Appendix 7. Literature review conducted by MBF highlighting the impact of aging on the enjoyment of food and the consequences on consumption and ultimately malnutrition

Age and Taste, Literature Review Full Review (note that highlighted sections form the Key Points)

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Abstract

An often-under-appreciated factor contributing to malnutrition in older adults is the age-related change in taste perception. In this review we examine the factors that influence taste in older adults with a focus on findings from residential age care settings. The review includes an overview of the physiology of taste, age-related changes in taste, impact of disease and medication on taste, and emerging findings examining the impact of time-of-day and sleep on taste. The review summarises the factors reported to promote taste and, hence, appetite, and discusses the need to change the focus from nutrients to food delivery. We conclude that strategies that improve food type, flavour perception, and the eating environment offer much promise in enhancing taste and, thereby, nutrition in older adults.
Malnutrition is recognised health risk in older age [1]. This is especially evident in residential aged care affecting an estimated one in two older Australian [2]. The factors underpinning malnutrition in residential aged care are myriad but can be broadly divided into institutional and clinical factors. Institutional factors include: the lack of knowledge about malnutrition, the low ranking of nutrition in the list of care priorities, the poor nutritional quality of food and inadequate staffing levels [3-5]. The clinical factors include: swallowing disorders, depression (affecting the motivation to eat), medication, dentition, dementia, gastrointestinal health and the impact of disease [6-11]. Of the latter a further and often under-recognised factor, but a problem often cited by older people in residential aged care is that food lacks taste [12]. A diminution in taste acuity or dysgeusia is a well-recognised feature of aging [13]. Taste acuity is known to be affected by salivary flow, odour perception, chemoreceptor sensitivity, oral health, dentition, mastication and oral texture perception, and a variety of medications [11]. However, two less well-appreciated influences on taste acuity include sleep and the timing of food. For example, the threshold for sour taste is elevated after sleep deprivation [14], while the threshold for salt taste demonstrates circadian rhythmicity with a raised threshold at night [15] and, similarly, appetite and food choice also demonstrate circadian rhythmicity with a lowered appetite and a preference for energy dense foods at night [16, 17]. Notably, sleep and circadian disorders are common in aged care residents [18-20], but the consequences for taste acuity and food choice have yet to be mapped.

Given its importance for appetite, strategies that promoting taste in residential aged care offer potential gains in health and life satisfaction. This review aims to summarise the literature examining taste acuity in older adults with a focus on findings from residential aged care settings. It will also expand on the physiology of taste, the factors contributing to dysgeusia in older adults with a particular focus on common diseases and medications, examine new findings in the sleep and circadian literature and discuss strategies that promote taste especially those examining the impact of food presentation, food texture, flavour enhancers, olfactory simulation and the dining environment.

Physiology of Taste

Taste is also known as chemosensory perception. As the word ‘chemosensory’ suggests, taste perceptions involve the detection of chemical compounds, which subsequently perceived as five widely accepted taste qualities namely sweet, sour, bitter, salty, and umami [21]. More recently, scientists have also discovered human’s ability to taste fat [22] and non-sweet carbohydrate [23]. Chemical compounds that give rise to taste perception are also known as taste stimuli or tastants. The detection of tastants begins in (but not limited to) the oral cavity. Gustation, or the sensation of tasting, is a complex process that involves multiple organs, and the most important of all is arguably the tongue. Some scientists suggest that the human tongue serves as a ‘gatekeeper’ that not only guides food intake and selection [24] but also allows humans to only select and consume foods that
are safe. For example, sour taste warns the body of potential ingestion of spoiled foods while bitter taste suggests toxic compounds.

