Proceedings of the Nutrition Society (2012), **71**, 556–565 doi:10.1017/S0029665112000742

First published online 13 August 2012

The Annual Meeting of BAPEN with the Nutrition Society was held at Harrogate International Centre, Harrogate on 29–30 November 2011

Conference on 'Malnutrition matters'
Nutrition Society Symposium: Muscle wasting with age: a new challenge in nutritional care; part 1 – the underlying factor

Ageing and taste

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Taste perception has been studied frequently in young and older adult groups. This paper systematically reviews these studies to determine the effect of ageing on taste perception and establish the reported extent of sensory decline. Five databases were searched from 1900 to April 2012. Articles relating to healthy ageing in human subjects were included, reviewed and rated (Downs and Black scoring system). Sixty-nine studies investigated the effect of ageing on taste perception; forty examined detection thresholds of which twenty-three provided sufficient data for meta-analysis, eighteen reported identification thresholds and twenty-five considered supra-threshold intensity perception. Researchers investigating detection thresholds considered between one and thirteen taste compounds per paper. Overall, the consensus was that taste detection thresholds increased with age (Hedges' $g = 0{\cdot}91$, $P < 0{\cdot}001$), across all taste modalities. Identification thresholds were reported to be higher for older adults in seventeen out of eighteen studies. Sixteen out of twenty-five studies reported perception of taste intensity at supra-threshold levels to be significantly lower for older adults. However, six out of nine studies concerning sucrose found perceived intensity of sweet taste not to diminish with age. The findings of this systematic review suggest taste perception declines during the healthy ageing process, although the extent of decline varies between studies. Overall, the studies reviewed had low Downs and Black scores (mean 16 (SD 2)) highlighting the need for more robust large scale and longitudinal studies monitoring the impact of ageing on the sensory system, and how this influences the perception of foods and beverages.

Age: Taste: Threshold: Detection: Intensity

Older adults are at risk of under nutrition due to a multitude of physiological, psychological and socio-economic factors. Physiological factors are diverse, such as malabsorption of nutrients, infection, dysphagia, as well as loss of appetite and sensory decline. Older people frequently complain of blandness of foods or sensory changes that may influence their liking and subsequent consumption of food, further impacting on their risk of malnutrition[1]. Previous researchers have used taste enhancement, aiming to increase liking and consumption of meals by older adults, with conflicting results[2,3]. Therefore, in order to develop foods leading to improved liking and consumption by older adults, analysis of age-related changes in taste perception is essential. This paper systematically reviews the evidence for deterioration of taste perception within healthy ageing and discusses the extent of change.

Methods: search strategy, selection, scoring and data extraction

Medical databases Medline, EMBASE and CINAHL as well as Science Direct and Web of Science databases were

Abbreviation: AFC, alternative forced choice.
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searched from 1900 to April 2012 for relevant articles. Search terms were: 'taste, tastant, gustation, threshold, identification, perception, intensity, acuity.' Within the medical databases the search included age category limits of over 65, over 80 years and human subjects' studies. In the latter two databases, search terms 'age, elder, old and geriatric' were also included. Articles were excluded by either the abstract or the full paper if they did not fall within the inclusion criteria; the papers had to investigate both younger adults and older adults (over 65 years), be related to healthy ageing and not a disease state. Aroma, olfaction and smell were also excluded. Review articles found in searches were hand searched for relevant articles within reference lists, with resulting studies assessed for relevance and where suitable included in this review. Accepted articles were reviewed by two researchers independently and appraised using the Downs and Black scoring system[4]. The checklist comprised twenty-six questions to evaluate the reporting, external and internal validity (bias and confounding). The final question regarding statistical power was removed as most studies were not intervention studies and hence did not provide a power calculation; however, the total number of participants in each study was reviewed. Disagreements in ratings were discussed and final consensus scores were given for each study. The data extracted included whether the study investigated taste detection or identification thresholds or supra-threshold intensities, as well as authors, publication year, sensory methodology, participant information and key findings. Meta-analysis was carried out on the data extracted from articles which investigated taste-detection thresholds using the Comprehensive Meta-Analysis software (Version 2).

Results

Sixty-nine relevant articles were included in this review, from the initial search acquisition of 3959 articles of which 127 non-English articles were excluded. Participant numbers varied greatly depending on the study type and size, from twelve to 761 respondents; however, the study sizes were small with sixty participants as the median size. Taste detection thresholds were studied in forty papers of which twenty-three provided sufficient data to be included in a meta-analysis, either as independent group means with standard deviation or as correlation coefficients of threshold against age. Identification thresholds were reported in eighteen papers and taste intensity perception was considered in twenty-five papers. The taste modalities considered included sweet, salty, sour, bitter and umami. Papers ranged in their consideration from one to all modalities; the number of tastant compounds considered within each modality varied from one to thirteen.

