cafeïne en kinine, monosodium glutamaat (MSG of ve-tsin) and inosine 5’-monophosphate (IMP) vastgesteld bij 21 jongeren (19-33) en 21 ouderen (60-75) door het gemiddelde van zes oplopende 2AFC-tests te bepalen. Er werd een significant effect van leeftijd gevonden, maar niet van geslacht. Er werd echter wel een interactie-effect van leeftijd en geslacht gevonden. De oudere mannen waren minder gevoelig dan de jonge mannen en vrouwen voor azijnzuur, suiker, citroenzuur, natrium- en kaliumchloride en IMP. Om een in water opgeloste smaakstof te kunnen detecteren, hadden zij een 1.32 (aspartaam) tot 5.70 (IMP) keer hogere concentratie nodig dan de jongeren. De drempelwaarden werden lager naarmate het aantal testen toenam, d.w.z. dat er een faciliterend effect van de taakuitoefening werd gevonden. De ouderen hadden een minder specifiek smaakvermogen dan de jongeren, waarvoor de ruishypothese zowel op neuraal als op psychologische niveau of op een combinatie van beide niveaus een verklaring biedt.

Hoofdstuk 4

De invloed van veroudering op de bovendrempelige waarneming van dezelfde smaakstoffen als in hoofdstuk 5, opgelost in water en in gebruikelijke producten, werd onderzocht in dezelfde groep ouderen en jongeren. De resultaten tonen aan dat, terwijl de relatieve waarneming (discrimineren van intensiteiten) opmerkelijk bestand bleek te zijn tegen veroudering, de absolute waarneming (schaalmetingen van intensiteiten) was afgenomen met het vorderen van de leeftijd voor alle smaakstoffen, wanneer zij opgelost waren in water, maar alleen voor de zoute en zoete stoffen wanneer zij zich in product bevonden.

Wanneer de proefpersonen de producten beoordeelden terwijl ze een neusclip droegen, ging het voordeel dat de jongeren hadden ten opzichte van de ouderen te niet, terwijl de oordelen van de ouderen juist gelijk bleven aan hun oordelen in de conditie zonder neusclip. Alleen de waarneming van de zoute smaken nam af met de leeftijd. Dit suggereert in sterke mate dat de jongeren hun reukzintuig gebruiken wanneer ze smaken beoordelen, in tegenstelling tot de ouderen, die daar minder toe in staat zijn omdat ze in hun reukvermogen achteruit zijn gegaan.

De hellingen van de psychofysische functies waren vlakker voor de responsen van de ouderen dan voor die van de jongeren voor de zoete, bittere en umami smaakstoffen in water en alleen voor de zure smaakstoffen in product. De gevonden leeftijdseffecten zijn bijna geheel en al generiek en nooit smaakstof specifiek binnen een bepaalde smaakkwaliteit. Dit onderzoek toont aan dat de relevantie van het bepalen van waargenomen intensiteiten in water voor de dagelijkse waarneming van smaken in complexe voedingsmiddelen nogal beperkt is.

Hoofdstuk 5

In dit hoofdstuk worden de relaties tussen drempelgevoeligheid en bovendrempelige gevoeligheid voor dezelfde tien smaakstoffen als in de hoofdstukken 5 en 6 , en de aangenaamheid van deze stimuli in producten, onderzocht in dezelfde proefpersonen. De drempelgevoeligheid was voor de jongeren ongerelateerd aan de bovendrempelige gevoeligheid voor alle stoffen en in alle experimentele condities. Voor de ouderen werd alleen wanneer zij een neusclip droegen en dan nog slechts in enkele gevallen een relatie gevonden tussen de drempel- en de bovendrempelige gevoeligheid. Met uitzondering van beide zoete smaakstoffen, waarbij oudere mannen een hoger optimaal geprefereerde concentratie lieten zien dan de jongeren, verschilde de optimaal geprefereerde concentratie van de gevarieerde smaakstoffen niet voor ouderen en jongeren wanneer de producten zonder neusclip weren geproefd. De optimaal geprefereerde concentratie hing niet af van de aangenaamheid van de producten en was ongecorreleerd met de drempelgevoeligheid, maar vertoonde een negatieve correlatie met de bovendrempelige gevoeligheid voor suiker, aspartaam en citroenzuur voor de ouderen en voor keukenzout, suiker en cafeïne wat de jongeren betreft. De conclusie is dat dit onderzoek geen ondersteuning biedt aan de vaak gehoorde veronderstelling dat leeftijdsgebonden verliezen in smaakgevoeligheid uiteindelijk tot een voorkeur voor smaakbekrachtigde voedingsmiddelen zullen leiden.

