Self-report Measures of Hearing and Vision in Older Adults Participating in the Canadian Longitudinal Study of Aging are Explained by Behavioral Sensory Measures, Demographic and Social Factors

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Author contributions:

A.H. designed and performed the data analyses and wrote the paper. M.K.P.-F., W.W., N.P. and P.M. conceived of the study. P.M. obtained data from the CLSA. All authors discussed the study design, results and implications, contributed to writing the manuscript, and approved the final version of the manuscript.

Abstract

Objectives. Our objectives were to 1) determine the prevalence of self-reported hearing, vision and dual sensory (both vision and hearing) difficulties in older Canadian adults; 2) examine the association between self-report and behavioral sensory measures; and 3) controlling for behavioral sensory measures, examine variables that might explain self-reported sensory difficulty, including age, sex, cultural background, socio-economic status, non-sensory comorbidities, cognitive function, and social factors.

Design. We used baseline data collected from the 30,097 participants of the comprehensive cohort of the Canadian Longitudinal Study on Aging (CLSA). Participants who were 45 to 85 years of age (mean age = 63 years) were recruited using provincial health registries and random-digit dialing. Analyses were conducted for the sample as a whole or stratified by age. Behavioral sensory data for hearing (pure-tone audiometry) and vision (pinhole-corrected visual acuity) were collected at 11 data collection sites. Self-reported sensory and personal data were obtained through in-person interviews. “Difficulty” was defined as a response of “fair” or “poor” (versus “excellent,” “very good” or “good”) to questions about a.) hearing ability (using a hearing aid if used) and b.) vision (using glasses or corrective lenses if used). Individuals with both hearing and vision difficulties were defined as having dual sensory difficulties. Variables associated with self-reported sensory difficulties were analyzed with multiple regression models.

Results. *Objective 1.* The prevalence of impairments based on behavioral measures was higher than the prevalence of difficulties based on self-report measures. The prevalence based on both types of measures increased with age, but the increase was steeper for behavioral

measures. *Objective 2.* In addition to the expected positive associations between self-report and behavioral measures of hearing (OR = 2.291) and vision (OR = 16.139), self-reported sensory difficulty was also explained by other within-modality sensory variables, such as the symmetry of impairment and the use of aids. *Objective 3.* Controlling for behavioral measures of hearing (better-ear pure-tone average) or vision (better-eye visual acuity), older participants were significantly less likely than younger participants to self-report sensory difficulty. Sensory difficulties were reported more often by males, and those with more comorbid health conditions. Compared to those who did not report vision difficulties, those who did report them were more likely to also report hearing difficulties (OR = 2.723) and vice versa (OR = 2.922). There were modality-specific associations with social variables; for example, independent life space was associated with hearing difficulties, and perceived availability of social support and loneliness with vision difficulties.

Conclusions. The low prevalence of self-reported sensory difficulties relative to the behavioral measures of sensory impairments indicates that 1) a simple screening question about sensory ability may not be sufficient to identify older adults who are in the early stages of sensory decline, and 2) self-reported sensory ability is associated with sensory and non-sensory factors. Age, gender, and comorbidities are the most notable non-sensory predictors for both hearing and vision. These findings shed light on how the self-reported sensory difficulties of older adults may reflect clinical measures of sensory impairment as well as non-sensory factors.

Introduction

Self-report measures of vision or hearing are often used in large-scale population surveys of health and disability (e.g., Viljanen et al. 2014; Fuller et al. 2018; Han et al. 2018).

Questionnaires are less costly and easier to administer compared to behavioral tests. Some population studies of aging, such as the Australian Longitudinal Study of Aging (Luszcz et al. 2016) and the Health-ABC Study in the United States (<https://healthabc.nia.nih.gov/datasets-documentation>), have included both self-report measures and behavioral measures of visual acuity and audiometric thresholds. Other studies of aging, such as The Amsterdam Longitudinal Study of Aging (Hoodendijk et al. 2016) and the UK Biobank Study (Sudlow et al. 2015), have included both self-report and behavioral measures for both vision and hearing, but used automated tests to measure speech-in-noise thresholds instead of testing audiometric thresholds. For over three decades, many studies have compared self-report and clinical tests of sensory impairment, but large-scale population studies of aging offer new opportunities to compare self-report to behavioral measures of hearing, vision and dual sensory impairment in the context of a wide range of non-sensory variables that change during adult aging.

Association of Behavioral Measures of Impairment and Self-reported Sensory Difficulties

In general, self-report measures are only weakly associated with measures of visual acuity (Steinberg et al. 1994; Carta et al. 1998; Laitinen et al. 2007) and audiometric thresholds (e.g., Corbin et al. 1984; Brainerd & Frankel 1985; Klein et al. 2001; Choi et al. 2016; Kamil et al. 2016). A key finding of several studies is that the proportion of older adults who self-report hearing difficulties is less than the proportion with clinically significant hearing impairment defined in terms of audiometric thresholds, although the reverse pattern has been found for

middle-aged adults (e.g., Sindhusake et al. 2001; Kiely et al. 2012; Choi et al. 2016; Kamil et al. 2016). Notably, the disparity between estimates of hearing loss based on self-report measures compared to estimates based on audiometric thresholds increases with age in those over 60 years of age (Bainbridge & Wallhagen 2014). There is a similar disparity between self-report measures for vision and visual acuity measures in older adults (Laitinen et al. 2005; Carta et al. 1998) and the disparity may be even larger for vision than for hearing (Kempen et al. 1996).

Non-sensory Factors Explaining Self-reported Sensory Difficulties

Self-reported sensory difficulties are explained partially by clinically measurable sensory impairment, but other factors are important and become increasingly so with age. Consistent with the International Classification of Functioning, Disability and Health (ICF) of the World Health Organization (WHO 2001), self-reported sensory difficulties based on individuals' awareness of the effects of sensory impairment on activities and participation could vary depending on a number of personal and environmental factors that may change with age to either facilitate or compromise activity and participation (e.g., Sharma, 2016; Humes et al. 2019). It is well-known that the disparity between self-report measures of hearing and audiometric thresholds depends on age (e.g., Nondahl et al. 1998), but also on other factors, including social (e.g., Chang et al. 2009), health (Wiley et al. 2000), personality (e.g., Jang et al. 2002) and cognitive factors (e.g., Gatehouse 1990). A similar range of variables explain disparities between self-report measures and speech-in-noise thresholds (e.g., Pronk et al. 2018). Furthermore, psychological wellbeing has been associated with measures of activity and participation rather than behavioral measures of hearing impairment (e.g., Helvik et al. 2006).

Associations between self-reported sensory measures and participation are expected because 1) receiving and processing sensory information is essential to many social interactions; 2) sensory limitations can limit independence and opportunities for many types of social participation (Laitinen et al. 2007; Viljanen et al. 2014; Polku et al. 2015); and 3) social situations may offer opportunities for more accurate self-assessment of everyday problems resulting from sensory declines.

Age-related Changes in Self-reported Sensory Difficulties

Older adults may not perceive age-related declines in hearing or vision because these impairments progress slowly without abrupt changes in everyday functioning. Difficulties in many situations may go unnoticed if individuals can compensate for declines in one sense by relying more heavily on the other sense or by using situational knowledge (Brennan et al. 2005; Saunders & Echt 2007). Those with sufficient cognitive capacity may compensate by allocating more cognitive resources to meet the additional demands of functioning in everyday life with age-related sensory declines (e.g., Li & Lindenberger 2002; Heyl & Wahl 2012; Wettstein et al. 2018). Factors such as changes in health (e.g., onset of comorbid health conditions) or lifestyle (e.g., retirement) may also alter everyday demands and obscure the consequences of sensory impairments on activity and participation. Awareness and appraisal of age-related sensory problems may also depend on social psychological factors such as whether an individual holds negative views of aging (Chasteen et al. 2015). In general, as health declines, older adults may shift their internal standards for evaluating quality of life (Sprangers & Schwartz, 1999). They may base self-evaluations of health on social comparisons to peers with greater disabilities (e.g., Heidrich & Ryff 1993). Consistent with the 'disability paradox', older adults who cope well

with severe disabilities may even consider themselves to have a high health-related quality of life (Albrecht & Devlieger 1999). Notably, findings for sensory health are similar to those for other health domains, with relatively slow change in self-reported sensory measures despite increases in impairment (Wettstein et al, 2016).

Need to Examine Contributions of Sensory and Non-sensory Variables

The contributions of potentially relevant psychological, social and health factors have been investigated, but most studies have examined only a few such variables. One of the most comprehensive analyses of self-report and audiometric measures of hearing indicated that audiometric thresholds were associated more with socioeconomic and health risk factors, whereas self-reported hearing difficulty was primarily associated with perceived limitations in work, social, and leisure activities (Choi et al. 2016). Self-reported vision difficulties increase with lower socioeconomic, poorer cognitive and general functioning, and with psychological health factors such as depression (e.g., Kempen et al. 1996; Globe et al. 2004; Tabrett & Latham 2011). In studies in which several variables have been considered simultaneously, the relative importance of their additive effects is difficult to judge because the results are frequently based on stratified, univariate analyses and/or relatively small sample sizes.

Comparing Hearing, Vision and Dual Sensory Loss

Self-report and behavioral measures of both hearing and vision have rarely been analyzed in the same study. To our knowledge, three publications have reported associations between behavioral and self-report measures for both senses (Holland & Rabbitt 1992; Kempen et al. 1996; Hickson et al. 1999;) and only one small-scale study included self-report and behavioral measures for dual sensory loss (Hickson et al. 1999). Considering both vision and

hearing is important because the number of older adults with dual sensory loss is increasing due to population aging and the increasing prevalence of dual sensory loss with age and because dual sensory loss tends to have more severe consequences on functioning than losses in a single sense (Brennan et al. 2005; Fuller et al. 2018). Given the general paucity of studies examining both senses and dual sensory loss in the aging population, little is known about whether the same or different factors are associated with self-reported abilities across sensory modalities. In particular, little is known about how sensory loss in one modality might influence the self-reported problems in the other modality (e.g., effect of behavioral or self-reported vision difficulties on self-reported hearing ability; Tremblay et al. 2015) or vice versa. Such associations might be expected given that one sensory modality could be used to help to compensate for impairment in another modality. Another possibility is that there are individual differences in tendency to self-report better or worse performance across multiple domains.

When the same explanatory variables have been considered in analyses of behavioral and self-report measures of vision and hearing, the influence of those variables on self-reported sensory loss was found to differ between the sensory modalities. Specifically, Kempen and colleagues (1996) found that self-reported and performance-based vision measures were less correlated than those based on hearing measures. The vision measures were more closely correlated in participants with better education and cognition, while the discrepancy between self-reported versus behaviorally measured hearing loss was greater for participants expressing depressive symptoms. Personality also affected discrepancies between behavioral and self-report measures. Specifically, extroversion affected discrepancies between vision measures,

whereas all measured personality variables (extroversion, neuroticism, and mastery or personal control) affected discrepancies between hearing measures.