Effects of ageing on taste detection

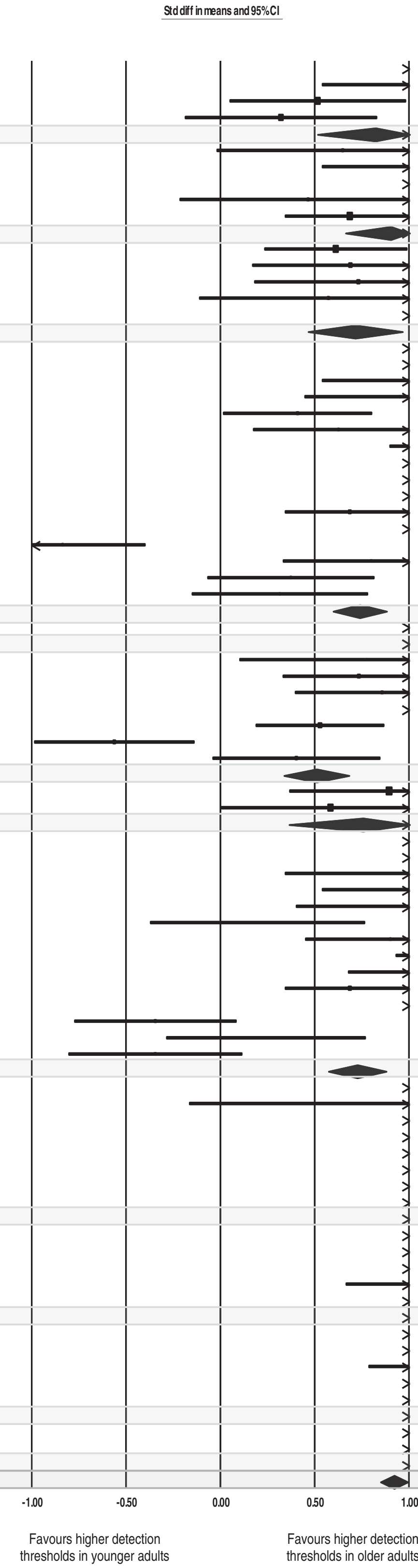
Fig. 1 summarises the meta-analysis output across all taste modalities reported. The effect size (reported as Hedges' *g*), the sample size and the significance (*P* value) of each study can be seen in Fig. 1. Where the bar is located to the right side of the plot it indicates that a study found higher detection thresholds in older adults, the bar is on the left where thresholds were higher in younger adults; centred bars indicate no difference in thresholds between either group. However, only the tastants typically tested have been included in the plot, for example, sucrose for sweet taste and NaCl for salt taste. Other tastants within each modality, which were included in a limited number of studies, are discussed later separately. The overall consensus across all tastes and all papers is given at the end of the Fig. and the consensus for each taste modality is given within Fig. 1. The weighting of each study to the consensus is given to the right of the plot; these were derived from the sample size.

Of the total twenty-three relevant articles that underwent meta-analysis, twenty found taste detection thresholds to significantly increase with age, and these covered all five modalities (Fig. 1). However seven studies found no effect of age for sucrose (four studies), NaCl (two studies), quinine hydrochloride (two studies), caffeine (one study), quinine sulphate (one study), citric acid (one study) and glutamate (one study). One study[5] unexpectedly found a significant decrease in taste-detection threshold with age for females only across two taste modalities (sour and salt). It is clear from Fig. 1 that the trend of increasing detection thresholds with age is most conclusive for umami, where all studies have observed thresholds to increase. However, this modality has only been studied by two research groups. Thresholds for salt and sour tastants increase in more than 80% of studies. Bitter and sweet tastants have also been found to be negatively affected by healthy ageing in 70% of studies.

There are numerous reasons for discrepancies across studies, including the widely varying number of participants tested, different age ranges, varying male:female ratios and different exclusion or inclusion of confounding factors such as participants with dentures and smokers. In addition, sensory-testing methodologies varied, as did the tastants used coupled with their concentration ranges and progressions. Many studies commented that there were gender differences in thresholds as well as age differences, so as the genders were not balanced in all studies this will have contributed to discrepancies[5–9].

Of the forty papers investigating detection thresholds, the majority used some form of alternative forced choice (AFC) procedure where tastants were presented in aqueous solution alongside control water samples; either 2-AFC[10,11] where each sample concentration was presented against one water control and the volunteer stated which was the stronger sample, or 3-AFC[5,9,12] where each sample was presented against two controls. In some cases, volunteers were only presented each concentration once (an ascending AFC method)[12–19], whereas more rigorous papers used a staircase methodology where 'turning points' are established through presenting the volunteer samples below and above their individual threshold more than once to have more confidence in the individual's threshold[8,10,11,20–27]. Hybrids between these two method types do exist, for example where authors have used an ascending AFC method and then repeated the determined threshold[28]. The papers in the meta-analysis are