The tongue is able to detect and discriminate various taste qualities at very low concentrations because of its unique anatomical features [25]. This is due to taste buds that are found in distinct gustatory papillae (small bumps) of the tongue namely circumvallate, foliate and fungiform papillae [26]. However, the density of taste buds is not uniform across these papillae and between individuals [27], hence similar concentration of tastants may be perceived as different intensities between individuals. Different taste cells can be found in each bulb-shaped taste bud. Of these, type I, II and III taste cells are elongated and have different types of microvilli apically that reach the pore of the taste bud, which allows taste cells to detect tastants. Taste cells possess transmembrane taste receptors or ion channels for specific taste. For example, type II cells are able to detect non-ionic sweet, bitter and umami tastants due to the presence of G-protein coupled receptors [28]; type III cell possess channels for ionic sour taste [29]; sodium can enter taste cells through epithelial sodium ion channels, thus invoke salty taste [30]. It should be highlighted that apart from the tongue, taste buds are also found in the epithelium of the palate, oropharynx, larynx and the upper oesophagus [31]. Sweet taste receptors have also been found outside of the oral region and throughout the gastrointestinal tract in humans, however the activation of sweet taste receptors outside of the oral cavity is not reported to affect the perception of sweet taste [32].

Two other important factors that affecting taste perception are saliva and the functioning of the neural networks innervating taste cells. Saliva plays a crucial role in facilitating the tastants (chemical compounds) to be detected by taste receptors in taste cells. Eating, or to a lesser extent the smelling and sighting of foods alone [33], stimulates saliva production. Saliva plays a number of key roles in food ingestion such as breaking down of foods, assisting in the swallowing and digestion of food, tooth protection, as well as protection of oral mucosa [34]. Saliva also allows chemical compounds from the breakdown of foods (mechanically or via enzymatic reactions), i.e. tastants, to be dissolved, detected by the microvilli of taste cells to be perceived as taste qualities.

The second important factor affecting taste perception is the innervation of taste cells [35]. Chorda tympani branch of cranial nerve VII, cranial nerve IX [36], and cranial nerve X (vagus nerve) transmit signals to the nucleus of solitary tract and gustatory cortex of the brain [37]. In addition to taste the other elements that contribute to food flavour such as smell, temperature, chemical irritation (by alcohol, spicy foods, menthol, carbonation) and texture are also transmitted to the brain via the trigeminal nerve [38, 39]. These nerves are vulnerable to peripheral damage from multiple sources (e.g., otitis media, tonsillectomy, head injury, radiation treatment) impacting taste perception and other elements involved in food flavour [40, 41].

**Older Adults and Taste Sensitivity**
Taste sensitivity is well known to be diminished in older adults [42-44], especially older adults in acute care settings [45]. Moreover, there appears to be a gender difference with a greater loss of taste reported in older men [46]. However, not all elements of taste perception appear to change with age. Winkler et al. [47] in their review conclude that there is an age-related decrease in the sensitivity to salty and bitter but not sweet and sour tastes. By contrast, more recent findings suggest that sour taste may be affected by age [48]. The mixed findings may be partly explained by the difficulty of disentangling the age-related changes in taste perception from the effect of disease (e.g. Alzheimer’s disease, diabetes mellitus, obesity) [21, 49] and impaired olfactory function in older adults [50]. Both disease and impaired olfactory functioning in older adults are associated with impaired taste perception with negative implications for appetite and food enjoyment [51, 52]. As well as the latter confounds, methodological differences such as study design, inappropriate comparison groups may also underlie the mixed findings [53].

There are a number of possible explanations underlying blunted taste sensitivity in older adults. A major factor is thought to be the age-related reduction in taste bud density. The density of both the number of taste buds and, as well, the number of taste cells within taste buds are reported to be lower in older than younger individuals [54, 55]. Lower taste bud density is associated with reduced taste intensity perception [27, 56]. A further contributory factor may be age-related changes in the neural systems involved in the signalling of taste perception, but this possibility remains to be explored.

Another potential explanation for blunted taste sensitivity in older adults are the age-related changes in saliva. Aging is associated with a reduction in the secretory reserve capacity of salivary glands, reduced salivary flow rates (especially post-menopausal women [57]) and those with select diseases or on certain medications [e.g. 58, 59]) and change in salivary composition towards higher concentrations of sodium and potassium [60-63]. A primary role of saliva is to dissolve and deliver tastants to taste cells. Adequate salivary flow is important for maintaining the milieu of taste receptors and, in turn, appetite [64]. Higher concentrations of sodium and potassium are known to lead to gustatory adaptation and, as a consequence, higher salt taste threshold which can lead to excess salt intake in older adults with consequent risks for cardiovascular disease [65].