Hoofdstuk 6

De invloed van de experimenteel gevarieerde concentratie van de smaak-kwaliteiten op de andere waarneembare smaakkwaliteiten, in dezelfde producten als in de hoofdstukken 5, 6 en 7, is beschreven in dit hoofdstuk. Een toename in concentratie van één van de smaken in echt voedsel kan niet alleen de waarneming van de smaak van de gemanipuleerde smaakstof maar ook de andere waarneembare smaken beïnvloeden. Het effect van een concentratieverhoging van natrium- of kaliumchloride in tomatensoep, suiker of aspartaam in ijsthee, azijn- of citroenzuur in mayonaise, cafeïne of kinine in chocolademelk en monosodium glutamate (MSG) of inosine 5'-monofosfaat (IMP) in bouillon op de andere waarneembare smaken in deze producten is onderzocht in dezelfde groep ouderen en jongenren als voorheen. De resultaten tonen aan dat voor ieder van de smaakstoffen, met uitzondering van de twee zuren, een toename in concentratie significant positieve of negatieve interactie-effecten, d.w.z. versterking of onderdrukking, in de waarneming van een of meer andere smaakkwaliteiten van het product teweeg bracht. Verder bleek dat de reuk in de beoordeling van smaakintensiteit speciaal bij de jongeren een grotere rol speelt dan tot nu toe werd aangenomen.

De bevinding tenslotte, dat ouderen hun aandacht meer verdelen over de verschillende smaken in het product, is nog niet eerder gerapporteerd en zou, gezien zijn gerontologische implicaties, vervolgd moeten worden in verder onderzoek. Geconcludeerd wordt dat de ruishypothese mogelijk deze resultaten zou kunnen verklaren.

Hoofdstuk 7

In dit hoofdstuk wordt de rol van de reuk in het smaakonderzoek bestudeerd. Gewoonlijk worden de stimuli in smaakonderzoek geacht reukloos te zijn. Dit werd onderzocht in twee experimenten met waterige oplossingen van twee representatieve smaakstoffen voor ieder van de vijf smaakkwaliteiten, inclusief umami, d.w.z. met dezelfde tien smaakstoffen als in de voorgaande experimenten.

In het eerste experiment beoordeelden oudere en jongere proefpersonen de intensiteit en aangenaamheid van drie stimulusconcentraties, terwijl ze al of niet een neusclip droegen. De speekselproductie werd eveneens gemeten. Het blokkeren van de reuk beïnvloedde de speekselproductie alleen bij umami. Het verlaagde de intensiteitsoordelen, maar net als al in een eerder experiment met dezelfde stoffen in product, was dit effect sterker bij de jongeren, die bovendien de stimuli lekkerder vonden wanneer ze een neusclip droegen.

In het tweede experiment probeerde een groep jongeren de geuren van de smaakstoffen, die opgelost waren in drie typen water, te detecteren. Het merendeel van de proefpersonen kon regelmatig zeven van de tien smaakstoffen door gewoon orthonasaal ruiken detecteren en de mate waarin ze dat deden correleerde significant met de verlaging van de smaakintensiteitsoordelen voor de verschillende smaakstoffen onder invloed van het dragen van een neusclip in het eerste experiment. Gesuggereerd wordt dat de meeste smaakstoffen geroken kunnen worden en dat deze geur bijdraagt aan smaakintensiteitsoordelen.

Hoofstuk 8

In hoofdstuk 8 wordt geconcludeerd dat de smaakwaarneming generiek van aard is aangezien meer dan 90% van de totale variantie die aan leeftijdsfactoren toegeschreven kan worden aan veroudering alleen is toe te schrijven en voor minder dan 6% aan verschillen in de waarneming van de verschillende smaakstoffen. Daarnaast werd geconcludeerd dat de differentiatie tussen de smaakstoffen minder scherp was voor ouderen dan voor jongeren. Beide resultaten wijzen in de richting van meer algemene verklaringen. Drie daarvan zijn mogelijk ruis-hypothesen, die deze bevindingen kunnen verklaren. Ten eerste wordt wel een afgenomen signaal of een toegenomen ruis ten gevolge van een verminderd functioneren of van een verlies van hersencellen voorgesteld om deze verschijnselen te verklaren. Ten tweede kan er een probleem zijn met de selectieve aandacht: het vermogen om irrelevante informatie te negeren zou verminderd kunnen zijn. Deze irrelevante informatie kan beschouwd worden als een vorm van ruis, maar meer op een psychologisch/ waarnemingsniveau dan op neuronaal niveau.
Ten derde zou de “aangrenzende ruis” hypothese, welke een ongeschikte laterale inhibitie veronderstelt, een aanvullende ruishypothese zijn om de tweede bevinding te verklaren.

