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Article

Age-Related Decline in Senses and Cognition – A review

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Abstract

Background: Age-related decline in the senses is well-known, with a decline in the sensitivity of all senses having been observed. Decline in the senses can be connected to different neurological disorders and cognitive function and may even be a possible predictor of death.
Aim: The aim of this narrative review was to find and explore recent literature on the covariation between age-related decline in the different senses and co-existing effects on cognitive ability and quality of life.
Results and Discussion: Six themes could be identified, these were: "Decline due to normal ageing?", "Technical aids and solutions", "Wellbeing", "Memory training", "Verbal exercises" and "Sensory training". Large differences between the different senses were obtained. However, the senses showed similar patterns in the different themes.
Conclusion: It could be concluded that there are many similarities concerning the connections between the decline in individual senses and cognition and memory. Measurements of wellbeing and quality of life are common in the evaluation of the senses, and all types of decline have an impact on activities in daily life.

Keywords: review, decline, human senses, cognition

Introduction

There is currently an on-going rapid demographic change; by 2050, the population aged 65 years and over will account for 30% of the total population in Europe (1). Age-related decline in the human senses is well-known. Decline in the sensitivity of each of the senses has been observed at different ages, with large variance between individuals. For some senses there is a vast number of publications that explore the reasons for this, and the effect it has on quality of life, whereas for other senses there is very little information. An earlier decline is commonly observed in men compared to women (2,3). Significant correlations between a decline in the senses and decrease in cognition have been observed (4,5), but to date there is no general understanding of how the decline in the individual senses interacts with cognitive decline. Additionally, a decline in the different senses influences quality of life. The aim of this narrative review was to find and explore recent literature on the covariation between age-related decline of the different senses and co-existing effects on cognitive ability and quality of life.

Background

The decline of the ***olfactory*** *sense*, i.e. the perception of odours and flavours, has been connected with age in several studies (6,7,8). Individual differences have proven to be large and the decline is often larger in men than in women (9). However, studies suggest that the heterogeneity in olfactory decline is often related to secondary events of ageing, such as increased dependency, use of medication, and dental health (10,11). Recent findings suggest that the age-related decline in olfactory sensitivity is not uniform but rather odour specific, as a mushroom-like odour and cinnamon were found to be equally identified across all ages (12). The ***gustatory*** *sense*, the taste sense, seems, however, to be affected by ageing to a smaller extent. The ability to identify the basic tastes (sweet, salt, sour, bitter and umami) is high in older people.

However, the intensity perception of the tastes was shown to become significantly reduced with age (13). This decrease in the ability to perceive taste intensity was recently shown to be connected not only to degradation of the peripheral gustatory tissues, but also to various neural signatures in the central nervous system (14).

The natural decline in ***hearing*** ability with age is called presbycusis or presbyacusis. The typical pattern is an upward shift of the hearing threshold starting in the highest frequency bands, with the shift gradually increasing with age, both in magnitude and in frequency range (the lower frequency limit of the affected region will be shifted downwards). However, several determinants are considered to influence the severity of the hearing loss, e.g. demographic and lifestyle-related factors (15). The differences in exposure to damaging noise accumulated over a lifespan is generally believed to be the most important factor, and an increased prevalence of hearing loss found in the US is believed to reflect both an ageing population as well as a heightened risk due to exposure to damaging noise (15). A low exposure to noise is rare in modern society. However, in a classic study of a relatively noise-free population in Sudan, hearing loss among older adults was only a fraction of that found in corresponding age groups in the US (16). Nowadays, the conclusion is that age-related and noise-induced hearing loss (AHL and NIHL, respectively) are closely interrelated (17). It should be noted that infrequent very short and loud noise bursts, as from e.g. gunshots, may only contribute

slightly to the total noise dose but can result in another type of hearing loss with a significant unilateral hearing shift at a specific narrow frequency band (typically around 4 kHz). The natural and most obvious change in ***visual*** function with age is presbyopia, i.e. the loss of acuity of close objects due to loss of accommodative ability. However, all spatial visual functions show a similar decline with age, e.g. disability glare (reduction in visibility caused by intense light sources in the field of view), contrast sensitivity, colour vision, stereo-acuity, recovery from glare and attentional visual fields (18).

Findings of sensory decline with age for the ***somatosensory system/haptic*** (mechanoreception, warming and cooling thermoreception and pain) are less conclusive than those for vision, audition and olfaction, due to significant individual differences (19). However, studies have shown that the receptors for mechano- and thermoreception decline with age, in connection with other age-related changes in the skin, which thereby affects sensitivity (20, 21). More obvious is that ageing is associated with a rapid increase in the risk for fall. Balance requires contributions from vision, the vestibular sense, proprioception, muscle strength and reaction time, all of which undergo a progressive loss of functioning with age, which contributes to balance deficits (22). It is hard to single out the effects of the vestibular function, but an age-related decline is documented (23). An age-related decline in proprioception has also been shown in various studies (24), for which the name presbypropria has been suggested (25).