Study name	Subgroup within study	Statistics for each study							Sample size		Relative weight
		Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Older	Younger	
Mojet et al (2005)	Bitter - Caffeine	6.592	0.783	0.613	5.058	8.126	8.423	0.000	21	21	4.00
Schiffman et al (1994)	Bitter - Caffeine	1.276	0.377	0.142	0.538	2.015	3.386	0.001	18	16	17.24
Wardwell et al (2009) F	Bitter - Caffeine	0.517	0.239	0.057	0.048	0.986	2.159	0.031	31	43	42.72
Wardwell et al (2009) M	Bitter - Caffeine	0.322	0.261	0.068	-0.189	0.833	1.234	0.217	22	46	36.04
		0.820	0.156	0.024	0.514	1.127	5.242	0.000			
Bartoshuk et al (1986)	Bitter - Quinine hydrochloride	0.649	0.342	0.117	-0.021	1.320	1.898	0.058	18	18	12.75
Fukunaga et al (2005)	Bitter - Quinine hydrochloride	1.079	0.276	0.076	0.537	1.621	3.904	0.000	30	30	19.52
Mojet et al (2005)	Bitter - Quinine hydrochloride	2.963	0.447	0.200	2.087	3.839	6.629	0.000	21	21	7.46
Schiffman et al (1994)	Bitter - Quinine hydrochloride	0.465	0.348	0.121	-0.217	1.148	1.337	0.181	18	16	12.30
Stevens (1996)	Bitter - Quinine hydrochloride	0.687	0.176	0.031	0.341	1.032	3.896	0.000	49	109	47.97
		0.901	0.122	0.015	0.662	1.141	7.381	0.000			
Cowart et al (1994)	Bitter - Quinine sulfate	0.612	0.194	0.038	0.232	0.992	3.157	0.002	60	52	43.21
Mavi & Cayhan (1999)	Bitter - Quinine sulfate	0.690	0.267	0.071	0.167	1.212	2.587	0.010	24	39	22.84
Mavi & Ceyhan (1999)	Bitter - Quinine sulfate	0.732	0.283	0.080	0.178	1.286	2.589	0.010	24	30	20.30
Schiffman et al (1994)	Bitter - Quinine sulfate	0.573	0.351	0.123	-0.114	1.260	1.635	0.102	18	16	13.21
Spitzer (1988)	Bitter - Quinine sulfate	15.112	1.922	3.694	11.345	18.879	7.863	0.000	17	15	0.44
		0.713	0.127	0.016	0.463	0.962	5.594	0.000			
Bales et al (1986)	Salt - Sodium chloride	5.441	0.551	0.303	4.361	6.520	9.879	0.000	32	30	1.72
Bartoshuk et al (1986)	Salt - Sodium chloride	2.667	0.580	0.337	1.529	3.804	4.596	0.000			1.55
Fukunaga et al (2005)	Salt - Sodium chloride	1.079	0.276	0.076	0.537	1.621	3.904	0.000	30	30	6.82
Grzegorczyk et al (1979)	Salt - Sodium chloride	0.953	0.259	0.067	0.444	1.461	3.674	0.000			7.75
Heft & Robinson (2010) F	Salt - Sodium chloride	0.409	0.202	0.041	0.013	0.806	2.024	0.043	48	52	12.74
Heft & Robinson (2010) M	Salt - Sodium chloride	0.627	0.232	0.054	0.172	1.082	2.702	0.007	38	40	9.68
Hyde (1981)	Salt - Sodium chloride	2.168	0.649	0.422	0.895	3.440	3.339	0.001	5	12	1.24
Mojet et al (2005)	Salt - Sodium chloride	12.275	1.374	1.889	9.581	14.969	8.931	0.000	21	21	0.28
Schiffman et al (1990)	Salt - Sodium chloride	5.634	0.931	0.867	3.809	7.459	6.051	0.000	10	13	0.60
Spitzer (1988)	Salt - Sodium chloride	8.422	1.111	1.234	6.245	10.599	7.582	0.000	17	15	0.42
Stevens (1996)	Salt - Sodium chloride	0.687	0.176	0.031	0.341	1.032	3.896	0.000	49	109	16.77
Stevens et al (1998)	Salt - Sodium chloride	2.414	0.538	0.289	1.360	3.467	4.490	0.000			1.80
Wardwell et al (2009) F	Salt - Sodium chloride	-0.836	0.225	0.051	-1.277	-0.395	-3.718	0.000	43	43	10.30
Wardwell et al (2009) M	Salt - Sodium chloride	0.800	0.239	0.057	0.330	1.269	3.340	0.001	30	50	9.09
Watanabe et al (2008)	Salt - Sodium chloride	0.374	0.227	0.051	-0.070	0.818	1.650	0.099	44	36	10.14
Wayler et al (1990)	Salt - Sodium chloride	0.316	0.239	0.057	-0.153	0.784	1.320	0.187	34	37	9.12
		0.737	0.072	0.005	0.595	0.878	10.210	0.000			
Mojet et al (2005)	Sour - Acetic acid	1.963	0.376	0.141	1.227	2.699	5.226	0.000	21	21	100.00
		1.963	0.376	0.141	1.227	2.699	5.226	0.000			
Bartoshuk et al (1986)	Sour - Citric acid	0.777	0.346	0.119	0.099	1.454	2.247	0.025	18	18	6.43
Heft & Robinson (2010) F	Sour - Citric acid	0.735	0.207	0.043	0.329	1.140	3.553	0.000	48	52	17.97
Heft & Robinson (2010) M	Sour - Citric acid	0.858	0.237	0.056	0.394	1.322	3.625	0.000	38	40	13.72
Mojet et al (2005)	Sour - Citric acid	1.886	0.371	0.138	1.159	2.613	5.084	0.000	21	21	5.59
Stevens (1996)	Sour - Citric acid	0.529	0.175	0.030	0.186	0.871	3.028	0.002	49	109	25.23
Wardwell et al (2009) F	Sour - Citric acid	-0.562	0.218	0.047	-0.988	-0.135	-2.582	0.010	46	42	16.24