The Present Study

The purpose of the present study was to examine what factors, in addition to impairment as measured in behavioral threshold or acuity tests, may explain self-reported hearing and/or vision difficulties. Importantly, those with unacknowledged hearing loss, who do not self-report hearing loss despite being categorized as having hearing loss based on audiometry, can be at increased risk of cognitive decline and social isolation (van Boxtel et al. 2000; Mick & Pichora-Fuller 2016). A better understanding of the variables that influence self-report measures could inform the design of new approaches to sensory screening (e.g., by targeting individuals most at risk of sensory loss who may not self-report problems), as well as informing policies to promote healthy aging and the collection and interpretation of data for population-level research on aging.

We used baseline data collected from the comprehensive cohort of the Canadian Longitudinal Study on Aging (CLSA) to 1) determine the prevalence of self-reported hearing, vision and dual sensory difficulties; 2) examine the association between self-report and behavioral sensory measures; and 3) controlling for the behavioral sensory measures, examine variables that might explain self-reported sensory loss, including age, sex, cultural background, socio-economic status, and social factors including measures of perceived social support, social participation and network size, and the size of independent life space on the likelihood of self-reporting hearing and/or vision problems.

Materials and Methods

The Canadian Longitudinal Study of Aging

The CLSA is a large-scale prospective population-based cohort study of Canadians aged 45-85 years at baseline (Raina et al. 2009; Griffith et al. 2018). The study consists of a tracking cohort (phone interviews for 21,241 participants at baseline) and a comprehensive cohort (interviews and testing at dedicated data collection sites and home visits for 30,097 participants at baseline). The present study uses the baseline data collected from the comprehensive cohort (data release version 3.2), for whom behavioral data as well as self-report measures of hearing and vision are available. For details on the study design, protocols, and background see Raina et al. (2009, 2018, <https://www.clsa-elcv.ca/>).

Comprehensive cohort participants were recruited from the vicinity (up to 50 km) of 11 Data Collection Sites (DCS) located across Canada using provincial health registries of all citizens and random-digit dialing. The initial, age-stratified sampling frame was approximately $n=160,000$ (about .01% of the roughly 16 million Canadians in the age range 45-85 years). Of these people, 89% had a valid address in the databases and were approached with an invitation to participate in the study (*Canadian Longitudinal Study on Aging (CLSA) Protocol*, <https://clsa-elcv.ca/doc/511>). Sampling was balanced to gain a representative sample of age groups, sexes, and provinces such that the sample was nationally representative (Griffith et al. 2018). Of pre-recruits approached by the CLSA (those who agreed for the recruitment package to be sent to them) approximately 50% became participants and the final overall response rate was 10% (Raina et al. 2018). Initial exclusion criteria at baseline included living in institutions or on a First Nations reserve, serving full-time with the Canadian Armed Forces, an inability to verbally respond in English or French, and known or suspected cognitive impairment (i.e., individuals

whom CLSA interviewers judged to be unable to understand the purpose of the study and/or provide reliable data). Participants visited a DCS, where they underwent vision and hearing testing as well as other clinical tests and biological sampling. Cognitive testing and interviews were conducted at DCSs and during home visits. The first wave of data collection started in 2012 and was completed in 2015, and these data were released to researchers in 2017. Longitudinal data will be collected at 3-year intervals over 20 years.

Selection of Variables

The variables used in this study were selected from over 4,000 CLSA variables and are defined in Tables 1 and 2. Additional details on the measures are presented below and in SDC1 in the Supplementary Digit Content. All data collection protocols, including information about all measures, are available from <https://www.clsa-elcv.ca/researchers>. The present project received ethics approval by the Research Ethics Boards of the University of British Columbia (#H15-00430) and the University of Montreal (#17-063-CERES-D).

Self-report measures. Self-reported vision and hearing were assessed with one question each, asking participants to evaluate their vision or hearing, using glasses/corrective lenses or a hearing device if applicable, on a five-level scale from poor to excellent. Responses “fair” and “poor” were considered to indicate self-reported vision difficulty (VD) or hearing difficulty (HD) (following Viljanen et al. 2014; Mick et al. 2018; Whillans & Nazroo 2016). Self-reported dual sensory difficulty (DSD) was defined as fair or poor self-reported hearing and vision (i.e., both VD and HD).

Audiometric thresholds. Hearing thresholds were measured in a quiet office at each of the 11 DCSs using an audiometer (Tremetrics RA 300+ Digital Screening Audiometer with Audio-

cup headphones, Eden Prairie, Minnesota, USA). Unaided pure-tone hearing thresholds were measured in each ear at 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz. If a participant did not respond when a tone was presented at the maximum test level of 100 dB HL, we arbitrarily coded a value 105 dB HL for that frequency. The number of participants with assignments of 105 dB HL ranged from N=0 (for 500 and 1000 Hz in both ears) to N=535 (8000 Hz in the right ear). We decided to use the pure-tone average threshold for the mid-range frequencies (1000, 2000, 3000 and 4000 Hz) in the better ear (BPTA) because we had determined that this audiometric summary measure was the most consistently associated with self-reported hearing across age groups in the CLSA, especially for the older age groups (Mick et al. 2019a). Six participants were estimated to have an unaided BPTA ≥ 100 dB HL.

Visual acuity. Visual acuity was assessed at the DCSs using a standard retro-illuminated Early Treatment Diabetic Retinopathy Study chart (ETDRS; Ferris III et al. 1982; see also Aljied et al. 2018) with binocular habitual correction (i.e., the participant wore their own glasses or contact lenses during testing), and then using a pinhole occluder. Habitual correction is often utilized to estimate daily visual experience, whereas pinhole acuity is used to estimate optically optimal acuity. Accordingly, we used the pinhole-corrected visual acuity in the better eye as the primary behavioral measure of visual acuity. The degree of uncorrected refractive error was calculated as the difference between habitual and pinhole-corrected visual acuity measures. In the standard pinhole-correction test the participant looks at an ETDRS chart through a pinhole occluder, one eye at a time, to measure visual acuity in the absence of refractive error (i.e. best-corrected vision). ETDRS fractions were transformed into a logMAR score (0.0 logMAR = 20/20 ft [6/6 m] = normal vision; 1.0 logMAR = 20/200 ft [6/60 m] = legally blind) and results

are reported in logMAR units. Participants who could not see the complete first line of the ETDRS chart at 2 m distance were here arbitrarily assigned a logMAR value of 1.1. There were 19 participants who were unable to see the top line with their better eye on the pinhole-corrected vision test (i.e., they are considered to be legally blind).

Criteria to Determine Prevalence. To quantify the prevalence of sensory impairments using behavioral measures, we created dichotomous variables for hearing, vision, and dual sensory impairment and calculated the proportion of participants defined by selected cut-offs. The criteria selected to dichotomize these variables were based on our evaluation of the correspondence between behavioral and self-report measures in the CLSA and common cut-offs used in clinical and epidemiological studies. However, there is no standard for using vision and hearing thresholds to define single sensory loss or dual sensory loss (Mick et al. 2019b).

We categorized participants with a BPTA > 25 dB HL as having a hearing impairment (HI). This cut-off was chosen based on criteria commonly used in previous research (e.g., Lin et al. 2011) and the current World Health Organization (WHO) *Grades of Hearing Impairment* (2019b), although the WHO is considering a proposal of the Global Burden of Disease group to revise this cut-off (Humes 2019). Participants with visual acuity > 0.2 logMAR (< 20/32 or 6/10) were categorized as having vision impairment (VI) that was at least mild (Colenbrander 2003). Rather than using 0.3 logMAR as been used in many studies, by using the 0.2 logMAR cut-off it was possible for a larger number of CLSA participants being categorized in the VI group (Mick et al., 2019a). Furthermore, the 0.2 logMAR cut-off has functional relevance because it may provide only moderate fluency in reading newsprint at 33 cm (Leat et al. 1999) as might be experienced by those in the earliest stages of presbyopia. To enable comparison to other

studies (e.g., Wahl et al. 2013), we also present the prevalence rates for hearing and vision impairment based on WHO cut-offs for moderate or worse HI or VI. These criteria were > 40 dB HL for moderate HI (WHO 2019b) and > 0.48 logMAR (< 20/60 or 6/18) for moderate VI (WHO, 2019a). The criteria used to define dual sensory impairment (DSI) have ranged widely and there is even less agreement about which cut-offs to use (Dawes et al. 2014). Any participant with at least mild HI and mild VI was considered to have DSI.

Predictors of Self-reported Sensory Difficulty

In addition to behaviorally measured HI and VI, we examined how well a number of variables predicted self-reported sensory difficulties. These variables are listed in Tables 1 and 2. As detailed in Table 1, sensory variables pertained to both hearing and vision (sensory asymmetry, use of assistive devices), hearing only (self-reported trouble hearing in noise), or vision only (better-eye refractive error, vision disease diagnosis, wearing visual correction during testing, recent access to vision care). Non-sensory covariates (Table 2) included demographic (age, sex, cultural background) and socioeconomic (education, household income) factors, number of health comorbidities (see SDC1 in the Supplemental Digital Content), cognitive measures (executive function and memory), and social measures associated with opportunities for interaction, social isolation and participation.

Cognitive measures. Cognitive measures were obtained with a series of behavioral cognitive tests chosen for their sensitivity to early-onset cognitive decline (Tuokko et al. 2017). Executive function was assessed with four tests: Mental Alternation Test, Animal Fluency test, Controlled Oral Word Association Test, and the Stroop test. Memory was measured using two measures (recall of 15 words after a 5-minute delay and word retention (i.e., the ratio of words

correctly recalled in the immediate vs. delayed trials) from a modified version of the Rey Auditory Verbal Learning Test which had a single learning trial. The cognitive measures were based on previously established protocols of common cognitive tests but were adapted slightly for use in the CLSA (e.g., for time efficiency). For details on the administration of these tests see Tuokko et al. (2017). We used a principal component analysis of the cognitive test results to derive a composite Executive Function score (PC1) and a composite Memory score (PC2), which together explained 60% of total variation in the cognitive data (for further information on these analyses see SDC1 in the Supplementary Digital Content and Phillips et al. in preparation).

Social measures. Social measures selected from the CLSA included independent life space, driving status, retirement status, living situation, loneliness, availability of social support, social participation and social network size. Life space was determined using the standard Life Space Mobility Composite index (Baker et al. 2003; Peel et al. 2005; hereafter “Life Space Index”); it is a variable based on items concerning a person’s movements in and outside of home during the last four-weeks, including indicators of the independence, frequency and distance of those movements. Life space has been used in research to examine the complex influences of multiple factors (e.g., cognitive, psychological, social, physical, economic) that may explain connections between disabilities and quality of life, including age-related changes in mobility (Stalvey et al. 1999; Webber, Porter & Menec 2010), hearing (Polku et al. 2015, 2018), and vision (Popescu et al. (2011). We included driving status (reported frequency of driving, dichotomized to driving at least occasionally vs. not at all) because reduction in driving may be one of the first adverse consequences of sensory impairments (particularly vision loss) on independence (Ivers et al. 1999; Green 1998; Huisinigh et al. 2017). Living situation (lives alone,

or with at least one other person in the household), retirement status (completely, partially, or not retired), and perceived loneliness in the past week (felt lonely at least sometimes in the past week, or not), were determined with a single question item, each. Perceived availability of social support was based on a standard composite score derived from responses to the Medical Outcomes Study (MOS) Social Support Survey (Sherbourne & Stewart 1991). Social network diversity was determined using a slightly modified version (CLSA collected information on 10 instead of 12 possible social roles as in the original index) of the Social Network Index (SNI; Cohen 1991). Social participation was assessed using 8 items developed for the Canadian Community Health Survey on healthy aging (Statistics Canada, <http://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=5146>). Social participation was measured as a) the number of *different types* of social activities that the participant engaged in at least weekly, and as b) the *frequency* of participation in community activities outside the home (Gilmour 2012).