There is considerable evidence for the age-related effects on **cognitive functioning** (for a review see Hedden and Gabrieli (26)). The decline begins already from 20-30 years of age (27), but usually becomes noticeable from the age of 60 years. There is often an assumption that the decline is limited to memory and only affects a few people, and that "training" could completely diminish this. More recent research, however, points out that it affects most people, begins earlier, and affects several different aspects. In a set of studies by Salthouse and colleagues (28), four main aspects have been tested on participants with reported good health: memory (recall task), reasoning (Raven's Progressive Matrices), speed (pattern comparison) and vocabulary (synonym finding). Vocabulary abilities tend to increase with age until a person reaches 50 years, but beyond 50 years they remain stable. The other 3 tasks all showed distinct declines from the age of 30 up to 80 years. This relation is primarily linear, suggesting that there are no distinct changes in life causing the declines. However, the slope increases around the age of 50 years. Several declines appear to be connected to a slowed speed of information processing, starting at the age of 30 years (29). The decline may often be difficult to discern in the younger ages, mainly because of increased abilities to compensate with a general increased knowledge and a reduced need to process new information. Kilian-Hütten and colleagues (30) further showed that older people have a stronger capacity to take advantage of multi-sensory congruent information than younger people.

A decline in the senses seem to be connected to different types of neurological disorders, cognitive function, and even death. For example, a decline in odour capacities is one of the earliest clinical features of both Alzheimer's disease and Parkinson's disease (31), and is also strongly related to memory loss. Olfactory perception and memory appear to be processed in similar areas of the brain (5). It has been shown that decline in cognitive status and masticatory function impact the perception

of food (32, 33). In addition, a decline in hearing is connected to dementia and cognitive decline (34, 35). It seems, therefore, that the loss of senses, e.g. odour, hearing, tactile capacities, may be a possible predictor of impending death.

Literature Search

A narrative literature review was conducted where scientific databases were searched for articles discussing decline in the senses in relation to age, health, cognition, and impact on daily life. The databases used were: Web of Science, Psychinfo, Scopus and Pubmed.
The criteria for selection of papers and the search string used is reported below.

Criteria for inclusion of papers

- The title should include at least one of the words: older, elderly or age-related
- Full text and written in English
- Peer reviewed
- Published 2010-2018
- From the included papers, select a maximum of 30 papers per sense based upon latest year of publication

Search string for identification of relevant literature:

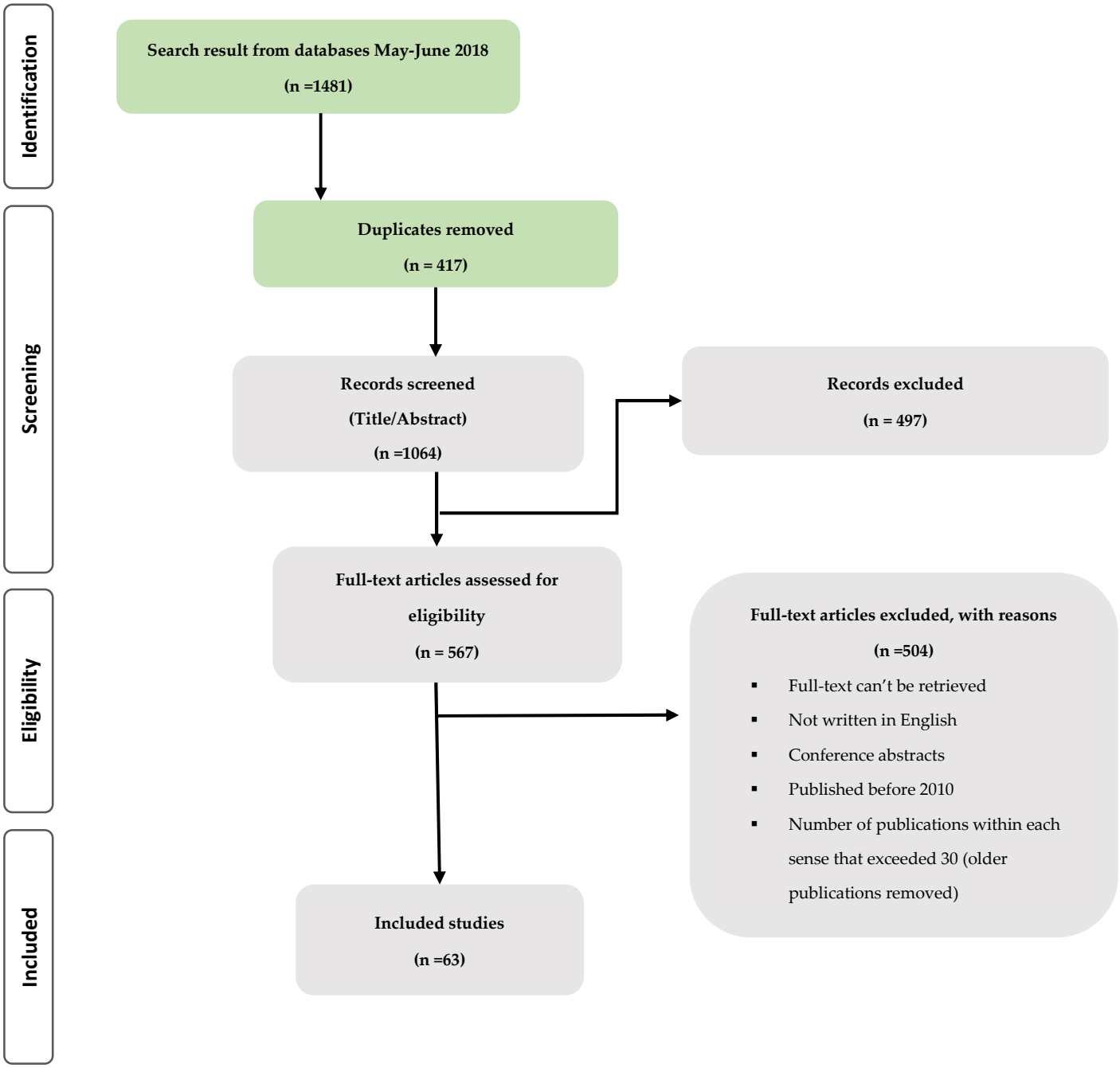
1: (people or *man) **and** (cognition decline or cognitive decline or cognitive impairment or cognitive deficit) **and** (auditory **or** hearing)
2: (people or *man) **and** (cognition decline or cognitive decline or cognitive impairment or cognitive deficit) **and** (olfaction **or** smell **or** odor **or** odour)
3: (people or *man) **and** (cognition decline or cognitive decline or cognitive impairment or cognitive deficit) **and** (vision **or** visual **or** sight)
4: (people or *man) **and** (cognition decline or cognitive decline or cognitive impairment or cognitive deficit) **and** (gustatory **or** taste)
5: (people or *man) **and** (cognition decline or cognitive decline or cognitive impairment or cognitive deficit) **and** (somatosensory **or** balance **or** touch **or** vestibular **or** tactility)
6: (people or *man) **and** (cognition decline or cognitive decline or cognitive impairment or cognitive deficit) **and** (multisensory)