Wardwell et al (2009) M	Sour - Citric acid	0.403	0.228	0.052	-0.043	0.850	1.772	0.076	32	51	14.83
		0.507	0.088	0.008	0.335	0.679	5.784	0.000			
Fukunaga et al (2005)	Sour - Tartaric acid	0.895	0.271	0.073	0.364	1.426	3.305	0.001	30	30	54.53
Kaneda et al (2000)	Sour - Tartaric acid	0.585	0.297	0.088	0.003	1.166	1.971	0.049	20	29	45.47
		0.754	0.200	0.040	0.362	1.146	3.770	0.000			
Bales et al (1986)	Sweet - Sucrose	3.333	0.393	0.154	2.564	4.103	8.489	0.000	30	32	3.93
Bartoshuk et al (1986)	Sweet - Sucrose	2.762	0.594	0.352	1.599	3.926	4.653	0.000			1.72
Easterby Smith (1994)	Sweet - Sucrose	1.084	0.379	0.143	0.341	1.826	2.862	0.004	16	16	4.22
Fukunaga et al (2005)	Sweet - Sucrose	1.079	0.276	0.076	0.537	1.621	3.904	0.000	30	30	7.93
Hyde (1981)	Sweet - Sucrose	1.569	0.596	0.356	0.400	2.737	2.630	0.009	5	12	1.70
Kaneda et al (2000)	Sweet - Sucrose	0.198	0.291	0.085	-0.373	0.769	0.678	0.498	20	29	7.13
Kennedy et al (2010)	Sweet - Sucrose	0.902	0.231	0.053	0.449	1.355	3.901	0.000	48	36	11.33
Mojet et al (2005)	Sweet - Sucrose	1.626	0.356	0.127	0.928	2.324	4.568	0.000	21	21	4.78
Spitzer (1988)	Sweet - Sucrose	1.457	0.398	0.159	0.676	2.238	3.658	0.000	17	15	3.82
Stevens (1996)	Sweet - Sucrose	0.687	0.176	0.031	0.341	1.032	3.896	0.000	49	109	19.49
Stevens et al (1995)	Sweet - Sucrose	2.812	0.515	0.265	1.803	3.821	5.461	0.000	15	15	2.28
Wardwell et al (2009) F	Sweet - Sucrose	-0.344	0.220	0.048	-0.775	0.087	-1.564	0.118	44	40	12.50
Wardwell et al (2009) M	Sweet - Sucrose	0.242	0.270	0.073	-0.288	0.772	0.895	0.371	21	40	8.28
Wayler et al (1990)	Sweet - Sucrose	-0.345	0.236	0.056	-0.807	0.117	-1.462	0.144	36	37	10.89
		0.723	0.078	0.006	0.571	0.876	9.298	0.000			
Mojet et al (2005) e	Umami - Glutamate	9.364	1.067	1.139	7.272	11.456	8.774	0.000	21	21	3.33
Schiffman et al (1979) f	Umami - Glutamate	1.176	0.685	0.469	-0.166	2.519	1.717	0.086	5	5	8.08
Schiffman et al (1991) a	Umami - Glutamate	2.605	0.467	0.218	1.691	3.520	5.582	0.000	18	16	17.39
Schiffman et al (1991) b	Umami - Glutamate	2.556	0.463	0.214	1.649	3.463	5.524	0.000	18	16	17.70
Schiffman et al (1991) c	Umami - Glutamate	2.591	0.472	0.223	1.665	3.516	5.486	0.000	17	16	16.99
Schiffman et al (1991) d	Umami - Glutamate	2.551	0.476	0.227	1.618	3.484	5.358	0.000	16	16	16.72
Schiffman et al (1991) e	Umami - Glutamate	4.654	0.670	0.449	3.340	5.968	6.941	0.000	17	16	8.43
Schiffman et al (1990) e	Umami - Glutamate	2.682	0.577	0.333	1.550	3.813	4.645	0.000	10	13	11.37
		2.876	0.195	0.038	2.494	3.257	14.773	0.000			
Schiffman et al (1991) a	Umami - Glutamate with 0.1 mM IMP	48.806	5.929	35.148	37.186	60.426	8.232	0.000	18	16	0.19
Schiffman et al (1991) b	Umami - Glutamate with 0.1 mM IMP	3.313	0.529	0.280	2.277	4.350	6.267	0.000	18	16	24.26
Schiffman et al (1991) c	Umami - Glutamate with 0.1 mM IMP	5.035	0.711	0.505	3.642	6.429	7.082	0.000	17	16	13.41
Schiffman et al (1991) d	Umami - Glutamate with 0.1 mM IMP	1.416	0.384	0.148	0.663	2.169	3.687	0.000	18	16	45.96
Schiffman et al (1991) e	Umami - Glutamate with 0.1 mM IMP	4.339	0.647	0.419	3.070	5.608	6.702	0.000	16	16	16.18
		2.926	0.260	0.068	2.416	3.437	11.237	0.000			
Schiffman et al (1991) a	Umami - Glutamate with 1 mM IMP	4.287	0.623	0.388	3.065	5.508	6.879	0.000	18	16	13.89
Schiffman et al (1991) b	Umami - Glutamate with 1 mM IMP	3.012	0.516	0.267	2.000	4.024	5.832	0.000	16	16	20.22
Schiffman et al (1991) c	Umami - Glutamate with 1 mM IMP	1.578	0.405	0.164	0.784	2.371	3.898	0.000	16	16	32.91
Schiffman et al (1991) d	Umami - Glutamate with 1 mM IMP	3.985	0.602	0.362	2.806	5.164	6.624	0.000	17	16	14.90
Schiffman et al (1991) e	Umami - Glutamate with 1 mM IMP	3.502	0.546	0.298	2.431	4.573	6.411	0.000	18	16	18.07
		2.951	0.232	0.054	2.496	3.406	12.705	0.000			
Mojet et al (2005)	Umami - IMP (Inosine monophosphate)	7.587	0.883	0.780	5.855	9.318	8.588	0.000	21	21	26.74
Schiffman et al (1991)	Umami - IMP (Inosine monophosphate)	3.199	0.534	0.285	2.153	4.246	5.994	0.000	16	16	73.26
		4.373	0.457	0.209	3.477	5.268	9.571	0.000			
		0.919	0.036	0.001	0.848	0.990	25.222	0.000			