Statistical Analyses

We conducted all analyses using Stata version 15.0. We examined whether predictor variables were associated with self-reported sensory difficulties after accounting for the effects of behavioral sensory measures. We created separate logistic, multiple regression models for self-reported HD, VD, and DSD. All models included demographic, socioeconomic, health, and social variables, as well as behavioral measures of both hearing (HI) and vision (VI), and the self-reported measure of difficulties in the opposite modality (e.g., HD was included as a predictor variable in the VD model to quantify the association between the self-reported sensory difficulties). The list of the predictor variables included in each model is shown in Figure 1. To

assess the possible multicollinearity, we computed variance inflation factors (VIF) for all variables of interest in the models. As this analysis did not identify any serious collinearity (VIF range: 1.03 to 3.06; i.e., all below the conservative threshold VIF=4; see e.g. O'Brien 2007), we included all variables of interest in the models.

We chose to model self-reported HD, VD and DSD in separate logistic regression models to be able to include self-reported vision as a predictor of self-reported hearing and vice versa. Individuals with DSD were also counted as individuals with HD in the logistic HD model and as individuals with VD in the logistic VD model. We also tested for moderating effects of age on the association between self-reported and behavioral hearing/vision by including an interaction term of BPTA with age in the model of self-reported hearing difficulty, and logMAR with age in the model of self-reported VD. We further examined whether the pattern of findings differed when using multinomial logistic regression, in which the response variable was comprised of four mutually exclusive sensory categories (no sensory difficulty; VD only; HD only; DSD) (results in Table S5 in Supplementary Digit Content).

Imputation of missing data. Due to a large proportion of missing raw data for some of the covariates of interest and the resulting substantial reduction in sample size when using complete-case regression analyses (sample sizes for complete cases: HD N= 20,292; VD N= 16,311; DSD N= 13,763), we imputed missing data for all variables using chained-equations multiple imputation ($M=30$ imputed data sets) prior to estimating the models using the Stata *mi*-package (Royston & White 2011; White et al. 2011). The missing data and the multiple imputation methodology and diagnostics are detailed in Table S6 of the Supplementary Digit Content.

After imputations, the sample size was N=30,097 for each regression model. The sample ranged from 45 to 85 years of age (mean = 62.96 years, SD = ± 10.25) with 50.9% females. They had an average mid-range BPTA of 18.96 dB HL (SD = ± 13.98) with 11.4% reporting HD, and average pinhole VA of 0.11 logMAR (SD = ± 0.14) with 7.7% reporting VD.

National representativeness. Inverse probability sampling weights were used in all of the analyses to improve the national representativeness of prevalence estimates. CLSA statisticians assigned each participant a sample weight that was inversely proportional to the probability of inclusion in the study according to their sex, age, and province of residence. In other words, individuals from age/sex/province groups that were under-represented relative to the national population were assigned higher weights, and individuals from age/sex/province groups that were over-represented were assigned lower weights (*CLSA Technical Document: Response Rates and Sample Rates*, 2017). The Taylor linearization method was used for estimating standard errors that accounted for the survey weights.

Results

Missing data

Nearly all participants responded to the self-report hearing question (N=28 missing responses) and to the self-report vision question (N=19 missing). Self-report DSD had N=45 missing responses (missing self-reported hearing, vision, or both responses).

For behavioral hearing measures, BPTA could not be calculated for 928 participants. These 928 participants included 824 who were missing all audiometric data and 104 of 775 participants who were missing partial audiometric data (i.e., 671 of those with partial audiometric data were not missing thresholds for the frequencies required to calculate the BPTA). Audiometric threshold data for individuals with current ear infections, wax build-up,

collapsed ear canal, or other possible issues that may have caused unreliable test results for the better ear were considered missing.

Better-eye visual acuity data were missing for 712 participants due to a missing/mislaid pinhole occluder, participant refusal, or exclusion criteria such as current eye infection, or eye surgery or a detached retina within the past three months. Behavioral DSI data were missing for 1057 participants (missing data on vision, hearing, or both behavioral measures). The unimputed sample sizes following these exclusions were $N = 29,368$ for vision (2.5% missing data); $N = 29,035$ for hearing (3.5% missing); and $N = 28,479$ for dual sensory difficulties (5.4% missing). All behavioral and self-report prevalence measures are reported based on unimputed data.

Prevalence of Sensory difficulties based on self-report and Behavioral Measures

Across age groups, the overall prevalence of at least mild HI (BPTA > 25 dB HL) was 25.89% based on BPTA and 11.26% based on self-reported HD. The prevalence of at least mild VI (VA > 0.2 logMAR) was 13.1% based on pinhole-corrected visual acuity and 7.4% based on self-reported VD. The prevalence of DSI was 5.47% based on the BPTA and pinhole-corrected visual acuity measures, and 1.76% based on self-reported DSD.

The prevalence rates of both self-reported and behaviorally measured sensory difficulties/impairments increased with age, but the increase was steeper for behavioral than for self-report measures for HD, VD, and DSD (Figure 2 and Table S1 in the Supplemental Digital Content). For those under 60 years of age, self-reported sensory difficulties were more prevalent than behaviorally measured impairments (Figure 2), whereas the reverse pattern was observed for those 60 years of age or older. Notably, the mismatch between better self-

reported and worse behaviorally measures of sensory loss increased with age for participants older than 60 years of age, with a more marked mismatch for hearing than for vision and the least mismatch for dual sensory measures (Figure 2).

An examination of the distribution of behavioral hearing and vision measures for each self-report response option (Excellent to Poor) revealed a wide range, especially for those participants who self-reported fair or poor hearing or vision (Figure 3). While participants with fair or poor self-reported hearing and vision were more likely to have behavioral hearing and vision impairments, any given self-assessment response could be associated with practically any behavioral hearing/vision measure from normal sensory function to moderate sensory impairment, especially in the older age groups. This finding indicates that other variables besides the behavioral sensory thresholds used in this particular study may help to explain self-reported sensory ability. Notably, as seen in Figures 2 and 3, age is an important factor in determining the associations between self-reported and behavioral sensory measures.

Predictors of Self-reported Sensory Loss

The predictors in each model and the results obtained from each of them are summarized in Figure 1 and detailed output for the statistically significant variables ($p < 0.05$ and confidence intervals not overlapping one) for each model is provided in Table 3 for HD, Table 4 for VD, and Table 5 for DSD. The detailed results of the full models with statistics for all variables can be found in Tables S2, S3 and S4 in the Supplementary Digital Content.

Sensory predictors. As expected, VD and HD were each associated with a number of variables specific to that sensory modality. Not surprisingly, having a higher BPTA increased the odds of both self-reported HD (Table 3) and DSD (Table 5). Having worse visual acuity predicted both self-reported VD (Table 4) and DSD (Table 5). A larger difference in behavioral sensory thresholds between left and right ear/eye was associated with higher odds of self-reported sensory difficulties. A larger asymmetry in hearing increased the odds of self-reporting HD by 50% (Odds Ratio, OR=1.5 for an increase of 10 dB in the difference in hearing between ears) and increased the odds of reporting DSD by 20% (OR=1.2). A larger asymmetry in vision increased the odds of self-reporting VD more than six-fold (OR=6.46 / 1 logMAR) and tripled the odds of reporting DSD (OR=3.05).

The odds of self-reported HD were higher for those who also self-reported trouble hearing in noise. The proportion of participants self-reporting trouble hearing in noise exceeded the proportion self-reporting general HD (Figure 2B). Those participants who used a hearing device were less likely to self-report HD (note that the question about hearing asked participants to assess their hearing when wearing their hearing device if they used one).

Participants with a diagnosis of cataracts, macular degeneration or glaucoma reported VD with more than twice as high odds as those without such diagnoses. The odds of self-reporting VD also increased somewhat with the degree of uncorrected refractive error in the better eye, use of prescription glasses or lenses or visual aids, or a recent consultation with an eye care professional.

The odds of self-reporting HD nearly tripled if the participant also self-reported VD (OR 2.7). Similarly, the odds of self-reporting VD nearly tripled if the participant self-reported HD

(OR 2.9). In contrast to the strong positive associations between self-reported HD and VD, the behavioral measure of HI was negatively associated with self-reported VD (i.e., a higher BPTA, reduced the odds of self-reported VD). Visual acuity was not associated with self-reported HD. Sensory variables associated with DSD were a combination of variables associated with vision or hearing, including poorer behaviorally measured hearing and vision, larger hearing asymmetry, vision asymmetry, trouble hearing in noise, a diagnosis of a visual pathology, and the use of a visual aid (Table 5 and Figure 1).

Non-sensory predictors. The only predictors common to self-reported VD, HD, and DSD (controlling for behavioral measures) were older age, male sex, and a higher number of comorbidities (Tables 3, 4, and 5, and Figure 1). The adjusted odds of self-reporting vision, hearing, and dual sensory difficulties all significantly decreased with age (3-4% decrease in adjusted odds of self-reporting sensory loss in any modality with each additional year) (Tables 3-5 and Figure 2). Despite the larger discrepancy between behavioral and self-report sensory measures at older ages (discrepancy increases with age in all sensory modalities, Tables 3, 4 and 5 and Figure 2A, 2B, and 2C), we found no significant interactions between behavioral sensory measures and age in the multiple regression analyses. Thus, the age-specific odds of self-reporting sensory difficulties were not moderated by the degree of behaviorally measured sensory loss, but rather age and behaviorally measured sensory performance independently influenced self-reported sensory difficulty. Males had a 1.2 (VD), 1.4 (HD) to 1.8 (DSD) times higher odds to self-report sensory difficulties compared to females. Those participants who suffered from a higher number of chronic comorbid conditions self-reported VD, HD and DSD with slightly but significantly higher odds (OR 1.06-1.09; Tables 3, 4 and 5).

A better socioeconomic status significantly decreased the odds of self-reported VD (Table 4), but not HD (Table 3), with the odds of reporting VD being twice as high in the lowest income category relative to the highest category. There was a similar but weaker effect of education.

Overall, the various social variables were relatively weakly associated with self-reported difficulties. Aside from driving status, any social variable was associated with only HD or VD, but not both. Driving was independently associated with VD, such that those who were drivers self-reported difficulties with 46% lower odds. Interestingly, this association was opposite that found for hearing: participants who drove a car at least occasionally were more likely to self-report HD. The only other social variables associated with self-reported HD were a lower Life Space Index but a slightly greater social network index (i.e., a more complex social network). Those who lived alone or reported greater availability of social support were significantly less likely to self-report VD, while those who felt lonely at least sometimes were more likely to self-report VD; however, availability of social support and feeling lonely were only moderately correlated with each other (Spearman correlation: $r = -0.36$), consistent with these constructs being different (Newall & Menec 2019).