The papers fulfilling the criteria were further analysed for information concerning the following:

1. Cognitive ability
2. Type of degradation
3. Impact on daily life
4. Health state

A flow-chart of the review process is given in **Figure 1.**

Figure 1


Identification
Screening
Eligibility
Included
Search result from databases May-June 2018
(n =1481)
Duplicates removed
(n = 417)
Records screened
(Title/Abstract)
(n =1064)
Records excluded
(n = 497)
Full-text articles assessed for eligibility
(n = 567)
Full-text articles excluded, with reasons
(n =504)
Full-text can't be retrieved
Not written in English
Conference abstracts
Published before 2010
Number of publications within each sense that exceeded 30 (older publications removed)
Included studies
(n =63)

Results and Discussion

From the literature search, 567 scientific publications were found. A total of 63 papers were selected for this narrative review. The selected articles and their characteristics are compiled in Tables 1 and 2. The number of published papers differed largely between the individual senses, where the auditory and visual senses were represented by high numbers of publications, while the number of publications concerning the olfactory sense was very low. The number of papers selected per sense were: 18 auditory, 5 gustatory, 11 haptic, 7 olfactory and 22 visual. No publication with a multisensory approach was found.

Table 1. Overview of selected publications, publication years, authors and titles. The papers are divided into the senses, resp. A= Audition, G=Gustation, H=Haptics, O=Olfaction, V=Vision.

Paper	Publication year	Authors	Title
A01	2017	Deal JA., et al. (36)	Hearing impairment and incident dementia and cognitive decline in older adults (…)
A02	2017	Golub JS. (37)	Brain changes associated with age-related hearing loss
A03	2017	Goossens T, et al. (38)	Masked speech perception across the adult lifespan: Impact of age and hearing impairment
A04	2017	Guerreiro MJS, et al. (39)	Disregarding hearing loss leads to overestimation of age-related cognitive decline
A05	2017	Hewitt D. (40)	Age-Related Hearing Loss and Cognitive Decline: You Haven't Heard the Half of It
A06	2018	Huo L, et al. (41)	The Default Mode Network Supports Episodic Memory (...) Contributions to Immediate Recall and Delayed Recall
A07	2018	Loughrey DG, et al. (42)	Association of age-related hearing loss with cognitive function, cognitive impairment, and dementia (...)
A08	2017	Meister H. (43)	Speech audiometry, speech perception, and cognitive functions: English version
A09	2018	Murphy CFB, et al. (44)	Auditory processing performance of the middle-aged and elderly: Auditory or cognitive decline?
A10	2017	Namioka N, et al. (45)	Geriatric problems correlated with cognitive decline using a screening test (...)