F, female; M, male
Type of glutamate: a, ammonium; b, calcium; c, magnesium; d, potassium; e, sodium / monosodium; f, L-glutamic acid

Fig. 1 Forest plot from meta-analysis of data from studies measuring taste detection thresholds in younger and older adults (five taste modalities and most commonly studied tastants).

https://doi.org/10.1017/S0029665112000742 Published online by Cambridge University Press

Proceedings of the Nutrition Society

predominantly of this type. The AFC approach has also been used where small quantities of samples have been applied directly to the tongue by a pipette[23,29]. Simpler methods have been used; for example some researchers have used only single presentation of samples rather than a discrimination test between samples and controls. This has been carried out using solutions presented for normal drinking, either as a series of increasing concentrations[30,31] or as simply a single tastant solution[32,33]; alternatively as tastants absorbed onto filter paper discs that were placed directly onto the tongue[34], or as small aliquots of tastant solution (1 ml) sprayed directly into the mouth[6]. The obvious advantage of such simpler methods is to avoid excessive presentation of samples to elderly participants, avoiding fatigue; however, it can lead to less reliable results. Using a single concentration of tastant and determining the proportion of people that can detect its presence, is arguably not a method from which taste-detection thresholds can be quoted. However, it has provided useful data across very large subject cohorts (*n* 226) where the age of the older cohorts has been higher than in any other studies (101·9 (SD 1·4) compared with 70·5 (SD 5))[33]. This Italian study found an overall significant reduction in perception of taste ($P<0·001$) in centenarians compared with both adults (mean age 28) and older people (mean age 71)[32,33]. Another method developed to apply tastant solutions directly to the tongue was a gustometer, which enabled continuous presentation for 2 s intervals. Following each 2 s presentation the subjects give their degree of certainty concerning whether a stimulus was present or not. A large number of repetitions per person were possible using this method and results were analysed using a signal detection procedure (*R* index)[35]. This paper investigated salt detection thresholds that were found to increase with age ($P<0·0001$), in line with the AFC-type studies, and noted that there was regional sensitivity across the tongue. Finally, taste-detection thresholds can be measured without the presentation of any tastant stimulus, instead through the use of electrogustometry, a technique used to first report differences with age in the 1960s[36], which has received attention again more recently[37,38]. The technique assumes that responses to electrical stimulation of the tongue mimic taste function.

It was noted that electrical thresholds increased with age across all three studies[36–38]; however, one study noted that there was poor correlation between electrical thresholds and sour or salty taste thresholds[37]. It is perhaps reasonable to conclude that although the use of electrogustometry is very useful as a clinical tool to detect substantial increases in taste thresholds, it cannot be used to infer specific taste thresholds.

Where authors investigated the same taste modality using differing tastant compounds, it was found that the taste detection responses with age vary[11,13,15,16,18]. In addition, very few papers have evaluated detection thresholds within food or beverage systems[12] although more researchers have considered the perceived intensity of supra-threshold levels of tastants within products[11,39–45].

Despite the overall consensus that taste detection deteriorates with age, there is less evidence to suggest when this decline starts, as most studies have compared a cohort of older adults with one of younger adults. Three recent studies have investigated taste detection thresholds over an age continuum. The electrogustometry method was used with 461 participants with an age range of 15–94 years[38]. It was found that electrogustometry thresholds increased from either age 60+ or 70+ depending upon the exact site of measurement. The study by Yamauchi where aliquots of tastant solution were sprayed directly into participants mouths[6] investigated four tastants with 670 participants of age 20–90 years. They found salt thresholds to be significantly higher at 70+ years, bitter at 80+years, sour was significantly higher at 60+ years in males but not until 80+ years in females, whereas sweet thresholds were not affected by age in their study. A study that presented a series of increasing concentrations of salt solutions to 109 participants of age range 19–95 years[31] found no significant effect of age on thresholds. Results from the latter paper conflict not only with the Yamauchi paper, but with almost all papers in the meta-analysis that considered salt (Fig. 1). It is not clear why as all age groups were well represented in the Watanabe paper[31]; however the difference in sensory method used may have led to discrepancies. Summarising from the limited number of papers that have considered an age continuum, it appears that taste deterioration with age is only noted in later life, beyond at least 60 years of age.

Extent of taste decline with ageing

The extent of taste perception decline with age is rarely quantified and often disputed between research studies. However, it was clear that the effect of sensory decline depended largely upon the taste modality and upon the specific tastant.

Salt

It was clear from the meta-analysis (Fig. 1) that the NaCl taste thresholds increased with age, except for females in one study[5]. A similar result was found for other salt-taste compounds including potassium chloride[11] as well as Na salts of acetate, ascorbate, carbonate, citrate, phosphate, succinate, sulphate and tartrate (all at pH 7)[16]. Schiffman found the magnitude of salt perception decline varied from 2·7- to 26·7-fold depending on the type of Na salt[16]. Across studies investigating NaCl thresholds were found to increase between 1·4-[27] and 6·7-fold[16]. The mean thresholds quoted over all studies varied considerably; for older people the range was from 4·9[20] to 58 mM[34]; with an average across the studies of 21 mM (0·12 %, w/w) compared with the average across studies for younger adults of 11 mM (0·06 %, w/w). Data from one study were removed from the calculation of mean threshold as the paper quoted means values in different units for younger and older adults, implying a 57-fold decrease in threshold with age, which contradicted the direction of change quoted in the paper[34].

This difference in means across studies equated to a mean increase between younger and older adults of 2·0-fold. It is interesting to consider whether this extent of

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increase could effect detection of salt in meals by older people, certainly a level of 0·12 % (w/w) would be below the level of salt in most foods. The British Dietetic Association class low, medium and high-salt food to contain levels within the ranges of ≤0·3 g, 0·3–1·5 g and >1·5 g per 100 g product. Although the distribution of individual salt detection thresholds is wide, a large study (*n* 146) by Baker[8] found that very few individuals had thresholds above 50 mM (0·3 % NaCl).