A slight negative effect of income, driving, and Life Space Index were also found on self-reported DSD (Table 5). All predictors of dual sensory difficulties were also associated with either hearing and/or vision difficulties. We found no evidence of effects of cultural background, retirement status, or the frequency of social participation, executive function, or memory on any self-reported sensory difficulties.

Discussion

Overview of Main Findings

The purpose of the present study was to evaluate the sensory and non-sensory factors associated with self-reported sensory difficulties in Canadians aged 45-85 years, using baseline data from the CLSA. We confirmed previous findings indicating that the prevalence of both behaviorally measured sensory impairments and self-reported sensory difficulties increase with increasing age. Consistent with previous studies (Kempen et al. 1996; Carta et al. 1998; Sindhusake et al. 2001; Laitinen et al. 2005; Kiely et al. 2012; Choi et al. 2016; Kamil et al. 2016), for those over 60 years of age, we found that the prevalence of self-reported sensory difficulties is lower than suggested by the audiometric and visual acuity measures, and that this discrepancy increases with increasing age. Thus, older adults are less likely than younger adults to self-report sensory difficulties even when they may have a sensory impairment according to behavioral measures of hearing thresholds and visual acuity. We expanded upon these findings by demonstrating the same pattern of results for dual sensory impairment.

Asymmetry of sensory impairment was independently associated with self-reported difficulties, and that VD was associated with HD, and vice versa. After controlling for behaviorally measured sensory impairment, male sex and comorbidities are consistently associated with a higher likelihood of self-reporting sensory difficulties. Socioeconomic status was only found to be associated with VD and DSD but not HD. The present findings add to the increasing evidence that the social environment and participation are associated (albeit quite weakly in the present study) with self-reported sensory difficulties, but that some social factors may have modality-specific effects. For example, those with a lower Life Space Index were more likely to self-report HD and DSD but not VD, whereas greater availability of social support,

feelings of loneliness, and living alone were all associated with better self-reported vision and not associated with HD or DSD. We discuss these findings below in further detail.

Prevalence of Sensory Difficulties in the CLSA Comprehensive Cohort at Baseline

As observed in previous studies of older adults, we found that the overall prevalence based on behavioral assessment of sensory abilities was approximately twice as high as the prevalence based on self-reported “fair” or “poor” vision and/or hearing. While the differing methodologies among studies (different self-report questions, different age ranges and other sample characteristics) makes direct comparison difficult, we observed generally lower prevalence rates of self-reported sensory difficulty than previous studies of similar age groups, especially for hearing.

Hearing. In the CLSA Comprehensive cohort, 11.4% of all participants self-reported HD (and 10.6% self-reported HD in the tracking cohort, Mick et al. 2018). In the Epidemiology of Hearing Loss Study (EHLS) sample of adults who were 48-92 years old, 14% of women and 23% of men reported HD (Wiley et al. 2000). In the large US National Health and Nutrition Examination Survey (NHANES, cycles 1999-2006; 2009-2010), 40% of participants who were 50 years and older reported at least a little trouble hearing (Kamil et al. 2016); however, the NHANES hearing question asks about hearing without a hearing aid, while CLSA asks about self-reported hearing with a hearing aid if the person uses one. The relatively low prevalence of HD in CLSA is likely due in part to a lower prevalence of HI in the CLSA compared to the prevalence of HI in some previous studies (Cruickshanks et al. 1998; Lin et al. 2011; Feder et al. 2015) and it may also partially result from the gradually decreasing incidence of hearing impairment over past decades (Laitinen et al. 2005; Zhan et al. 2010; Bourne 2014).

Vision. The prevalence of self-reported VD was 7.7% (ranging from 6.17% in youngest age group, to 11.44% in oldest age group) in the CLSA comprehensive cohort (7.9% in the tracking cohort, Mick et al. 2018). The prevalence of VD in the CLSA is similar to those of other studies and the prevalence VI in the CLSA (Aljied et al. 2018; Mick et al. 2019a) is also similar to findings from other studies (Laitinen et al. 2005; Bourne 2014). An earlier population study of Canadians observed self-reported vision “limitations” with a range of 3.5% for those 45-54 years olds to 13.4% for those 75 years of age and older (Brennan & Sleightholm 2006). Of adults in the USA aged 45 years and older, 17% self-reported some type of VD (Horowitz et al. 2005). The self-reported prevalence rates of DSD (fair or poor hearing and vision) was 1.85% in CLSA, relative to 1.6% self-reporting severe DSD in a large US population aged 45 years and above (Fuller et al. 2018).

Sensory Factors Explaining Self-reported Sensory Measures

After controlling for BPTA in the better ear and visual acuity in the better eye, other sensory variables also explained variation in self-reported difficulties for the same modality. Hearing or vision aid/device use, trouble hearing in noisy conditions, magnitude of refractive error, vision disease diagnosis, and vision care access were all associated with the self-reported difficulties for the corresponding sense.

Sensory asymmetry. The degree of asymmetry between ears for HI and eyes for VI was an important predictor of self-reported HD and/or VD. The significance of asymmetry implies that asymmetric sensory loss may make it more obvious to a person that they have vision or hearing difficulties. The effects of the degree of asymmetry on self-reported sensory ability in older adults has sometimes been studied, but in one previous study of an older age group (70-

85 years), no difference was observed in the association HD with audiometric thresholds in the better- vs. the worse-hearing ear (Salonen et al. 2011). The authors attributed this lack of a difference to the fact that age-related hearing loss tends to be symmetric. The CLSA data reflect age-related sensory loss as well as earlier-onset sensory losses due to a range of etiologies (including some that are more likely to be characterized by asymmetries) and the onset and etiology of sensory loss cannot be determined with current CLSA data.

Epidemiology studies that utilize behavioral measures of hearing or vision often define impairment using the better ear or eye (but see Stevens et al. 2013), thereby classifying individuals with single-sided impairment as “normal” and underestimating the degree of difficulty that those with asymmetric loss may experience in everyday life. For example, people with asymmetric HI may have more difficulty because unbalanced binaural hearing would compromise spatial listening and a listener’s ability to segregate and attend to sounds in complex auditory environments (Pichora-Fuller et al. 2017). Defining impairment according to the better side has the benefit of simplicity, but more sophisticated classification schemes may better reflect the functional abilities of individuals with sensory asymmetries, especially given the importance of binaural and binocular cues to navigation and communication in complex everyday situations.

Dual sensory loss. As a consequence of the age-related declines in both vision and hearing, dual sensory loss is increasing in prevalence as the population ages. DSI has been linked to reduced competence in everyday activities (Davidson & Guthrie 2017; Brennan et al. 2005), quality of life (Heine & Browning 2015), and participation in social activities (Viljanen et al. 2014; Mick et al. 2018), as well as adverse health outcomes such as a higher risk of falls and

cognitive impairment (Kulmala et al. 2009; Yamada et al. 2014; Fuller et al. 2018) and even mortality (Gopinath et al. 2013; Fisher et al. 2014). Effective screening is important so that the adverse effects of DSI on individuals and society can be mitigated. Our results indicate that reporting difficulty in one sensory modality increases the odds of reporting difficulty in the other sensory modality. Notably, in addition to factors associated with the sensory impairment, a lower Life Space Index and not driving (indicators of ability to move about independently) are associated with self-report of dual sensory loss. The present study is the first to examine the determinants of DSD, controlling HI and VI.

We are aware of only one other study (Hickson et al. 1999) that has examined associations between self-reported difficulties and behavioral measures of dual sensory impairment. In the Australian study of Hickson et al. (1999), 19% of the participants (60-93 years old) were considered to have DSI based on behavioral tests, and out of those, 35% self-reported both vision and hearing difficulties. In the present Canadian study, there were 5.5% across all ages (and up to 26.5% of those 80+ years old) with DSI based on behavioral measures (N=1559), and only 8% of those (N=123/1559) self-reported DSD. Thus, the prevalence rates of both self-reported and behaviorally measured dual sensory loss were substantially lower in the present study than in the Australian study. Furthermore, the proportion of Canadians with DSI who reported DSD was remarkably low compared to the Australian study. The high prevalence of dual (and vision) impairment in the Australian study may be partially due to the lower threshold considered as visual impairment (0.15 logMAR cut-off for normal vision) relative to the cut-off we used (0.2 logMAR cut-off). The discrepancies may also be a consequence of differences in study design: the number of Australian participants was much smaller (N=240)

and they were recruited on a voluntary basis through advertisements, which may have attracted people with existing sensory concerns. Nevertheless, both studies corroborate the view that people with measurable impairments in both vision and hearing relatively rarely self-report DSD. This finding prompts further questions about the self-perception of sensory loss and the cross-modal compensatory strategies of older adults, thus presenting interesting avenues for further research. Specifically, future studies should aim to examine the degree to which people with DSI perceive difficulties with hearing and vision relative to the severity of each impairment and which factors predict their perception of each of the coexisting sensory impairments. It would also be useful to examine potential differences in self-reported sensory difficulties between older adults who experienced an early onset or congenital sensory impairment relative to those who acquired sensory impairments at an older age.

Cross-modal effects. We assessed the associations of both behavioral and self-reported status across sensory modalities and discovered that the associations depend on whether self-report or behavioral measures are examined. Previous studies of the effects of sensory impairment in one modality on self-reported sensory difficulties in another modality have been inconclusive. In one study, behavioral measures of neither visual acuity nor contrast sensitivity were associated with HD (Wiley et al. 2000). However, in another study, those with HD were more likely to self-report VD (Tremblay et al. 2015). Consistent with the study of Tremblay et al. (2015), we found that HD increased the odds of VD and vice versa. Consistent with the study of Wiley et al. (2000), we observed no association between behavioral VI and the odds of HD. Surprisingly, worse hearing (higher BPTA) was associated with lower odds of VD. Our results suggest that behaviorally measured sensory ability in one sense does not necessarily influence

the odds of self-reporting difficulties in another sense despite the finding that, independent of behavioral measures of sensory loss, self-reporting difficulties in one sense increases the likelihood of reporting difficulties in the other sense. This pattern of results suggests that personal characteristics such as self-efficacy (e.g., Dawes et al. 2015) could underlie individual differences in the propensity to self-report health problems in general.

Non-sensory Factors Explaining Self-reported Sensory Measures

Age. Corroborating findings of a large number of studies, the prevalence of both behaviorally measured sensory impairments and self-reported sensory difficulties significantly increased with advancing age, but the prevalence of self-reported sensory difficulty was consistently lower than the prevalence of sensory impairment based on behavioral measures in older age groups (Holland & Rabbitt 1992; Feder et al. 2015; Kamil et al. 2016). Notably, this association was reversed in middle-aged adults below approximately 60 years, as has been observed previously by others (Kiely et al. 2012; Bainbridge & Wallhagen 2014; Kamil et al. 2016).