A11	2017	Nirmalasari O, et al. (46)	Age-related hearing loss in older adults with cognitive impairment
A12	2018	Rutherford BR, et al. (47)	(...) Linking age-related hearing loss to late-life depression and cognitive decline
A13	2017	Sonnet MH, et al. (48)	Cognitive Abilities and Quality of Life After Cochlear Implantation in the Elderly
A14	2017	Sutcliffe R, et al. (49)	(...) Age-related decline in musical and facial emotion recognition
A15	2018	Verrusio W, et al. (50)	The development of a new tool for the evaluation of handicap in elderly (...)
A16	2017	Völter C, et al. (51)	Application of a computer-based neurocognitive assessment battery in the elderly with and without hearing loss
A17	2018	Yuan J, et al. (52)	The risk of cognitive impairment associated with hearing function in older adults (...)
A18	2018	Zhao J, et al. (53)	Effects of creative expression therapy for older adults with MCI at risk of Alzheimer's disease
G01	2015	Arganini C, et al. (54)	Chemosensory impairment does not diminish eating pleasure and appetite in independently living older adults
G02	2018	Caballero A, et al. (55)	Taste priming and cross-modal taste-olfactory priming in normal aging and in older adults with MCI
G03	2017	Jacobson A, et al. (56)	Age-Related Changes in Gustatory, Homeostatic, Reward, and Memory Processing of Sweet Taste in the Metabolic Syndrome
G04	2014	Solemdal K, et al. (57)	Impaired Taste and Increased Mortality in Acutely Hospitalized Older People
G05	2013	Toffanello ED, et al. (58)	Taste loss in hospitalized multimorbid elderly subjects
H01	2018	Haripriya S, et al. (59)	Effect of a Multi-Component Exercise Program on Functional Mobility, Exercise Capacity and Quality of Life in Older Adults
H02	2018	Marmeleira J, et al. (60)	Exercise merging physical and cognitive stimulation improves physical fitness and cognitive functioning in older nursing home residents: (…)

H03	2018	Balsalobre-Fernandez C, et al. (61)	Movement velocity in the chair squat is associated with measures of functional capacity and cognition in elderly people at low risk of fall
H04	2018	Moreira N, et al. (62)	Multisensory exercise programme improves cognition and functionality in institutionalized older adults: (…)
H05	2018	Delle Fave A, et al. (63)	Promoting Well-Being in Old Age: The Psychological Benefits of Two Training Programs of Adapted Physical Activity.
H06	2018	Taylor ME, et al. (64)	Inaccurate judgement of reach is associated with slow reaction time, poor balance, impaired executive function and predicts prospective falls in older people with cognitive impairment.
H07	2018	Demnitz N, et al. (65)	Cognition and mobility show a global association in middle- and late-adulthood: (…)
H08	2019	Morais A, et al. (66)	Psychomotor, functional, and cognitive profiles in older people with and without dementia: (…)
H09	2017	Woo MT, et al. (67)	Falls, Cognitive Function, and Balance Profiles of Singapore Community-Dwelling Elderly Individuals: (…)
H10	2017	Lazarou L, et al. (68)	International Ballroom Dancing Against Neurodegeneration: (…)
H11	2017	Yeh HF, et al. (69)	Predictors of postoperative falls in the first and second postoperative years among older hip fracture patients
O01	2018	Birte-Antina W, et al. (70)	Olfactory training with older people
O02	2016	Fischer ME, et al. (71)	Age-Related Sensory Impairments and Risk of Cognitive Impairment
O03	2016	Wehling EI, et al. (72)	Longitudinal changes in odor identification performance and neuropsychological measures in aging individuals
O04	2016	Sivam A, et al. (73)	Olfactory dysfunction in older adults is associated with feelings of depression and loneliness
O05	2012	Gopinath B, et al. (74)	Olfactory impairment is associated with functional disability and reduced independence among older adults