Vanuit een ander gezichtpunt gezien is er bewijs dat er bij de uitoefening van cognitieve taken het rekruteren van hersencellen minder specifiek of gedifferentieerd is voor ouderen dan voor jongeren (Park et al., 2001). Het aantal hersengebieden dat ingezet om een taak uit te voeren neemt toe met de leeftijd of verschilt van de gebieden die jongeren gebruiken. Drie vormen van deze zogenoemde dedifferentiatie zijn geclassificeerd: een contralaterale (homologe) rekrutering, een unieke rekrutering (niet homologe rekrutering van aanvullende hersengebieden) en een vervanging (waarbij andere structuren activatie laten zien), hetgeen een probleem in het aantrekken van gespecialiseerde neurale mechanismen inhoudt. Tot nu toe is het niet duidelijk of deze dedifferentiatie ook optreedt bij sensorische taken. Neuro-imaging onderzoek zou meer licht op deze zaak kunnen werpen.

Niettemin kunnen mogelijke verklaringen voor de leeftijdsgerelateerde veranderingen in smaakwaarneming ook in de periferie gezocht worden. Er is mogelijk een verminderde toegankelijkheid tot de smaakknoppen doordat hun aantal is verminderd en/of doordat speekselproductie afneemt met het toenemen van de leeftijd.

In dit hoofstuk is gesuggereerd dat de resultaten van de experimenten in dit proefschrift mogelijk verband houden met de bevindingen van Scott en Plata-Salaman (1999) die vonden dat in de primary taste cortex ongeveer 73% van de op smaaksignalen reagerende cellen gericht waren op de detectie van zoete (circa 38%) en zoute (circa 34%) stimuli, terwijl ongeveer 22% van de neuronen op bitter waren afgestemd, en er slechts om en nabij de 5% gericht waren op de detectie van zuren. De conclusie van deze auteurs was dat de primaire taste cortex waarschijnlijk het gebied is waar de meest accurate analyse van de waargenomen smaakkwaliteit plaats vindt.

Waarschijnlijk is het meest interessante en onverwachte resultaat van dit proefschrift dat de reuk een cruciale rol speelt in de smaakwaarneming. Wanneer de olfactorische input is geblokkeerd, dan verdwijnt rond de 70% van het leeftijdsverschil.

De bevinding dat de optimaal geprefereerde concentratie van smaakstoffen in producten niet anders is voor ouderen dan voor jongeren houdt mogelijk verband met de bevinding van Reilly en Pritchard (1995), die rapporteerden dat laesies in de thalamische smaak nucleus van makaken slechts kleine veranderingen in waardering veroorzaakten. De veronderstelling dat waarneming en waardering in andere delen van de hersenen worden verwerkt zou ook gebruikt kunnen worden om te verklaren waarom in dit proefschrift de smaakgevoeligheid en de optimaal geprefereerde concentratie van smaakstoffen in alledaagse producten geen verband met elkaar houden.

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Curriculum Vitae

Jozina Mojet werd geboren op 18 april 1942 te ‘s Gravenhage. Zij doorliep de lagere en de middelbare school (HBS-B) te Alkmaar. Naast het vroege ouderschap van vier kinderen was zij gedurende enige jaren parttime werkzaam bij het Jongeren Advies Centrum te Amersfoort. Nadat in 1979 ook haar jongste kind naar de middelbare school ging begon zij met de studie psychologie aan de Universiteit van Utrecht. In 1988 studeerde zij af met als hoofdrichting sociale experimentele psychologie en als nevenrichting psychofysiologie. Tijdens haar studie verrichtte zij gedurende vele jaren assistentschappen bij het geur- en smaakonderzoek van de vakgroep Psychonomie. Na haar studie werkte zij enkele jaren als toegevoegd onderzoeker bij de vakgroep Psychonomie van de Universiteit Utrecht, waarna zij vanaf 1989 tot en met 1996 werkzaam was bij Unilever Research te Vlaardingen, eerst vijf jaar als hoofd van de afdeling Productevaluatie en vervolgens twee jaar als fundamenteel onderzoeker. Vanaf eind 1996 tot aan 2000 werkte zij als productmanager sensorisch en consumentenonderzoek bij TNO-Voeding te Zeist totdat de overstap naar Agrotechnology & Food Innovations werd gezet. Hier is zij werkzaam als programma coördinator voor het sensorisch en consumentenonderzoek. Naast haar kinderen heeft zij inmiddels vijf kleinkinderen.

Aart Reijn, 6 jaar

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