No data are available regarding the etiology and duration of hearing loss in CLSA participants; however, it is possible that the middle-aged participants included those with earlier onset hearing loss due to causes other than age-related hearing loss, as well as those in the early stages of ARHL who had become aware of the onset of difficulties understanding speech in noise even though their audiometric thresholds remained largely normal. In addition, there is evidence that middle-aged adults are more vulnerable than older adults to the effects of hearing loss on quality of life and mental health (Tambs, 2004). Nevertheless, we found no evidence of a moderating effect of age (no significant interaction of age with VI or HI) after

controlling for other variables of interest. Thus, the increasing divergence between the prevalence of self-reported difficulties and the prevalence of sensory impairment (most notably, HI) in the older age groups is likely explained by factors other than age itself. Other age-related factors, such as a declining health or an increasing number of comorbid conditions could contribute to this divergence. Alternatively, lifestyle changes at older age may place lower demands on sensory systems (Wu & Bentler 2012), with withdrawal from participating in more demanding activities reducing awareness of sensory difficulties in everyday life. Another possibility is that older adults who maintain active participation in everyday life have developed successful coping or compensatory strategies that mitigate the functional effects of their impairments. Successful coping may depend on cognitive and social factors.

Cognition. Many studies have demonstrated that cognitive function in older adults is associated with sensory function measured by both behavioral (e.g., Lin 2011; Chen et al. 2017; Thomson et al. 2017) and self-report measures (e.g., Fuller et al. 2018). One previous study found that poorer memory and verbal intelligence scores explained some of the divergence between results on self-report and behavioral measures for vision but not for hearing in a sample of 627 adults who were 57 years of age or older (Kempen et al. 1996). However, we observed no association of memory or executive function scores with self-reported sensory difficulties after adjusting for behavioral sensory measures. In fact, simple correlations between cognitive measures and self-report measures were not significant, but there were significant correlations between behavioral measures of both vision and hearing and executive functions (PC1) and between behavioral measures of hearing and memory (PC2). Given the relatively low prevalence of sensory loss (especially DSI) and the absence of cognitive impairments in the

CLSA sample at baseline, it is possible that some associations are too weak to extract even with this large sample at baseline, but such associations may emerge in future longitudinal data.

Social variables. Age, sex, and multimorbidity were the only common predictors for HD, VD and DSD. Thus, after controlling for behaviorally measured sensory impairment, it seems that different non-sensory factors influence the perception of sensory difficulties (see also Wahl et al. 2013). This pattern of findings could reflect the specific activities and social interactions that become difficult to perform or participate in according to type of sensory impairment. In a recent study of the CLSA tracking cohort for which only self-reported sensory ability was measured, we found that participants who self-reported VD, HD, and/or DSD also had lower outcomes on a subset of the social variables used in the present study, with some of the associations being age-, sex-, and modality-specific (Mick et al. 2018). Exploratory analyses indicate broadly similar results between the findings in the CLSA tracking cohort study (Mick et al. 2018) and the present study of the CLSA comprehensive cohort if self-reported sensory ability is analyzed without controlling for behavioral measures (data not shown). Social-sensory associations using self-report measures have also been observed by others for vision (e.g., Lamoureux et al. 2004) and hearing (e.g., Weinstein & Ventry 1982; Bertoni et al. 2015). Only in the present study, however, were the associations between social engagement variables and self-reported sensory difficulties examined after controlling for sensory impairment. With these adjusted measures, we found no evidence of social participation contributing significantly to self-reported sensory difficulties in either sensory modality. We observed a weak positive association of social network diversity with the odds of self-reporting HD, but no association of social network diversity with VD or DSD. These findings indicate that while sensory impairments

may be associated with reduced social functioning, social factors are not consistently associated with the likelihood of self-reporting sensory difficulties after the degree of sensory impairment has been controlled. Importantly, in a companion study, we found that behavioral measures of sensory impairment are strongly associated with social factors in the CLSA data (Hämäläinen et al. under review). Surprisingly, the present findings indicate that, after accounting for VI, perceived loneliness, low availability of social support, and living alone were associated with lower odds of VD (but there were no similar associations HD or DSD). These findings may imply that people with fewer everyday interactions have fewer opportunities to self-evaluate and notice sensory difficulties or that they judge their vision to be better because it does not prevent them from living and functioning independently. It is unclear, however, why this association was found only for VD, but not HD or DSD.

Interestingly, two variables associated with “getting around independently” were also associated with self-reported sensory difficulties. A higher Life Space Index (a composite score based on frequency, distance, and need for help to leave home) was associated with lower odds of self-reported HD and DSD, and driving a car at least occasionally was associated with lower odds of self-reported VD and DSD. Life space may be restricted in those with sensory impairments or diseases (Popescu et al. 2011; Polku et al. 2015), possibly through cessation of driving (O’Connor et al. 2010; Huisingh et al. 2017). Larger life space and ongoing driving may signal resilience to sensory impairments (see also Hämäläinen et al. under review), or ability to tolerate or compensate for impairments without significant limitations to activity or function in everyday life. Those who maintain the ability to move around independently may not notice difficulties so long as their sensory impairments do not restrict activities and participation.

Implications

The accumulating evidence that older adults have a low probability of self-reporting HD and VD, even when such impairments can be detected with behavioral measures, could have at least two explanations: 1) “mild” sensory impairments do not inevitably constrain activity and participation, possibly depending on the person’s goals for everyday functioning, situational demands on hearing and vision, and ability to compensate; 2) the evaluation of declining sensory function is conditioned by social psychological factors including the view that losses are a normal consequence of aging. While both explanations may be true, sensory impairments can have negative consequences on health and everyday life which can often be treated or alleviated. Findings from this study and other studies suggest that it could be valuable to augment self-report measures with behavioral measures of impairment, as well as health and social factors, when evaluating the effects of sensory loss on functioning in older adults.

Limitations and Future Directions

While the CLSA collected a rich selection of variables to measure multi-dimensional aspects of aging, there are few sensory measures available; for example, potentially relevant sensory measures that were not collected are speech-in-noise thresholds, reading ability, visual field, visual contrast sensitivity, and central processing (e.g., Rubin et al. 2001). Similarly, the single question about hearing/vision limits inferences compared to previous studies that have used more complex questionnaires (e.g. Kempen et al. 1996; Nondahl et al. 1998; Rubin et al. 2001) or asked about sensory functioning relative to an earlier time point or to others in the same demographic segment to provide insights into the yardsticks used when people self-report sensory abilities (e.g. Hickson et al. 1999).

The data are only cross-sectional but longitudinal analyses will be possible as future waves of data are collected over the 20 years of the CLSA. Speech-in-noise thresholds will be measured in the next wave of data collection (Ellaham et al. 2016) and the authors are able to propose other measures for future waves of this 20-year study. The CLSA does not include institutionalized individuals, those living on First Nation reserves or those with cognitive difficulties at baseline. These groups tend to have lower general health than the rest of the population and likely have higher prevalence of sensory impairment. Thus, the overall proportion of older Canadians suffering from sensory impairments (especially congenital or early-onset DSI and blind or culturally Deaf individuals) is likely underestimated in the CLSA.

Conclusions

Overall, these findings are consistent with previous findings (e.g., Hickson et al. 1999; Choi et al. 2016), but add to our knowledge of extent to which self-reported hearing and/or vision difficulties are predictable from measures of sensory impairment as well as other sensory factors and non-sensory demographic, cognitive and social factors. An over-arching theme is the importance of understanding the individual's awareness of the consequences of sensory impairments within the context of a model such as the WHO ICF that encompasses impairment as well as activity and participation and acknowledges the contributions of physical and environmental factors. With the accumulation of more multi-dimensional information on the factors influencing the likelihood of self-reporting sensory difficulties, more accurate diagnostic tools or algorithms may be developed to assist in sensory screening in aging adults and to guide rehabilitation practice and social policies to promote healthy aging.

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Figure legends

Figure 1. Independent variables included in each of the three models of self-reported sensory difficulty: hearing difficulty (HD), vision difficulty (VD) and dual sensory difficulty (DSD) and their statistical significance. Predictor variables are grouped into demographic, socioeconomic, sensory (hearing, vision), cognitive, non-sensory comorbidity (multimorbidity), and social factors.

Figure 2. Age-specific proportion of the CLSA participants (N=30,097) with A) Hearing difficulties; B) Vision difficulties; C) Dual sensory difficulties. Shown in A) are the proportions with behaviorally measured hearing loss (mid-range BPTA (Better-ear Pure-tone (1,2,3,4 kHz) Average (dB HL)): mild HI > 25 dB HL (light bars); moderate HI > 40 dB HL (dark bars)) and self-reported fair or poor hearing (diamond) and self-reported trouble hearing in noise (triangle); including those with DSI. In B) are shown the proportions with mild (logMAR 0.2-0.5; light bars) and moderate (>0.5 logMAR; dark bars) VI based on pinhole-corrected visual acuity (without refractive error, orange) and habitual (with potential refractive error associate with incorrect prescription, grey) visual acuity, and the proportion self-reporting fair or poor vision in different age groups (diamonds); including those with DSI. In C) are shown the proportions with behaviorally measured and self-reported dual sensory impairment. Note different ranges of y-axes. The prevalence rates (the proportion of participants with sensory loss according to each threshold) are tabulated in the Table S1 in the Supplementary Digital Content.

Figure 3. Violin plots for audiometry (BPTA) and pinhole-corrected visual acuity (logMAR) for each category of self-reported hearing/vision ability, stratified by age decade. The shape of the violin area shows the distribution of the data; circle indicates group-specific median, with the

surrounding vertical bars indicating the percentiles (thick line: interquartile range (25th & 75th percentiles); thin line: 95% confidence interval). Fair and poor self-reported hearing (dark color) are taken to indicate self-reported sensory difficulties. Horizontal reference lines indicate the thresholds for mild (dashed) and moderate (solid) sensory impairment.

Table 1: Description of sensory variables included as predictors in models of self-reported hearing difficulty (HD), vision difficulty (VD) and dual sensory difficulty (DSD) (see Statistical analyses for details). “Ref.” indicates the reference level to which other levels of categorical variables are compared.