Interestingly, some of the effects of the age-related change in taste perception may be reversible. Shiffman et al. [52] discuss various techniques for improving salivary health including flavour intensification and strategies to stimulate smell and taste with positive effects on appetite. Abdel-Moemin et al. [66] discusses strategies that might better meet the needs of consumers who have sensory-taste deficits and recommends that the food science community begin designing food specifically for this client group.

Disease and Taste

Taste disorders are more prevalent in hospitalized and institutionalized older adults compared with those living in the community [45, 67]. Many diseases have been shown to be associated with
altered gustatory function (Table 1). Many of which are commonly seen in the elderly population, particularly Alzheimer’s disease, diabetes mellitus, obesity and heart disease [68, 69].

Alzheimer’s disease is one of the most commonly diagnosed neurodegenerative disorders in Adults over the age of 65 years and results in losses in the orbitofrontal cortex and limbic cortex [70]. This is important in this context as afferent taste stimuli run through the limbic cortex on the path to the orbitofrontal cortex, suggesting taste sensitivity may be impacted by Alzheimer’s disease due to processing within the brain [71]. Indeed consistent with this hypothesis, Ogawa [71] has demonstrated decreased gustatory functioning but not taste thresholds in Alzheimer patients compared to age matched controls.

**Table 1. Diseases associated with taste disruption [68, 69]**

<table>
<thead>
<tr>
<th>Disease Cluster</th>
<th>Disease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infections/ Autoimmune disease</td>
<td>Sinusitis, upper respiratory infections, chronic hepatitis C</td>
</tr>
<tr>
<td>Neurological</td>
<td>Dementia, Alzheimer’s disease, Parkinson disease, multiple sclerosis, epilepsy</td>
</tr>
<tr>
<td>Malignancy</td>
<td>Tumours</td>
</tr>
<tr>
<td>Endocrine/ Metabolic</td>
<td>Diabetes mellitus, hypothyroidism</td>
</tr>
<tr>
<td>Dental</td>
<td>Periodontal disease, dental caries, oropharyngeal candidiasis</td>
</tr>
<tr>
<td>Organ specific disease</td>
<td>Chronic kidney disease, heart disease, liver failure</td>
</tr>
</tbody>
</table>

A second common disorder in older adults is diabetes mellitus which has a well-described impact on gustatory function with an estimated more than one-third of adults with diabetes reporting a reduced ability to taste (i.e. hypogeusia) [68, 72, 73]. The reduction in taste perception may be secondary to the higher taste thresholds and lower density of fungiform papillae reported in older diabetics compared to age-matched controls [73]. Diabetes mellitus is also associated with a reduced sensitivity to sweet taste with potentially negative consequence for glycaemic control [74]. Hypogeusia is thought to underlie overeating and obesity in patients with diabetes [72]. Reduced taste sensitivity in patients with diabetes mellitus is also reported to affect adherence to dietary regimes resulting in poor glycaemic control with consequent negative effects on disease related comorbidities such as cardiovascular and chronic kidney disease [75].

**Medication and Taste**

In addition to the age-related decline in taste sensitivity in the elderly, various drugs commonly prescribed to this population have the potential to affect gustatory function. Altered taste is reported in as many as 75% of all adverse drug reactions between 1988 and 2008 [11]. Further to this, the effects of these drugs on taste can persist for months after cessation of the affecting drug [69]. Some of the regularly offending drugs include proton pump inhibitors, antiretroviral
medications, and chemotherapeutic drugs used to treat various forms of cancer (most common in the elderly) [76]. Drugs, excreted in saliva via passive diffusion from the plasma or carrier-mediated transport, have the ability to disturb gustatory function by a number of different mechanisms including drug-receptor interaction, action potential propagation in cell membranes, and altered neurotransmitter function [52, 68]. Medications can also have an indirect effect on taste perception secondary to mucosal dryness and burning mouth syndrome [77, 78].

Sleep, Time-of-Day and Taste

To anticipate daily changes in the environment, humans evolved internal time-keeping or ‘clocks’ made up of cellular feedback loops [79]. These cellular clocks help to control various bodily functions including sensing (e.g. smell), activity, feeding, metabolism, sleep, cognitive function and immune function [80] and many follow a 24h or circadian rhythm (from the Latin circa, meaning "around", and diem, meaning "day"). These rhythms mean that we are more likely to want to eat certain foods at certain times of the day. Sensitivity to a particular taste may make particular foods more attractive or palatable in the morning vs the evening or vice versa.