Sour

The tastants included in the meta-analysis plot (Fig. 1) were citric, tartaric and acetic acids, the thresholds for which were found to increase with age, except in one out of five studies on citric acid where thresholds were found to be higher in a younger group of females[5]. A study of hydrochloric acid with males found thresholds to increase with age[19]. From four citric acid studies, the reported increase in threshold varied between 1·4-[5] and 11-fold[46]; however, the actual thresholds measured were much lower in the latter study where the total sample size was small (*n* 36) and there was a disproportionate number of females (89 %). Across the studies the mean thresholds for younger adults was 0·4 mM and for older adults 0·7 mM, representing a 1·5-fold increase with age.

Bitter

The effect of age on bitter detection thresholds has been reported for thirteen different compounds across nine different studies[5,11,18,19,21,23,24,34,46] and in all but one case[5] have been found to increase with age. The most common tastants studied are quinine derivatives and caffeine (Fig. 1). The extent of increase reported for quinine detection thresholds was between 1·5-[18] and 7·4-fold[46]. For quinine hydrochloride the mean thresholds across four studies for the younger and older adult groups were 0·002 and 0·009 mM, respectively, representing a 4·1-fold increase. For quinine sulphate the means were 0·005 M and 0·019 mM, respectively, similarly, a 4·0-fold increase. Interestingly, the results for caffeine were less notable; the extent of increase with age reported to be from 1·1-[5] to 1·6-fold[11]. Across four studies the mean caffeine thresholds for younger and older groups was 1·4 and 1·8 mM, respectively, representing an overall mean increase of 1·2-fold with age.

It was noted that some studies took into account genetic differences in ability to detect the bitter phenylthiocarbamide or propylthiouracil, whereas others did not, which would be a confounding factor. However, studies investigating these tastants found thresholds to increase with age[18,46]. Schiffman[18] evaluated a wide range of thirteen bitter tastants in one study where participants were first screened into phenylthiocarbamide taste/non-taster groups. The detection thresholds were significantly ($P<0·05$) higher for the older group for seven of the compounds, with the extent of difference within the non-phenylthiocarbamide taster group ranging from 1·5-fold for quinine hydrochloride to 33-fold for magnesium nitrate. However, the total sample size was small (*n* 34; sixteen younger, eighteen older; half phenylthiocarbamide non-tasters).

Sweet

Sucrose-detection thresholds were measured in ten studies, four of which found no effect of age. The remaining seven studies did find an increase with age varying from 1·2-[28] to 2·6-fold[34]. The mean threshold across the studies was 12·4 mM for younger adults and 16·8 mM for older adults, representing a 1·4-fold increase. A limited number of studies have investigated sweeteners. Two studies on saccharin both concluded thresholds were approximately 4-fold higher in older adults[13,15]. Regarding aspartame, one study found thresholds to increase 4·1-fold with age[15], whereas two other studies found no difference between age groups[11,13]. Schiffman evaluated a further nine sweeteners and found detection thresholds of all to increase with age by between 1·5-fold (sodium cyclamate) to 4·7-fold (monellin)[15].

Umami

Detection thresholds for umami have been evaluated in fewer studies. Three studies of monosodium glutamate all found detection threshold to increase with age. The mean threshold across studies was 2·5 mM for younger adults and 5·5 mM for older, representing a 2·2-fold increase. Two studies of inosine monophospate reported 4·4-fold higher detection thresholds in older adults (1·5 mM compared with 0·3 mM). Schiffman investigated thresholds of a further four glutamate salts all of which were between 3·7- and 8·5-fold higher for older adults[17]. Glutamates and inosine monophospate interact synergistically to increase overall umami taste. Thresholds for all four glutamate salts tested in combination with inosine monophospate also had higher thresholds in older adults compared with younger[17].

Effects of ageing on taste identification thresholds

Eighteen studies considered identification thresholds[5,6,12,15–17,30,32–34,42,47–53]. Some authors using the AFC methodology report identification thresholds post-detection within the same procedure. Others used simpler methods such as ascending presentation of a series (state when identified), either as solutions[42,47] or taste discs[34], presenting a single concentration of a tastant and determining the proportion of subjects that can name it[32,33]. A recent simple but effective means to determine identification thresholds has been the use of taste strips; four different concentrations per tastant, applied directly to the tongue[48,52]; or similarly using four concentrations of solution applied as drops[50,53]. Seventeen studies found taste-identification thresholds to increase with age, although one study reported only a weak relationship between age and taste strip results[52]. Only one study found no significant difference between age groups[53]; however, their older group was younger than in all other studies reported in this review (age 51–65), and therefore outside of our inclusion criteria.