Predictor category	Variable	Definition
Hearing	Self-reported hearing measure	Response to question “Is your hearing, using a hearing device, if you use one: Excellent, Very Good, Good, Fair, or Poor?”. Responses “fair” and “poor” were considered as self-reported hearing difficulty (HD)
	Behavioral hearing measure (BPTA)	Better ear pure-tone average (BPTA): Mean of 1000, 2000, 3000, 4000 Hz pure-tone thresholds in better ear (greater = worse hearing). BPTA > 25 dB HL is taken to indicate hearing impairment (HI).
	Age x BPTA	Interaction: Age x BPTA
	Hearing asymmetry	Difference between ears in pure-tone average
	Hearing device use ¹	Reports using any hearing device (ref. is ‘no’)
	Trouble hearing in noise	Response to question “Do you find it difficult to follow a conversation if there is background noise, such as TV, radio or children playing, even if using a hearing aid as usual?”; Yes or no. (ref. is ‘no’)
Vision	Self-reported vision measure	Response to question “Is your eyesight, using glasses or corrective lenses, if you use them: Excellent, Very Good, Good, Fair, Poor or non-existent?”. Responses “Fair” or “Poor” were considered as self-reported vision difficulty (VD).
	Behavioral vision measure (visual acuity)	Better eye visual acuity based on pinhole-corrected logMAR (greater = worse vision). Visual acuity of logMAR > 0.2 is taken to indicate vision impairment (VI).
	Age x visual acuity	Interaction: Age x Better eye visual acuity
	Vision asymmetry	Difference between eyes in visual acuity (pinhole-corrected logMAR)
	Better eye refractive error	Habitual-corrected (i.e., wearing glasses or contact lenses, if the person usually uses them) visual acuity minus Pinhole-corrected acuity in the better-seeing eye. Refractive error for each eye was coded as missing if habitual visual acuity was better than pinhole visual acuity, as this likely reflects measurement error due to incorrect use of the pinhole occluder.
	Vision disease diagnosis	Diagnosis of glaucoma, macular degeneration, or current cataracts (ref. no diagnosis)
	Wearing visual correction	Wore lenses for the habitual test; or Did not wear lenses despite reporting wearing them normally (ref. Does not normally wear corrective lenses)
	Visual aid use ²	Use of any vision devices other than glasses/lenses (yes/no; ref. no)
	Vision care access	Visited optometrist/ophthalmologist in past year (yes/no; ref. no)
Dual sensory	Self-reported dual sensory difficulty (DSD)	Difficulties with both hearing and vision based on self-report measures: Fair or poor self-reported hearing and vision (VD & HD)
	Behavioral dual sensory impairment (DSI)	Impairment in both hearing and vision based on behavioral measures: HI (BPTA > 25 dB HL) & VI (visual acuity > 0.2 logMAR)

1. Hearing aids/devices: Hearing aid, Computer to communicate (e.g., e-mail or chat services), Volume control telephone, TTY or TTD, Message relay service, Other phone-related devices (e.g., flashers), Closed caption T.V. or decoder, Amplifiers (e.g., FM, acoustic, infra-red), Visual or vibrating alarm, Cochlear implant, Another aid
2. Vision aids/devices: Magnifiers, Braille reading materials, Larger print reading materials, Talking books, Recording equipment or portable note-takers, Closed circuit devices (e.g., CCTVs), A computer with Braille, large print, or speech access, A white Cane, A guide dog, Another aid

Table 2: Description of non-sensory variables included as predictors in models of self-reported hearing difficulty (HD), vision difficulty (VD) and dual sensory difficulty (DSD) (see section on Statistical analyses for details). “Ref.” indicates the reference level to which other levels of categorical variables are compared.

Predictor category	Variable	Definition
Demographic	Age	Years (45-85)
	Sex	Female / Male (ref. is ‘female’)
	Cultural background	White / any minority background; dichotomized due to small percentage and high diversity of minorities. (ref. is “other than ‘white’”)
Socio-economic	Education	Highest level of education attained: 1) "Post-secondary degree"; 2) "Some post-secondary education"; 3) "Secondary school graduate"; 4) "Less than secondary school graduation". (Ref. is 1)
	Household income	Annual household income in CAD: 1) $\geq$ \$150,000; 2) \$100,000-149,999; 3) \$50,000-99,999; 4) \$20,000-49,999; 5) $<$ \$20,000. (Ref. is 1)
Comorbidity	Multimorbidity	# of diagnosed chronic conditions, derived from health survey using a series of questions “Has a doctor ever told you that you have [condition]?” See Supplementary Digital Content SDC1 for details.
Cognition	Executive function	Composite score of Executive function derived from principal component analyses of five cognitive tests (PC1). See SDC1 for details.
	Memory	Composite score of Memory derived from principal component analyses of five cognitive tests (PC2). See SDC1 for details.
Social	Life Space Index	Compound score of independence, frequency and distance moved in/from home (greater score is better)
	Driving status	Participant drives a vehicle at least occasionally; (ref. is “never”)
	Retirement status	Not retired or partly retired (ref. is “fully retired”).
	Lives alone	“Yes” indicates the participant lives alone; “No” that household size $>$ 1
	Loneliness	Feelings of loneliness: “In the past week, how often did you feel lonely?” Participants were classified as lonely if they responded “some of the time (1-2 days)”, “Occasionally (3-4 days)” or “All of the time (5-7 days)”. Those who responded “Rarely or never (less than 1 day)” were considered not to be lonely.
	Social support availability	Self-reported available social support of different types; composite score of the perceived availability of emotional/informational, tangible, and affectionate social support, and positive social interaction (the Medical Outcomes Study (MOS) social support score)
	Social network index	Number of different types of social interactions (0-10), one point for contact at least every 1-2 weeks (over the past year) with each of: children, other close family members, friends, neighbors, work colleagues, schoolmates, fellow volunteers, members of non-religious community groups, members of religious groups, and being married or in a domestic partnership.
	Social participation (frequency)	Frequency of participation in community activities: Never in past year; At least once in past year; At least monthly; At least weekly; Daily

Social participation (types of activities)	Number of different types of social activities in which person participated (0-8): family or friendship activities outside of the household; church or religious activities; sports or physical activities with others; educational or cultural activities with others; service club activities; community or professional association activities; volunteer work; any other recreational activity involving other people.
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Table 3: Statistically significant odds ratios (ORs) and confidence intervals (Cis) for predictors of self-reported hearing difficulties (HD) derived from logistic multiple regression models (fair/poor self-reported hearing).

		OR	95% CI		t	P
			CI 2.5%	CI 97.5%		
Age	Years	0.972	0.960	0.983	-4.770	<0.001
Sex	Male (ref. is "female")	1.368	1.230	1.523	5.750	<0.001
Behavioral hearing threshold	BPTA (per 10 dB)	2.291	1.797	2.920	6.700	<0.001
Hearing asymmetry	PTA difference between ears (per 10 dB)	1.556	1.453	1.666	12.670	<0.001
Trouble hearing in noise	Yes	6.267	5.611	7.000	32.510	<0.001
Hearing device user	Yes	0.763	0.635	0.917	-2.890	0.004
Self-reported VD	Fair/Poor self-reported vision (ref. good-excellent)	2.723	2.338	3.171	12.880	<0.001
Multimorbidity	Number of chronic conditions	1.059	1.034	1.085	4.710	<0.001
Life Space Index	Composite score	0.995	0.992	0.998	-3.160	0.002
Social participation	Social network index	1.041	1.001	1.084	1.990	0.046
Driving status	Drives at least occasionally	1.240	1.022	1.504	2.180	0.029
Intercept		0.026	0.011	0.064	-7.950	<0.001

Non-significant predictors of self-reported hearing difficulty: Cultural background, Education, Household income, Age x BPTA, Better-eye visual acuity, Executive function, Memory, Living alone, Retirement status, Availability of social support, Feeling lonely, Social participation (types of activities), Social participation (frequency)

Table 4: Statistically significant odds ratios (ORs) and confidence intervals (Cis) for predictors of self-reported vision difficulties (VD) derived from logistic multiple regression models (fair/poor self-reported vision).

		OR	95% CI		t	P
			CI 2.5%	CI 97.5%		
Age	Years	0.958	0.948	0.969	-7.780	<0.001
Sex	Male	1.182	1.050	1.330	2.780	0.006
Education	Post-secondary degree	Ref.				
	Some post-secondary education	0.997	0.817	1.216	-0.030	0.976
	Secondary school graduate	1.126	0.944	1.342	1.320	0.187
Household income	Less than secondary school graduation	1.260	1.011	1.571	2.060	0.040
	>= \$150,000	Ref.				
	\$100,000-149,999	1.422	1.146	1.764	3.200	0.001
	\$50,000-99,999	1.669	1.365	2.041	4.990	<0.001
	\$20,000-49,999	2.021	1.609	2.539	6.050	<0.001
Behavioral visual acuity	<\$20 000	2.172	1.617	2.918	5.150	<0.001
	Pinhole-corrected logMAR	16.139	2.058	126.562	2.650	0.008
Vision asymmetry	logMAR difference between eyes	6.393	4.880	8.375	13.470	<0.001
Refractive error	Habitual-corrected - Pinhole-corrected logMAR	1.651	1.045	2.609	2.160	0.032
Vision disease diagnosis	Diagnosed with macular degeneration, glaucoma, or current cataract	2.287	1.973	2.652	10.980	<0.001
Use of visual aid	Uses vision aid(s)	2.576	2.240	2.961	13.290	<0.001
Vision care access	Yes	1.146	1.014	1.295	2.180	0.029
Wearing visual correction for test	Does not wear glasses	Ref.				
	Wore glasses to habitual test	1.324	1.101	1.592	2.990	0.003
Behavioral hearing threshold	Did not wear prescribed glasses	1.012	0.825	1.243	0.120	0.907
	BPTA (/10dB HL)	0.890	0.844	0.938	-4.330	<0.001
Self-reported HD	Fair/Poor self-reported hearing (ref. good-excellent)	2.922	2.515	3.394	14.030	<0.001
Multimorbidity	#chronic conditions	1.068	1.041	1.096	5.060	<0.001
Driving status	Drives at least occasionally	0.544	0.459	0.645	-7.030	<0.001
Living situation	Lives alone (ref. lives with others)	0.734	0.635	0.849	-4.160	<0.001
Social support	Perceived availability of social support	0.994	0.991	0.997	-4.550	<0.001
Loneliness	Felt lonely at least sometimes	1.174	1.034	1.332	2.480	0.013
Intercept		0.551	0.227	1.335	-1.320	0.187

Non-significant predictors of self-reported vision loss: Cultural background, Age x visual acuity, Executive function, Memory, Life space index, Retirement status, Social network index, Social participation (types of activities), Social participation (frequency)

Table 5: Statistically significant predictors of self-reported dual sensory difficulties (DSD) derived from logistic multiple regression models (fair/poor self-reported hearing and vision).

		OR	95% CI		t	P
			CI 2.5%	CI 97.5%		
Age	Years	0.958	0.944	0.972	-5.750	<0.001
Sex	Male	1.767	1.411	2.214	4.960	<0.001
Household income	>= \$150,000	Ref.				
	\$100,000-149,999	1.233	0.765	1.987	0.860	0.389
	\$50,000-99,999	1.652	1.081	2.525	2.320	0.020
	\$20,000-49,999	1.732	1.087	2.759	2.310	0.021
	<\$20,000	1.709	0.967	3.023	1.840	0.065
Behavioral visual acuity	Pinhole-corrected logMAR	10.589	5.919	18.944	7.950	<0.001
Behavioral hearing threshold	BPTA (/10dB HL)	1.369	1.270	1.476	8.200	<0.001
Vision asymmetry	logMAR difference between eyes	3.193	2.047	4.979	5.120	<0.001
Hearing asymmetry	PTA difference between ears (/10dB HL)	1.209	1.051	1.391	2.660	0.008
Use of visual aid	Uses vision aid(s)	1.737	1.341	2.250	4.190	<0.001
Trouble hearing in noise	Yes	4.144	3.226	5.323	11.130	<0.001
Refractive error	Pinhole-corrected – habitual-corrected logMAR	2.636	1.166	5.956	2.330	0.020
Vision disease diagnosis	Diagnosed with macular degeneration, glaucoma, or current cataract	1.608	1.263	2.046	3.860	<0.001
Multimorbidity	#chronic conditions	1.083	1.033	1.136	3.310	0.001
Driving status	Drives at least occasionally	0.676	0.487	0.937	-2.350	0.019
Life space index	Composite score	0.992	0.986	0.999	-2.370	0.018
Intercept		0.027	0.006	0.129	-4.540	<0.001

Non-significant predictors of self-reported dual sensory loss: Cultural background, Education, Hearing device use, Better eye refractive error, Wearing visual correction, Vision care access, Executive function, Memory, Living alone, Retirement status, Availability of social support, Feeling lonely, Social network index, Social participation (frequency), Social participation (types of activities). Interactions tested with a separate model: no significant effect of Age x visual acuity or Age x BPTA.