O06	2011	Wehling E, et al. (75)	Unawareness of olfactory dysfunction and its association with cognitive functioning in middle aged and old adults
O07	2011	Bahar-Fuchs A, et al. (76)	Awareness of olfactory deficits in healthy aging, amnestic MCI and Alzheimer's disease
V01	2016	Bowen M, et al. (77)	The Prevalence of Visual Impairment in People with Dementia
V02	2016	Grimmer K, et al. (78)	The Australian 75+ Health Assessment: could it detect early functional decline better?
V03	2018	Aljied R, et al. (79)	Prevalence and determinants of visual impairment in Canada
V04	2017	Arnaoutoglou NA, et al. (80)	Color perception differentiates Alzheimer's Disease from Vascular Dementia patients
V05	2019	Bazzazi N, et al. (81)	Visual Impairment Was Related to Educational Level but Not to Cognitive Performance Among Adults in Their 60s
V06	2016	Creuzot-Garcher C, et al. (82)	The Montrachet Study: Study design, methodology and analysis of visual acuity and refractive errors in an elderly population
V07	2019	Dawes P, et al. (83)	Interventions for hearing and vision impairment to improve outcomes for people with dementia
V08	2016	Gopinath B, et al. (84)	Hearing and vision impairment and the 5-year incidence of falls in older adults
V09	2016	Hajek A, et al. (85)	Effect of visual impairment on physical and cognitive function in old age
V10	2016	Hong T, et al. (86)	Visual Impairment, Hearing Loss and Cognitive Function in an Older Population
V11	2016	Jaywant A, et al. (87)	Perception of Communicative and Non-Communicative Motion Defined Gestures in Parkinson's Disease
V12	2018	Kasagi M, et al. (88)	γ-Aminobutyric acid type A receptor binding affinity in the right inferior frontal gyrus at resting state predicts the performance of healthy elderly people in the visual sustained attention test
V13	2017	Liljas AEM, et al. (89)	Self-reported vision impairment and incident prefrailty and frailty in English community-dwelling older adults

v14	2018	MacDonald SWS, et al. (90)	Contrasting Olfaction, Vision, and Audition as Predictors of Cognitive Change and Impairment in Non-Demented Older Adults
V15	2018	Maharani A, et al. (91)	Visual and hearing impairments are associated with cognitive decline in older people
V16	2017	Mertes C, et al. (92)	Compliance instead of flexibility? On age-related differences in cognitive control during visual search
V17	2017	Palmiero M, et al. (93)	Verbal and visual divergent thinking in aging
V18	2017	Prince M, et al. (94)	Persistent visual perceptual disorders after stroke: Associated factors
V19	2016	Schenk S, et al. (95)	Out of sight, out of mind: Categorization learning and normal aging
V20	2016	Soler V, et al. (96)	Visual impairment screening at the geriatric frailty clinic (…)
V21	2018	Stuart S, et al. (97)	Saccade frequency response to visual cues during gait in Parkinson's disease: (…)
V22	2018	Wiegand I, et al. (98)	EEG correlates of visual short-term memory in older age vary with adult lifespan cognitive development

The contents of selected papers were summarised in terms of Ability, Type of degradation, Impact on daily life and Health state. This summary is given in **Table 2**.

Table 2. Summary of the content of the selected papers. Paper number is referring to the overview in table 1. Ability, type of degradation, impact on daily life and health state is shortly summarized for each paper. Abbreviations below the table.

Paper	Ability	Type of degradation	Impact on daily life	Health state
A01	VM, perceptual speed, and processing speed	Dementia	-	Healthy or incident dementia
A02	Cognitive abilities associated with brain changes (neuroimaging findings)	Smaller brain volumes and white matter tract dysfunction as a function of ARHL, in addition to CI and dementia	-	ARHL

A03	Speech perception performance	Temporal processing and central EFs	Missing out on conversations	No diagnosed MCI. HI (elevated auditory threshold)
A04	WM, selective attention, processing speed, inhibitory control, and abstract reasoning	Degrading of WM, selective attention, processing speed, inhibitory control, and abstract reasoning	-	Normal health from various age groups. Cognitive challenges due to HL and ARHL
A05	Cognitive effort while listening to speech in noisy places	Crossmodal auditory cortical re-organization due to ARHL (need for increased cognitive effort)	Conversational difficulties. Resulting in feelings of isolation, reduced QoL and depression	ARHL
A06	VM	EM decline (neural mechanisms of neurodegenerative diseases)	Memory, i.e. learning new material and retrieval of new and existing information	Healthy, from a cognitive perspective
A07	Cognitive function in 10 subdomains including memory and various EFs	Cognitive function, CI, and dementia	-	Cohort studies / incidence of ARHL
A08	WM, attention	Cognitive function, speech perception, HI		HI
A09	WM test + Speech-in-noise, dichotic digit, and frequency pattern tests	WM performance	-	Healthy, normal hearing to moderate ARHL
A10	CGA	Poor medication adherence. Auditory visual, urinary and extremity function disorder	ADL decline (strong correlation)	Inpatients
A11	MMSE	CI, dementia		Patients on tertiary memory clinics

A12	Activation in central auditory pathways	Cognitive decline, depression	Social isolation, loneliness, depression	Depression and Cognitive Decline
A13	MMSE	Speech intelligibility, sensory abilities, EFs	Autonomy, WHO QoL, ADL	Various deafness states
A14	Emotion detection (music & faces)	Difficulties detecting emotions (music & faces)	Emotion regulation	Healthy/general cognitive decline
A15	MMSE (CGA/GHS)	CGA/GHS	ADL; Instrumental ADL; Barthel index; Global Evaluation Functional Index	Various states
A16	Eight aspects of cognitive ability, such as memory and other EFs	Delayed recall and VF, WM	"Generalized benefits"	Healthy or HL
A17	Various	Cognitive function (tests of memory, attention, EF, perception, and semantic knowledge)	Various	Cohort studies / incidence of ARHL
A18	Several, e.g. Montreal Cognitive Assessment, ADL scale and Auditory Verbal Learning Test (Chinese versions), etc	Dementia	ADL	MCI
G01	Eating pleasure and appetite	Chemosensory impairment	No decreased appetite or eating pleasure	Healthy
G02	Identification (naming) of foods after priming	Chemosensory impairment	Avoidance of harmful food and the rewarding effects of eating appetizing meals with aging	MCI
G03	Activation in the hypothalamus due to taste and reward (satiety)	Taste and hormonal decrease	Impact on hunger / caloric intake	Metabolic syndrome