Over all there has been very little research into the circadian rhythms of taste. Research using an animal model has found that the clocks regulating taste help the animal to restrict daily food consumption [81] and that gustatory physiology in general appears to be tuned to a higher level during daytime. This suggests that feeding is, in some animals, gated by taste. In humans it has been found that changes in mouth physiology that influence taste have a circadian rhythm such as oral temperature and salivary flow [82]. Both are highest in the late afternoon between 3pm and 5pm.

Several studies have examined recognition thresholds for salt and sweet tastes—i.e. the level at which a taste stimulus can not only be detected but also recognised. Both salt and sweet tastes have been found to exhibited time-of-day variations. Interestingly, they are opposite to each other. The salt threshold, when tested every 3-h for a 24-h period shows the sensitivity to salt is highest in the afternoon [15]; while the sweet threshold shows highest sensitivity in the morning around 8am [83]. However it appears that this diurnal variation is sweet-taste selective—it has not been observed in thresholds for other taste stimuli (such as citric acid, quinine, and monosodium glutamate) [83].

Changes to sleep and sleep loss have implications for health and increase the risk for weight gain [84]. A number of recent studies have found that this relationship is causal with reduced sleep times impacting glucose metabolism [85], increasing appetite for sweet foods [86], and increasing neural responses in brain regions involved in both gustatory and reward processing to images of palatable foods [87]. It has been hypothesised that sleep loss or disrupted sleep might change the way we perceived the taste of foods and, therefore, why we might seek out or crave certain types of foods when we are sleep deprived.

Results from studies on the impact of sleep duration on taste are mixed. Some studies have found that taste is impacted, while others have not. One study that did find a change with sleep duration
examined sleep loss and taste for umami, sourness, and bitterness [88]. That group found that increasing sleepiness due to reduced sleep time was a significant factor in the perceived intensity of both umami and sour taste, with both rated as significantly higher with increasing sleepiness. Sleepier participants also reported a higher cravings for high fat sweet foods, perhaps leaving them vulnerable to overconsumption [88]. A number of studies have also reported no link between sleep loss and taste. These studies focused on perceptions of sweet or salty foods [89] and found that taste did not change with reduced sleep time. This suggests that altered processing of sweet tastes is an unlikely to be the mechanism by which sleep deprivation affects the hedonic control of eating.

Taken together there is emerging evidence suggests that there are time-of-day changes in how we taste sweet and salty food and that sleep loss and sleepiness can impact some aspects of taste—the savoury umami and sour flavours are increased, while others, the sweet and salty flavours remain unaffected. This is important when considering how people who may not sleep well might respond to certain foods and what kinds of food they might prefer in the morning versus the afternoon. It is important to keep in mind that all the sleep and time-of-day studies have been conducted in young healthy men and women. How circadian rhythms and sleep might impact taste in older populations is unknown and worthy of further research.

Promoting Taste and Appetite: Changing the Focus from Nutrients to Food Delivery

Food plays a profound role in one’s life. The ability to choose what, when to eat as well as the eating environment all influence the pleasure associated with eating. There are differences in the way individuals perceive flavours that depend on physical differences, including genetics and differences in the tongue [90, 91]. One of the factors that influences when and how much we eat is our feelings of satiation, which tell us when to stop eating, and our satiety, which affects the interval between food consumption periods [92]. Satiation and satiety effects of foods are a product of our senses and our cognition. In addition to physical responses to foods governing how full we feel (e.g. gastric distension, hormonal cascades), we have anticipatory sensory and cognitive reactions to foods (e.g. how pleasurable we think consumption will be, other associations with the food) [92]. In this way, our preferences are strongly linked with lifetime experiences and traditions and removing the ability to decide on foods to eat can impact on overall quality-of-life [93]. The familiarity of foods that taste like home and remind them of their ethnic identity has been reported as being important [94]. These factors remain important as we age, yet in residential aged care settings these factors can be a challenge to manage [95].