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Table 1 Review of studies comparing perceived intensity of tastants and supra-threshold levels in younger and older adults

Ref	DB	*n* (OP)*	*n* (YP)†	Age (OP)	Age (YP)	Method	Tastants§	Significance‖	Key Finding
(55)	16	12	27	71 (SD 2)	19 (SD1)	ME	SU (56)	NS	No difference between YP and OP in sweet intensity perception
(57)	18	42(f)	108	Not given	18–22	ME	Amino acids (3–14)	Mean ratio 2·55 (slope YV/slope OV)	Perceived intensity flatter for OP (mean ratio was 2·55 : slope YP/slope OP)
(7)	16	24	28	75 (SD 6)	28 (SD 3)	Line scale	SU, NaCl, CA, Caf (7)	SU and NaCl ns; CA $P<0·05$, Caf $P<0·01$	OP scored lower intensities for sour and bitter (gender differences)
(15)	14	12	12	75–81	19–24	ME	Sweeteners (9–11)	Mean ratio 2·06 (slope YV/slope OV)	Psychophysical function (plotting log of perceived intensity against log concentration) flatter for OP
(56)	15	20, 20	20	(65–78) (80–95)	20–25	ME	NaCl (5)	NS	No age-related differences in intensity scoring
(46)	13	18	18	74–93	20–30	ME	SU, NaCl, CA, QHCl (9–13)	NS	Slope flatter, OP tended to score lower concentrations more intense and higher cons less intense
(58)	17	32	22	>70	22–39	ME	SU, NaCl, CA, QS(7)	SU ns, CA, NaCl and QS $P<0·05$	Trend for OP to rate lower
(39)	12	60, 60	60	(70–79) (80–99)	20–29	ME	NaCl (levels not declared)	$P=0·025$ (in water) ($P=0·001$ in soup)	OP rated high salt samples lower intensity than young, but the very old rated them higher
(40)	20	60, 60	60	(70–79) (80–99)	20–29	ME	CA (6 levels)	$P<0·001$ solution and drink	OP rated high acid samples lower intensity than YP, but the very old rated them higher
(41)	16	60, 60	60	(70–79) (80–99)	20–29	ME	CA, NaCl (6)	$P<0·05$ solutions and products	Age had negative impact on intensity of perception
(10)	18	29	29	65–80	19–35	Category (13 pt)	SU, NaCl, CA, QS (3)	SU ns; NaCl $P<0·05$; CA and QS $P<0·01$	Correlation between threshold and age was very weak
(59)	16	12	12	72 (SD 3)	23 (SD 2)	Weber fraction‡	SU, Caf (21)	SU ns; Caf $P<0·05$	Caf Weber ratio for bitter: YP 0·4, OP 1·27. OP needed 74 % inc to detect difference (YP 34 %)
(60)	14	24	24	73 (SD 5)	20 (SD 3)	ME	SU, NaCl, CA, Caf (3)	SU and NaCl ns; CA and Caf $P<0·05$	OP lower intensities for sour (77 %) and bitter (56 %)
(27)	18	34	37	65–78	55–65	ME	NaCl, SU (6)	NaCl $P<0·01$, SU ns (trend $P=0·07$)	NaCl intensity lower for OP than YP. Salivary Na affected salt judgements
(61)	14	Continuous *n* 87		Continuous 25–93		ME	SU, NaCl (4)	Not given	No age-related differences in intensity scoring
(45)	14	48	Not given	>65	20–35	Ranking	NaCl (4) in products	Not given	No significant difference in ability to perceive salt at the four concentrations
(17)	15	18	16	87 (SD 4)	26 (SD 5)	ME	5 glutamate salts (7) w/wo IMP	Mean slopes of YP> OP ($P<0·05$) in 14 out of 15 cases	Dose responses curves flatter for the OP
(21)	13	60	52	65–86	18–38	Category (13 pt)	QS, urea (5)	Urea ns; QS $P<0·01$	Differences not large
(18)	13	18	16	81 (SD 2)	27 (SD 1)	ME	13 bitter compounds (7)	Mean ratio of slope(YP)/slope(OP) 1·76 ($P<0·05$)	Intensity slopes for YP greater than for OP, for four out of eight compounds
(42)	19	29	35	79 (SD 6)	22 (SD 2)	Category (10 pt)	SU (in 5 foods) (5)	$P<0·05$ (in yoghurt only)	OP rated higher sucrose yoghurts as less sweet then YP
(43)	17	24	24	60–75	20–30	Category (9 pt)	NaCl (5)	$P<0·05$ in water, ns in broth	OP found salt slightly less intense in water, same in broth
(62)	17	30	30	>65	19–34	Category (5 pt)	SU, CA (5) in juice	$P<0·01$	Perceived intensity flatter for OP

Table 1 (Continued)

Ref	DB	n (OP)*	n (YP)†	Age (OP)	Age (YP)	Method	Tastants§	Significance‖	Key Finding
(44)	17	21	21	60–75	19–33	Category (9 pt)	NaCl, SU, AA, Caf, MSG, KCl, Aspartame, CA, QHCl, IMP (5)	$P<0{\cdot}0001$ (in water), $P<0{\cdot}03$ (in product)	OP perception less intense
(63)	15	30	30	65–78	18–25	Weber fraction‡	NaCl, CA (18)	Overall $P<0{\cdot}01$ for effect of age on Weber ratio	NaCl 1·4, CA 1·5 × (ratio of JND to standard)
(11)	19	21	21	60–75	19–33	Category (9 pt)	NaCl, SU, AA, Caf, MSG, KCl, Aspartame, CA, QHCl, IMP (5)	Not given (tested in water and in products)	OP tended to rate intensity of tastants lower in both water and product

DB, Downs and Black score; OP, older participants; f, female; SU, sucrose; NaCl, sodium chloride; CA, citric acid; QS, quinine sulphate; Caf, caffeine; IMP, inosine monophsophate; AA, acetic acid; MSG, monosodium glutamate; KCl, potassium chloride; QHCl, quinine hydrochloride.
*Number of OP (x,y denotes two groups of older volunteers).
†Number of YP.
‡Weber fraction calculated from just noticeable difference (JND)/point of subjective equality (PSE); by 2-AFC (alternative forced choice).
§Number in brackets correspond to number of levels that tastants tested.
‖Indicates whether a significant difference was found between YP and OP.