G04	Taste ability	Taste recognition threshold. Connection between taste ability and morbidity	Low ability of taste increases mortality	Poor nutritional status/acutely hospitalized older people
G05	Taste ability	Taste degradation	Inadequate dietary intake	Severe comorbidity, severe CI and dysphagia.
H01	Balance training	Ageing	Health-related QoL significantly improved with exercise. So did mobility and functional capacity	Healthy
H02	Cognitive functioning (VAT, EF, IPS) + PF (strength, CRF, flexibility and balance) - significant increase after an 8-week program	Ageing	-	Institutionalized older people
H03	Muscular performance and effect on QoL, balance and functional capacity. Significant improvements	Muscular decline	Increased well-being	Healthy
H04	Cognition and balance - significant improvement, high effect size	Multisensory/Ageing		Institutionalized older people
H05	Handgrip and mental health	Ageing	ERQ/SLS - increased with physical activity	Healthy
H06	Increased RJE - correlated to global cognition and EF	RJE	-	CI

H07	Memory, EF and processing speed. All related to indices of mobility - moderated by age (mobility-cognition relationship increase by age)	Mobility (gait, balance and chair stands)		Healthy
H08	MMSE (people with dementia have higher percentage of cognitive deficit)	Psychomotor skills (people with dementia have poorer psychomotor performance)		Dementia vs healthy
H09	Adapted MMSE	Berg Balance Scale (MCI - more likely to fall)		MCI vs healthy
H10	Dance (intervention group showed better cognitive performance in comparison to control group)			Amnestic MCI
H11	CMMSE score. No significant differences between number of falls (0-multiple) and MMSE. After surgery there was a significant effect, where the risk decreased with 7-8% with an increase in MMSE of 1 point.	Quadriceps muscle maximum strength was assessed using the force of quadriceps contraction and was measured isometrically with the hip in a neutral position and the knee fully extended.		Post-operative patients before and after leaving hospital
O01	Verbal cognition	Olfactory	Improved subjective well-being and decrease of depressive symptoms	Healthy
O02	Cognition	Hearing, Visual, Olfactory	-	Healthy

O03	Verbal EM, mental processing speed, EF language	Odor identification	-	Healthy
O04	19 cognitive tests:	Odor identification (brief smell identification test)	More loneliness associated with worse olfaction	
O05	ADL	San Diego Odor Identification Test	Decreased independence with worse olfaction	Healthy
O06	Verbal learning, memory, attention/ processing speed	olfactory awareness	-	Healthy
O07	Olfactory ability awareness	Olfactory identification		Amnestic MCI (aMCI) + Alzheimer's disease
V01	Cognitive status with Standardised MMSE and FA and behaviour were assessed using the Bristol ADL Scale and CBI.	VI	The prevalence of VI is higher in people with dementia and has an impact on QoL	Dementia
V02	Indicators of early functional decline	Functional decline	New factors for detecting early functional decline	Healthy
V03	VA measured using the Early Treatment Diabetic Retinopathy Study. VI was defined as presenting binocular acuity worse than 20/40	Memory problems associated with VI	Memory problems	Healthy/None
V04	Neuropsychological testing	Visual perception	Deficits in attention and EF. Alzheimer's Disease patients suffer from a nonspecific type of colour blindness	Dementia, Alzheimer's Disease, Vascular Dementia
V05	Auditory IPS and flexibility	Cognitive performance	VI was unrelated to cognitive	Healthy/None

			performance, but was related to level of education	
V06	VA, refraction, visual field, ocular surface, photographs and optical coherence tomography (OCT) of the macula and the optic disc, measurement of IOP, CCT and macular pigment assessment.	Neurological diseases	Eye disease and its associations with cardiovascular and neurological diseases and their potential risk factors	Healthy/None
V07	Cognitive decline and QoL	HI and vision impairment	QoL	Dementia
V08	VA less than 20/40 (better eye), and HI as average pure-tone air conduction threshold >25 dB HL (500–4,000 Hz, better ear). CI was determined using the MMSE	DSI and incidence of falls. Hearing handicap and risk of falls	Impaired vision or hearing increased risk of incident falls	Healthy/None
V09	Physical and cognitive function were assessed using an adapted scale	How VI affects physical and cognitive function	VI affects physical and cognitive function	Healthy/None
V10	Vision, hearing and vision/hearing	The MMSE (MMS) was used to screen for possible CI	Neither VI, HL nor DSI was independently associated with subsequent decline in cognition.	Healthy/None
V11	Understanding communicative gestures	The Gesture Discrimination Task assessed whether patients could identify communicative and non-communicative	Men with PD may have particular difficulty in understanding the communicative gestures of others in interpersonal exchanges	PD