A focus on food hygiene to reduce the risk of food-borne disease may limit the variety of foods available to residents in aged care facilities [96]. In addition, food availability is also limited by the need to ensure that foods and fluids are provided that meet the nutritional requirements for the residents to ensure nutritional status is optimised, and that malnutrition risk [97] and dehydration risk [98] are minimised. Yet, it is important to recognise that food choice is strongly linked with resident food service satisfaction [99]. Mealtimes represent more than just an chance to provide nutrition; they may offer residents (and staff) the opportunity to develop important social relationships [100].
Furthermore, the environment that residents eat in will also impact on satisfaction associated with the food service [94].

These are critical concerns in the context of the well-documented phenomenon referred to as the "anorexia of aging" [92, 101]. As we get older, food consumption reduces. It has been estimated that between the ages of 40 and 70 years, energy intake reduces by about 25% [102]. In later life, we tend to eat more slowly, feel less hungry and thirsty, eat smaller meals, and eat less between meals [92]. Often, our reduction in energy expenditure is not sufficient to maintain energy balance, resulting in weight loss. In addition, as we age, our food perception and enjoyment is also influenced by changes in dental health, sensory changes (reductions in vision, taste, and smell), and changes in gut function. Alterations in cognition including dementia and mood disturbances also impact on our appetite and enjoyment of food [92, 101]. Perceptions of taste appear to be one of the main factors influencing energy intake in older adults [103, 104]. Therefore, when considering food provision for elderly people, especially in the context of aged care, it is important to go beyond a focus on nutrients to include consideration of food delivery. This includes thought regarding the types of foods offered, as well as the environmental, social, and sensory experience. These factors are summarised in Figure 1, and are the subject of elaboration in the following sections.

![Figure 1](image.png)

**Figure 1.** A summary of the personal, environmental and food presentation factors influencing the perception of taste and enjoyment of food.

**Addressing Food Types in Older Adults**

Older adults are more concerned about food texture compared to younger adults, as they commonly have difficulty consuming hard, crunchy, dry, and stringy textured foods [105]. When developing foods for older adults, consideration should be given to the increased requirements for specific macro- and
micronutrients with age, especially protein, calcium, vitamin D, and vitamin B [105]. In addition, the quality of fat should be a factor in food provided. One recommendation has include offering nutrient density snack options that are rich in several of these key nutrients such as dairy [97] and nuts or nut butters [106].

Detection thresholds in older adults for basic tastes such as sweeteners, salt, acids, and bitter compounds, have been found to be 4 to 5 times higher than in comparison to younger adults [107]. This reduction in their ability to detect flavours in food may lead to a bland food experience and to a move toward an increase in discretionary foods with more intense flavours, for example, those containing higher levels of sugar or salt [108]. When considering developing new foods it is essential to consider the nutrient quality but other aspects such as whether they are easily accessible, appealing, and with appropriate sensorial attributes (appearance, presentation, size, colour, flavour, texture, and consistency) that would be traditionally and frequently consumed [109, 110]

Flavour enhancers have been shown to increase food intake which can be of benefit when appetite is reduced [111, 112]. Incorporating natural ingredients rich in umami taste or intense flavour ingredients (such as tomatoes, sharp-aged cheese, shiitake mushrooms, soy and garlic, onion, concentrated fruit sauce or flavoured oils/vinegars, or spices with bolder aromas, that is, basil, chives, coriander, and sage rosemary) could also assist with enhancing appetite and pleasure associated with food consumption [105].

Addressing the Senses to Enhance Flavour Perception in Older Adults

There is also evidence that flavour perception can be altered by changing visual cues such as lighting, sounds, odours and texture of foods [113]. Not only the colour of an individual food, but also the variety and the arrangement of the differently-coloured components in a meal influence consumers' ratings of the pleasantness of a meal [114]. While in general, the variety of foods consumed decreases with age, voluntary consumption of food can be promoted by including an element of variety, even within very similar foods. For example, providing sandwiches with different fillings results in higher sandwich consumption in older adults [115]. Portion size is another important visual cue that influence taste perception and enjoyment. Presenting small portion sizes, in particular, when the foods presented are high in energy density, results in increased energy intake in older adults [92].