		HD	VD	DSD
Demographic	Age	-	-	-
	Male sex	+	+	+
	White cultural background	x	x	x
Socio-economic	Lower education	x	+	x
	Lower household income	x	+	+
Hearing	Worse hearing (higher BPTA)	+	-	+
	Self-reported hearing difficulty		+	
	Age x BPTA	x		
	Higher hearing asymmetry	+		+
	Hearing device use	-		x
	Trouble hearing in noise	+		+
Vision	Worse vision (higher logMAR)	x	+	+
	Self-reported vision difficulty	+		
	Age x visual acuity		x	
	Higher vision asymmetry		+	+
	Larger refractive error		+	x
	Vision disease diagnosis		+	+
	Wearing visual correction		+	x
	Visual aid use		+	+
	Vision care access		+	x
Cognition	Better executive function	x	x	x
	Better memory	x	x	x
Multimorbidity	# chronic health conditions	+	+	+
Social	Drives at least occasionally	+	-	-
	Higher life space index	-	x	-
	Retirement status	x	x	x
	Lives alone	x	-	x
	Feels lonely at least sometimes	x	+	x
	Higher availability of social support	x	-	x
	Higher social network index	x	x	x
	Higher social participation frequency	x	x	x
	Social participation (more activities)	x	x	x

positive effect (OR>1), P<0.001
 positive effect, P=0.001-0.05
 negative effect (OR<1), P<0.001
 negative effect, P=0.001-0.05
 no significant effect of the term
 term not included in the model

+
+
-
-
x

Self-report Measures of Hearing and Vision in Older Adults Participating in the Canadian Longitudinal Study of Aging are Explained by Behavioral Sensory Measures, Demographic and Social Factors

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Supplemental Digital Content

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Supplemental method description: multimorbidity and cognitive scores

Multimorbidity

A multimorbidity score was calculated as the sum of diagnosed chronic conditions reported by the participant. A list of all health-related questions included in the CLSA are available in the CLSA documentation (<https://www.clsa-elcv.ca/researchers/data-collection>). The screening was done by asking, for each of the following conditions: “Has a doctor ever told you that you have...”

- Heart disease (questions combined; including congestive heart failure, CHF, heart attack or myocardial infarction, angina)
- Peripheral vascular disease or poor circulation in limbs
- Diabetes
- Multiple sclerosis
- Epilepsy
- Migraine headaches
- Intestinal or stomach ulcers
- Bowel disorder
- Bowel incontinence
- Urinary incontinence
- Cancer (combined; any kind of cancer)
- Back problems excluding fibromyalgia and arthritis
- Kidney disease or kidney failure
- Osteoarthritis (of hands, hips, or knees)
- Rheumatoid arthritis
- Other type of arthritis
- High blood pressure or hypertension
- Hypo- or hyperthyroidism (combined)
- Stroke, CVA, TIA, or ministroke (combined)
- Asthma
- Osteoporosis
- Parkinsonism or Parkinson’s Disease
- Emphysema, chronic bronchitis, COPD, or chronic changes in lungs due to smoking
- Memory problem, Dementia, or Alzheimer’s disease (combined)
- Anxiety disorder
- Mood disorder

Cognitive scores

The cognitive tests used to compute the cognitive scores were:

- **Memory:**
 - **Rey Auditory Verbal Learning Test.** Participants listen to a recorded list of 15 words once, and are asked to repeat the words back immediately and again 5 min. Two variables were retained for analyses: **Delayed recall** (# words correctly recalled 5 min after hearing the recording) and **Retention** (ratio of delayed to immediate recall).
- **Executive function.**
 - **Controlled Oral Word Association Test.** Participant is asked to generate as many words as possible that begin with a given letter in 60s (3 trials, letters F, A, S). Test score = total number of words.
 - **Animal fluency test.** Participant is asked to generate as many animals as possible in 60 s. Test score = total number of different animals named.
 - **Mental alternation test.** Participant is asked to generate the numbers 1–26 and the letters of the alphabet, alternating between each (1-A, 2-B, 3-C, ...). Test score = number of correct alternations.
 - **Stroop test Victoria version.** Participant is asked to quickly name the color of a visual cue (dots or words on cards). Two variables were retained for analyses: **Interference score** (total time taken to name the ink colors, rather than the color word printed on a card) and **Stroop ratio** (ratio of Interference score to Control task score, naming the color of printed dots).

Details on the choice and administration of the cognitive tests are provided in (Tuokko et al. 2017; Raina et al. 2018), and the detailed method for deriving the cognitive scores through principal component analyses are provided in (Phillips et al. n.d.). In brief, we derived an imputed correlation matrix of the seven cognitive test results using an expectation-maximization (EM) algorithm for an arbitrary N=27 666 (the non-missing sample size for the cognitive test variable with largest proportion of missing cases). This matrix was then used for the principal component analysis of the cognitive variables. Details on the multiple imputation approach are provided in (Hämäläinen & Mick 2019).

Rotated loadings estimated using the EM algorithm indicated that the first axis captures mostly variance in the executive function test results (5 variables derived from 4 tests) and variables associated with memory (2 variables derived from one two-trial test) loaded strongly on the second axis. Thus, we extracted the scores for PC1, taken to represent Executive function, and PC2, taken to represent Memory. The weights for PC1 and PC2 derived from the EM-algorithm were used to calculate PC1 and PC2 scores for those participants who had existing data for all 7 test results and those participants with missing data for any of the 7 variables had missing data for both PC1 and PC2. We then included these principal components in a global, multivariate multiple imputation method (Hämäläinen & Mick 2019) to impute the missing cognitive scores (PC1 and PC2). This two-step imputation approach was chosen because 1) the cumulative proportion of missing data for the cognitive tests was relatively high (approx. 17%) although any one participant rarely lacked data for more than one test; and 2) it is recommended that the “final” form of the variables of interest be included in the multiple imputation process (here: PC-scores rather than the raw data); see e.g. (von Hippel 2009; UCLA Statistical Consulting Group n.d.)).

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Supplemental results

Table S1: Baseline prevalence of behaviourally measured and self-reported sensory loss in the Canadian Longitudinal Study on Aging (CLSA) stratified by age, sex, and sensory modalities.

		Hearing		Vision		Dual	
		% with B-HI ¹	% with S-HD ²	% with B-VI ³	% with S-VD ⁴	% with B-DSI ⁵	% with S-DSD ⁶
Age	45-49	3.29	7.27	2.98	6.17	0.14	1.19
	50-54	5.82	7.94	4.20	6.79	0.31	1.27
	55-59	11.15	9.09	7.23	6.27	1.10	1.19
	60-64	18.25	10.19	9.47	6.61	1.80	1.64
	65-69	28.83	12.1	14.88	6.44	4.58	1.54
	70-74	42.09	13.86	21.44	8.21	9.08	2.09
	75-79	59.21	16.06	26.23	9.93	15.53	3.17
	80+	76.38	19.26	35.00	11.44	26.53	3.22
Sex	Female	20.23	8.17	14.04	7.56	4.91	1.35
	Male	31.77	14.46	12.21	7.15	6.06	2.18
Behavioral HI	Normal	0	5.67	10.04	6.67	0	0.92
	Mild HL	100	21.16	19.86	8.95	19.88	3.58
	Moderate HL	100	39.33	24.51	9.55	24.36	5.41
Self-reported HD	Good-Excellent	21.23	0	12.57	6.29	4.43	0
	Fair-Poor	62.67	100	17.62	15.73	13.77	15.72
Behavioral VI	Normal	23.32	10.69	0	5.59	0	1.39
	Mild VL	42.08	14.83	100	16.40	41.89	3.79
	Moderate VL	48.72	16.67	100	57.43	48.47	11.35
Self-reported VD	Good-Excellent	25.33	10.21	11.48	0	4.77	0
	Fair-Poor	32.77	23.99	34.03	100	14.46	24.16
Total	%	25.89	11.26	13.14	7.35	5.47	1.76
	N	29035	29035	29368	29368	28479	28479

1. Behaviourally measured hearing loss (B-HI) refers to mid-range BPTA >25 dB HL.

2. Self-reported hearing difficulty (S-HD) = fair/poor self-reported hearing.

3. Behavioral vision impairment (B-VI) refers to pinhole-corrected better eye visual acuity of logMAR>0.2.

4. Self-reported vision difficulty (S-VD) indicates fair/poor self-reported vision.

5. Objective dual sensory loss (DSI) indicates participant had both behavioral HI and VI.

6. Self-reported DSD indicates that the participant self-reported difficulties with both hearing and vision.

Shown are percentages of CLSA participants with hearing, vision, and dual sensory difficulties based on behavioral (B) and self-report (S) measures. The sample size (N) refers to the number of participants with no missing data for a given sense (e.g., N=29,035 participants had no missing behavioral or self-report hearing data). Note that hearing and vision numbers include also those participants with difficulties in both senses.

Table S2: Full model output for self-reported hearing difficulties (logistic regression).