		gestures in a forced-choice format		
V12	WM. Rapid visual information/attention loss	Rapid visual information processing/attention loss	A decreased receptor binding affinity can be a sensitive marker of CI, age-related cortical neuronal damage or loss in the right inferior frontal gyrus might lead to the decline in attentional function	Healthy/None
V13	Vision impairment	Frailty and prefrailty	Non-frail older adults who experience poor vision have increased risks of becoming prefrail and frail	Healthy/None
V14	EM/cognition	Perceptual processing speed, inductive reasoning, VF, vocabulary and EM perceptual processing speed, inductive reasoning, VF, vocabulary and EM	Olfaction and, to a lesser extent, vision were identified as the most robust predictors of cognitive status and decline; audition showed little predictive influence	Healthy/MCI
V15	EM/Cognition	Vision and/or hearing and cognitive decline including dementia	Hearing and/or vision impairments are a marker for the risk of cognitive decline including dementia	Healthy/None
V16	WM /Cognitive abilities	Attentional capture of colour and/or shape	Age-related lack of reactive inhibition leads to stickiness in visual processing whenever	Healthy/None

			information is contingent on the attentional set, unveiling older adults' "Achilles' heel" in cognitive control	
V17	Cognition	Verbal and visual divergent thinking	Divergent thinking does not decline steadily in the elderly	Healthy/None
V18	Memory, verbal comprehension, stroke severity and sex	Motor-free Visual Perceptual Test - Vertical version	Among many variables, four (memory, verbal comprehension, stroke severity and sex) were most strongly associated with persistent visual perceptual disorders	Stroke
V19	Cognition	Categorization mediated by VAT and perceptual strategies	Categorization learning is affected by normal aging and modulated by perceptual processing and VAT	Healthy/None
V20	Autonomy and cognition	MMS (MMSE) for cognition testing, and the Short Physical Performance Battery (SPPB) for physical performance.	High prevalence of visual disorders were associated with lower autonomy and CI	Abnormal vision in patients screened for frailty
V21	Saccade frequency and gait response	Measurement of attention and vision	Attention rather than visual function was central to saccade frequency and gait response to visual cues in PD	PD
V22	Visual short-term memory	Visual short-term memory	Complex age-related changes in	Healthy/None

		performance with EEG. Higher vSTM capacity (K; measured by Bundesen's theory of VAT)	processes underlying behavioural and EEG measures of vSTM and suggest that the K-CDA relationship might be a marker of cognitive lifespan trajectories	

ADL - Activities of Daily Living; ARHL – Age-Related Hearing Loss; CBI - Cambridge Behavioural Inventory; CCT - Central Corneal Thickness; CDA - Contralateral Delay Activity; CGA - Comprehensive Geriatric Assessment; CI - Cognitive Impairment; CMMSE score - The CMMSE contains 11 items measuring orientation, memory, common sense, ability to use language, construction ability, as well as content of thought, form and process. The score ranges from 0–30, with a higher score representing stronger cognitive function; CRF - Cardiorespiratory Fitness/Endurance; DSI - Dual Sensory Impairment; EEG – Electroencephalography; EF - Executive Function; EM - Episodic Memory; ERQ - Emotion Regulation Questionnaire; FA - Functional Ability; GHS - Geriatric Handicap Scale ; HI - Hearing Impairment; HL - Hearing Loss; IOP - Intraocular Pressure; IPS - Information Processing speed; MCI - Mild Cognitive Impairment; MMSE - Mini-Mental State Examination; PD – Parkinson's Disease; PF - Physical Fitness; QoL - Quality of Life; RJE - Reach Judgement Error; SLS - Satisfaction with Life Scale; VA - Visual Acuity; VAT - Visual Attention; VF - Verbal Fluency; VI - Visual Impairment; VM - Verbal Memory; WM - Working Memory; vSTM - Visual Short-term Memory.

When examining the selected papers, a pattern with the six following themes was identified:

1. Decline due to normal ageing?
2. Technical aids and solutions
3. Wellbeing
4. Memory training
5. Verbal exercises
6. Sensory training

The themes identified in the selected papers were evident in some studies, as exemplified below, and less apparent in others, as described and discussed below. The results reveal large differences between the different senses although there are similar patterns in the identified themes.

Theme 1. Normal Ageing or not (decline due to normal ageing?)