Effects of ageing on perception of taste intensity at supra-threshold levels

Table 1 summarises the twenty-five extracted studies which report perceived intensity of tastants by younger and older adults. A similar review was done by Mojet in 2001(54). The most common assessment method was magnitude estimation followed by the use of various category scales and also the calculation of Weber ratios through just noticeable difference discrimination tests.

When aiming to relate taste perception to food liking and choice, it is perhaps perceived intensity at supra-threshold levels that is most important if the tastant levels in foods are likely to be above detection thresholds. As noted in Table 1, a wide range of tastants have been investigated and some researchers have measured perceived intensities in products(11,39,40,43–45,56,62–64). Sixteen of the twenty-five studies noted that age had a significant negative impact on the intensity of perception, and a further two reported non-significant trends. This finding was relatively consistent for caffeine, citric acid, quinine and NaCl. Regarding sucrose, six studies found no significant effect of age on perceived intensity, which was disputed in a further three studies. Magnitude estimation studies where psychophysical functions could be calculated by plotting log perceived intensity against log concentration, tended to find that the slope was flatter for older volunteers, particularly as higher concentrations of tastants were perceived as less intense than for younger volunteers. Only three studies reported no age-related differences in intensity scoring. The extent of effect was not frequently reported in the supra-threshold studies. However, Schiffman's magnitude estimation studies found the slope of perceived intensity against tastant concentration to be steeper for young adults than for older adults by a mean factor of 2·06 for sweet compounds(15) and 1·76 for bitter compounds(18). Four studies investigating both pure solutions and products found a significant decrease in perception with age in both cases(39–41,44). In the Mojet paper, this effect was consistent over a wide range of tastants(44). However, one study found a significant effect of age for salt solution intensity which was not supported in both products(43).

Quality of data and reporting of studies

The Downs and Black scores for the reviewed articles ranged between eleven and twenty-one out of a possible twenty-seven with an average rating of 16 (SD 2). This average is low, with many studies failing to fully incorporate and describe confounding factors, and very few reporting blinding of both the participants and the organisers throughout the investigation, usually typical of clinical trials. Furthermore, the use of various sensory methods, and small participant numbers in most studies, reduces the ability to collate and compare results without over-emphasising methodological noise.

Conclusion

Overall, this systematic review generally found an age-related decrease in taste thresholds and sensitivity with

https://doi.org/10.1017/S0029665112000742 Published online by Cambridge University Press

age. However, the extent and significance of this decline varied between taste modalities, tastants and studies.

The effect of age on sensory perception, and specifically taste perception, is complex, due to the highly heterogeneous nature of the older community. The main conclusion to be drawn from the studies reviewed in this paper is that taste perception declines with age. Understanding this decline in taste ability could help the development of specifically enhanced foods for older adults to compensate for sensory losses. While deterioration in salt perception should not be compensated for by the addition of extra salt in food for elderly people who may already be at risk of hypertension, CVD or hypernatraemia, authors have suggested that increased levels of umami tastants can improve liking and consumption of foods by older adults. Although this has typically been achieved through the direct addition of monosodium glutamate[2], it can also be achieved through the use of natural ingredients rich in umami taste compounds[65].

Sensory decline is a generic process and happens to everyone, yet several factors can influence the extent of this sensory decline. Nutritional status, vitamin and micronutrient intakes can all influence sensory perception, and the extent of decline with age, with research focussing on the involvement of Zn in taste perception[66]. Dentition in older adults could also influence sensory perception, especially if portions of the palate are covered, as well as impacting on salivation[27].

Although the majority of studies reviewed reported a significant age-related decline in perceived intensity at supra-threshold levels, the extent of decline was underreported. Yet, in order to determine how this should be addressed when developing foods and beverages for the older adult market, it is the extent of decline that is important to establish. Across a range of ten tastants in five product types, Mojet found no correlations between detection threshold sensitivity and preferred tastant concentration. However, there was evidence of a negative correlation between supra-threshold perceived intensity and preferred concentration in products for salt ($P<0{\cdot}05$), caffeine ($P<0{\cdot}001$), aspartame ($P<0{\cdot}01$) and inosine monophospate ($P<0{\cdot}05$). In other words, people with reduced intensity perception preferred higher concentrations of these tastants. Knowledge of the decline of taste and olfactory perception with age has led to the use of taste and flavour enhancement of foods, aiming to improve liking and ultimately consumption by older adults. Although this approach has been successful in some studies[2], it has not in others[3]. In order for such studies to succeed it may be important to know the extent of decline in intensity perception for more complex mixtures of tastants within real food systems, as well as to account for the numerous confounding factors within individual perception.

The Downs and Black scores obtained by these studies were low, and in order to judge the abilities of older cohorts and understand effects of ageing, more robust and larger cohort studies are needed. There are potentially a large number of factors beyond age which may differ between young and older adult groups. Longitudinal studies would clarify whether variation between cohorts is due to individuals or the effect of time and larger, more robust cohort studies maybe more practical at controlling some of these variables.

Acknowledgements

The authors declare no known conflicts of interest. The authors were partly supported by Research into Ageing (Age UK) and/or by Nestec Ltd in related research projects. L. M. conducted the systematic review jointly with V. A. and wrote the manuscript. V. A. jointly conducted the systematic review, carried out the Downs and Blacks scoring of the included papers, carried out the meta-analysis and edited the manuscript. C. W. carried out the Downs and Blacks scoring of the included papers and edited the manuscript. M. G. read, reviewed and improved the manuscript for submission.

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