Other visual factors that promote food consumption that have been studied in general (as opposed to specifically older) populations include: food that is arranged on a balanced way on the plate (i.e. not “asymmetric plating”) [116]; and having a larger container for the food relative to the portion size [117, 118]. People have also been shown to associate visual properties of food with certain flavours. Referred to as “synaesthetic associations,” these include relationships between roundness and sweetness, and angularity and bitterness [119]. People also more easily identify flavours that match with their typically associated colours [120]. Perceptions of food are also influenced by plate, bowl or
package colour, graphics [121-124], shape and curvature [122, 125], naming of the food and information provided [126, 127], and even the typeface of the written food information [128].

Given the above discussion regarding the importance of colour and flavour, other studies have investigated the provision of condiments along with meals. Not only can condiments add colour and flavour to the main dish, but depending on the packaging, or serving system, they can add colour and interest to the table setting (reviewed in [129]).

The texture of foods offered presents a challenge to enjoyment; residents may have impairments in the ability to chew and swallow easily which can result in very restricted or very soft food. These are often not as palatable as foods with a broad range of textures [130] and can lead to a poor appetite [131]. A study by Endo et al. [132] reported that providing a crunchy sound whilst adults consumed texture modified foods altered the perception of the food and improved satisfaction ratings.

Addressing the Eating Environment

The design of the dining room and the environment in the dining room can contribute to the dining experience. A supportive environment can provide a sense of familiarity, comfort, security, enjoyment, belonging and identity [133] and contribute to overall nutrition status by encouraging food consumption [134, 135]. Creating mealtime ambiance, through low temperatures, soft lighting, flowers, table-cloths, and full cutlery, is also reported to increase food consumption [92]. Nevertheless, not all studies report positive results. At least one study has reported that the amount of food consumed by aged care residents did not differ between those who had a positive compared to a negative view of the dining room environment [136].

Sound can impact on food consumption. For example, researchers have shown that food consumption goes up when music is played (reviewed in [137]). Studies have also suggested that sound level may impact differentially on different flavours. One study simulating airline cabin noise (>85 dB) reduced sweet taste intensity ratings, but augmented reports of umami flavours [138]. Research has also highlighted the importance of auditory feedback (e.g. crunching noise associated with biting) in perception of food texture [139].

The social aspects of meals are extremely important. Living alone and feeling socially isolated has been suggested to contribute to reduced food consumption, particularly for those who are older, and particularly for men. In contrast, eating with other people increases the amount of food consume [92]. In the residential care or hospital environment, meal-time ambiance can be improved by staff sitting and eating with residents, and encouraging family members or friends to visit during mealtimes can encourage people to eat [92]. Minimising procedural interruptions (e.g. for medication administration) is preferred to maintain perceptions of the importance of mealtimes, as well as to allow people to consume hot food before it cools, becoming less palatable. This also separates medical aspects from food consumption, ‘de-medicalising’ mealtimes [92]. Protected Mealtime Interventions
have been defined as minimising “unnecessary and avoidable interruptions, providing an environment conducive to eating” (p544, [140]). Studies support the promise of Protected Mealtime Interventions, especially when combined with eating support, where necessary, from trained professionals [92, 140]. All of these considerations impact on the emotional state of the individual, which in turn, influences appetite and taste perception. Negative moods have been associated with higher intensity reports of bitter tastes, whereas positive moods are associated with enhanced sweeter tastes [141].

Practical recommendations from qualitative interviews with residents have included making the environment feel like home, offering food choices without using trays (e.g. use hot carts in dining rooms), serve the food family style (where people serve themselves form bowls of food at the table) and allow residents dining together to choose portion sizes and which foods they prefer, serving cultural or ethnic foods regularly, providing an opportunity for anonymous feedback on the food to allow residents to have a voice and make suggestions [94, 99, 142]. Further suggestions have included flexibility in the timing of meals [94], the use of high visual contract tableware (e.g. bright red crockery) can help people with visual deficits [143]. A study by Hung et al. [133] suggested allowing staff to help residents see meal preparation. Another study in residents with dementia reported that including residents in the decision of how meals should be prepared added to the enjoyment of the meal and enhanced engagement in mealtime conversations [144].

A summary of the factors that influence taste perception and food intake in older adults is provided in Table 2, alongside related recommendations.