All senses decline with normal ageing (A04,07; V05,10,19) and may be connected to healthy ageing (G01,02; H01,03,05,07). It can, therefore, be hard to assess potential cause-effect relationships between sensory and cognitive decline (A04, A09). However, severe losses are often linked to dementia. Olfaction, and to a lesser extent vision, seem to be robust predictors of dementia (O07; V01,04,07,14,15,20,22). However, age-related hearing loss (ARHL) also has a small but significant association with dementia (A01, A07; V07) and milder cognitive impairments (A03,05,06,08,11,12,13,14,17; H06,09,10). Cohort studies indicate that ARHL precedes the onset of clinical dementia by 5 to 10 years (A07). It has also been shown that brain changes can be associated with ARHL, including both cognitive ability and neuroimaging findings; however, what is not shown is whether the association is causal (A02). Even though there is an association between cognitive impairments and ARHL, the driving factor seems to vary depending on context and may be hard to distinguish (A03, A08, A09, A11). Consequently, age-related cognitive decline may be overestimated if hearing impairment is disregarded (A04, A08).

Visual impairment may, parallel with a decline in cognitive function, also have an impact on physical function (V02,04,09,14,15,20) and older adults have an increased risk of becoming prefrail and frail (V13). It has been shown that neither visual impairment or hearing loss, nor dual sensory impairment, were independently associated with subsequent decline in cognition (V10). However, auditory and/or visual impairments have been shown to be markers for the risk of cognitive decline, including dementia (V15).

Theme 2. Technical aids and solutions

Technical aids of different kinds, e.g. glasses, hearing aids and cochlear implants, have positive effects on cognitive function and wellbeing (A03, A08,11,13; V01). One particular problem is the perception of speech in a noisy environment, which induces high cognitive load on the working memory (A03, A08). In such cases, the hearing aid signal processing plays an important role since, for example, artefacts are unfavourable for users with lower working memory capacity (WMC) (A08). Cochlear implants may improve the autonomy, executive functions, and quality of life of older people with severe hearing loss (A13). However, hearing aids are used to a low extent even though there is a high prevalence of hearing loss among older adults with cognitive impairments (A11). There are, however, no comparable aids to increase the perceptions of olfaction, gustation or haptic information.

Theme 3. Wellbeing

Gustation and olfaction are, together with haptic perception, highly related to wellbeing. It has been shown that an inability to perceive tastes and flavours will lead to a reduced food intake (G03,04,05) and thereby increase the risk of malnutrition (99). Concerning haptic perception, both mobility and balance are directly connected to wellbeing (H01,02,03,04). Healthy hearing is, for

example, essential for the ability to engage in conversations, which has a great impact on wellbeing (A03). Auditory abilities are important for social wellbeing and there is a risk that hearing impairment may lead to social isolation and depression (A12,A15). Impaired visual and auditory perception give an increased risk of incident falls (V08).

Theme 4. Memory training

The senses are well connected to memories. The senses may create subconscious triggers that characterise perceptions of a product or a related event (100). Training the senses has been shown to increase memory capacity (101). Recognition of tastes and flavours can recall memories (G04,05). Verbal memory can be connected to auditory function and may be used for the diagnosis of dementia (A01). There are also strong associations between age-related auditory decline and working memory (A04,08,09) and episodic memory (A05,06). Memory problems may also be associated with visual impairments (V03,12,16,18). Shortly, memory training of the senses can be divided into three different categories: 1) sensation training, e.g. olfactory training or moderated/mediated training by either 2) physical training or 3) verbal/cognitive training.

Theme 5. Verbal exercises

Sensory perception may change as a result of verbal input and training, especially auditory and olfactory perception (A13, A18; O03). Categorisation learning is affected by visual attention (V19) and it has been shown that visual impairment is correlated to level of education (V05).

Theme 6. Sensory training

Training of the senses occurs and has an impact on health status. This concerns mainly haptic functions where different types of training have been used, for example dance, balance etc. (H01,02,04,05,10). Olfactory identification training has also shown positive effects (5). It has recently been shown that the olfactory system is highly responsive to training, and there is speculation that the sense of smell may facilitate the transfer of learning to other sensory domains (101).

Search and inclusion criteria effects

This review was delimited by the criteria mentioned above. Only well-established databases were used, which may be regarded as a quality factor, but also means that some interesting papers may have been excluded.

The words in the search strings did not include the word “geriatric”, which may imply that some papers of a medical nature might have been excluded.

There was a large inequity in the number of papers found for each sense. The first search gave the following numbers of papers: Gustation: 11; Vision: 233; Audition: 108; Olfaction: 8 and Haptic function: 209. This means that the time period for the included papers may vary to some extent.

Conclusion

A large number of methods have been used in the investigation of the human senses, and in their capacity and age-related decline. This makes comparison on a detailed level difficult. However, from a larger perspective, many similarities concerning the senses and their connections between cognition, memory and decline can be found. Measurements of wellbeing and quality of life are the most common aspects in the evaluation of the different senses, and all types of decline have an impact on activities in daily life.

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Conflict of Interest

All authors have contributed equally to the manuscript. The Authors declare no conflict of interest.

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