		OR	SE	t	P	CI 2.5%	CI 97.5%
Age	Years	0.974	0.006	-4.470	<0.001	0.962	0.985
Sex	Male	1.372	0.075	5.810	<0.001	1.233	1.527
Cultural background	White	1.114	0.125	0.960	0.335	0.894	1.388
Education	Post-secondary degree	Ref.					
	Some post-secondary education	1.020	0.094	0.220	0.826	0.852	1.222
	Secondary school graduate	0.985	0.082	-0.180	0.860	0.838	1.159
	Less than secondary school graduation	1.009	0.099	0.090	0.931	0.831	1.223
Household income	>= \$150,000	Ref.					
	\$100,000-149,999	1.146	0.102	1.530	0.125	0.963	1.365
	\$50,000-99,999	1.146	0.094	1.670	0.095	0.976	1.346
	\$20,000-49,999	1.081	0.102	0.820	0.412	0.898	1.301
	<\$20 000	1.051	0.146	0.360	0.722	0.800	1.380
Behavioral hearing threshold	BPTA (/10dB HL)	2.238	0.279	6.470	<0.001	1.753	2.856
	BPTA * age	0.998	0.002	-1.380	0.168	0.994	1.001
Hearing asymmetry	PTA difference between ears (/10dB HL)	1.530	0.052	12.450	<0.001	1.431	1.636
Hearing device user	Yes	0.784	0.073	-2.630	0.008	0.653	0.939
Trouble hearing in noise	Yes	6.266	0.352	32.630	<0.001	5.612	6.996
Behavioral visual acuity	Pinhole-corrected logMAR	0.877	0.156	-0.740	0.462	0.619	1.243
Self-reported vision	Fair-Poor vision	2.730	0.211	12.990	<0.001	2.346	3.176
Multimorbidity	#chronic conditions	1.059	0.013	4.770	<0.001	1.035	1.085
Cognition	Executive function (PC1 score)	0.990	0.020	-0.520	0.603	0.952	1.029
	Memory (PC2 score)	1.043	0.023	1.880	0.061	0.998	1.089
Retirement status	Retired	Ref.					
	partly retired	1.092	0.087	1.100	0.270	0.934	1.275
	not retired	1.114	0.080	1.510	0.132	0.968	1.282
Driving status	Drives at least occasionally	1.229	0.118	2.150	0.032	1.018	1.484
Living situation	Lives alone (ref. lives with others)	0.943	0.063	-0.880	0.379	0.827	1.075
Life space index	Composite score	0.995	0.001	-3.130	0.002	0.992	0.998
Social participation	Social network index	1.017	0.015	1.140	0.254	0.988	1.046
Social participation	Types of activities	0.979	0.021	-0.970	0.332	0.939	1.021
Social participation	Participation frequency	0.994	0.048	-0.120	0.902	0.905	1.092
Perceived social isolation	Perceived availability of social support	0.998	0.001	-1.490	0.137	0.996	1.001
Perceived social isolation	Felt lonely at least sometimes	1.001	0.059	0.020	0.981	0.892	1.124
Intercept		0.025	0.012	-8.020	<0.001	0.010	0.062

Statistically significant results in bold.

Table S3: Full model output for self-reported vision difficulties (logistic regression).

		OR	SE	t	P	CI 2.5%	CI 97.5%
Age	Years	0.958	0.005	-7.750	<0.001	0.948	0.969
Sex	Male	1.187	0.071	2.840	0.005	1.054	1.335
Cultural background	White	0.943	0.105	-0.530	0.597	0.757	1.173
Education	Post-secondary degree	Ref.					
	Some post-secondary education	0.995	0.101	-0.050	0.958	0.816	1.213
	Secondary school graduate	1.131	0.101	1.370	0.170	0.949	1.348
	Less than secondary school graduation	1.261	0.142	2.060	0.039	1.011	1.573
Household income	>= \$150,000	Ref.					
	\$100,000-149,999	1.426	0.156	3.240	0.001	1.150	1.768
	\$50,000-99,999	1.673	0.172	4.990	<0.001	1.367	2.048
	\$20,000-49,999	2.050	0.237	6.220	<0.001	1.634	2.570
	<\$20 000	2.193	0.323	5.330	<0.001	1.643	2.927
Behavioral visual acuity	Pinhole-corrected logMAR	15.334	16.154	2.590	0.010	1.945	120.903
	Pinhole-corrected logMAR * age	1.022	0.016	1.410	0.159	0.991	1.055
Vision asymmetry	logMAR difference between eyes	6.461	0.895	13.470	<0.001	4.925	8.477
Refractive error	Pinhole-corrected – habitual-corrected logMAR	1.589	0.334	2.210	0.027	1.053	2.399
Vision disease diagnosis	Diagnosed with macular degeneration, glaucoma, or current cataract	2.307	0.181	10.630	<0.001	1.977	2.694
Wearing visual correction for test	Does not wear glasses	Ref.					
	Wore glasses to habitual test	1.318	0.123	2.950	0.003	1.097	1.584
	Did not wear prescribed glasses	1.017	0.106	0.160	0.874	0.828	1.248
Use of visual aid	Uses vision aid(s)	2.571	0.183	13.260	<0.001	2.236	2.956
Vision care access	Yes	1.159	0.073	2.340	0.019	1.024	1.311
Behavioral hearing threshold	BPTA (/10dB HL)	0.885	0.023	-4.800	<0.001	0.841	0.930
	Self-reported HL	2.957	0.225	14.240	<0.001	2.547	3.433
Multimorbidity	#chronic conditions	1.068	0.014	5.200	<0.001	1.042	1.095
Cognition	Executive function (PC1 score)	0.990	0.023	-0.420	0.675	0.946	1.036
	Memory (PC2 score)	0.974	0.024	-1.030	0.303	0.928	1.024
Retirement status	Retired						
	partly retired	1.009	0.096	0.100	0.922	0.838	1.215
	not retired	1.145	0.094	1.660	0.097	0.976	1.344
Driving status	Drives at least occasionally	0.547	0.045	-7.280	<0.001	0.465	0.644
Living situation	Lives alone (ref. lives with others)	0.735	0.054	-4.200	<0.001	0.637	0.849

Life space index	Composite score	0.998	0.002	-0.890	0.376	0.995	1.002
Social participation	Social network index	0.999	0.017	-0.080	0.940	0.966	1.033
Social participation	Types of activities	0.952	0.024	-1.930	0.054	0.906	1.001
Social participation	Participation frequency	0.993	0.051	-0.130	0.895	0.898	1.099
Perceived social isolation	Perceived availability of social support	0.994	0.001	-4.530	<0.001	0.991	0.997
Perceived social isolation	Felt lonely at least sometimes	1.172	0.076	2.460	0.014	1.033	1.330
Intercept		0.551	0.248	-1.330	0.184	0.228	1.329

Statistically significant results in bold.

Table S4: Full model output for self-reported dual sensory difficulties (logistic regression).

		OR	SE	t	P	CI 2.5%	CI 97.5%
Age	Years	0.960	0.007	-5.410	<0.001	0.946	0.974
Sex	Male	1.789	0.206	5.050	<0.001	1.427	2.242
Cultural background	White	0.996	0.233	-0.020	0.987	0.630	1.574
Education	Post-secondary degree	Ref.					
	Some post-secondary education	1.249	0.228	1.220	0.223	0.873	1.785
	Secondary school graduate	1.181	0.192	1.020	0.306	0.859	1.623
	Less than secondary school graduation	1.250	0.216	1.290	0.196	0.891	1.754
Household income	>= \$150,000	Ref.					
	\$100,000-149,999	1.231	0.297	0.860	0.389	0.767	1.975
	\$50,000-99,999	1.638	0.352	2.300	0.022	1.075	2.497
	\$20,000-49,999	1.706	0.398	2.290	0.022	1.080	2.694
	<\$20,000	1.700	0.486	1.860	0.063	0.971	2.976
Behavioral visual acuity	Pinhole-corrected logMAR	10.246	3.010	7.920	<0.001	5.760	18.224
Behavioral hearing threshold	BPTA (/10dB HL)	1.334	0.049	7.910	<0.001	1.242	1.433
Vision asymmetry	logMAR difference between eyes	3.035	0.690	4.880	<0.001	1.943	4.741
Hearing asymmetry	PTA difference between ears (/10dB HL)	1.189	0.083	2.480	0.013	1.037	1.364
Use of visual aid	Uses vision aid(s)	1.738	0.229	4.190	<0.001	1.342	2.250
Hearing device user	Yes	0.984	0.165	-0.090	0.925	0.708	1.368
Trouble hearing in noise	Yes	4.186	0.535	11.200	<0.001	3.258	5.377
Refractive error	Pinhole-corrected – habitual-corrected logMAR	1.898	0.765	1.590	0.112	0.861	4.184
Wearing visual correction for test	Does not wear glasses	Ref.					
	Wore glasses to habitual test	1.326	0.241	1.560	0.119	0.930	1.893
	Did not wear prescribed glasses	0.956	0.192	-0.220	0.824	0.645	1.417
Vision disease diagnosis	Diagnosed with macular degeneration, glaucoma, or current cataract	1.581	0.203	3.570	<0.001	1.229	2.034
Vision care access	Yes	0.914	0.107	-0.760	0.445	0.727	1.150
Multimorbidity	#chronic conditions	1.086	0.026	3.400	0.001	1.036	1.139
Cognition	Executive function (PC1 score)	0.956	0.038	-1.150	0.252	0.885	1.033
	Memory (PC2 score)	0.976	0.044	-0.540	0.592	0.894	1.066
Retirement status	Retired	Ref.					
	partly retired	0.891	0.158	-0.650	0.517	0.630	1.262
	not retired	1.225	0.189	1.320	0.186	0.906	1.657
Driving status	Drives at least occasionally	0.682	0.115	-2.280	0.023	0.490	0.948
Living situation	Lives alone (ref. lives with others)	0.896	0.119	-0.830	0.406	0.691	1.162
Life space index	Composite score	0.992	0.003	-2.350	0.019	0.986	0.999
Social participation	Social network index	1.011	0.031	0.370	0.712	0.952	1.074

Social participation	Types of activities	0.926	0.048	-1.480	0.140	0.837	1.025
Social participation	Participation frequency	1.059	0.105	0.580	0.561	0.872	1.287
Perceived social isolation	Perceived availability of social support	0.996	0.003	-1.450	0.148	0.991	1.001
Perceived social isolation	Felt lonely at least sometimes	0.921	0.114	-0.670	0.505	0.722	1.174
Intercept		0.027	0.022	-4.570	<0.001	0.006	0.128

NB: interaction terms of age with BPTA and logMAR were tested in a separate model. While neither interaction was statistically significant, including both interaction terms in the same model masked the main effects of vision and hearing, leaving them non-significant. As this is most likely a spurious effect of overfitting the model, we chose not to present the interaction models here.

Statistically significant results in bold.

Table S5: Multinomial model (VD only; HD only; DSD as levels of response variable).

		VD only		HD only		DSD	
		RRR	P	RRR	P	RRR	P
Age	Years	0.963	<0.001	0.969	<0.001	0.939	<0.001
Sex	Male	1.123	0.088	1.324	<0.001	1.895	<0.001
Cultural background	White	0.942	0.617	1.111	0.384	1.015	0.949
Education	Post-secondary degree	Ref.					
	Some post-secondary education	0.933	0.540	0.988	0.904	1.214	0.291
	Secondary school graduate	1.132	0.216	0.973	0.752	1.170	0.336
	Less than secondary school graduation	1.238	0.098	0.998	0.982	1.301	0.124
Household income	>= \$150,000	Ref.					
	\$100,000-149,999	1.484	0.001	1.183	0.071	1.272	0.321
	\$50,000-99,999	1.660	<0.001	1.160	0.084	1.708	0.013
	\$20,000-49,999	2.080	<0.001	1.096	0.364	1.762	0.016
	<\$20 000	2.307	<0.001	1.117	0.463	1.738	0.053
Behavioral hearing threshold	BPTA (/10dB HL)	0.892	0.001	1.924	<0.001	1.650	<0.001
Hearing asymmetry	PTA difference between ears (/10dB HL)	0.909	0.076	1.549	<0.001	1.320	<0.001
Hearing device user	Yes	1.021	0.898	0.747	0.003	0.904	0.549
Trouble hearing in noise	Yes	1.167	0.019	6.722	<0.001	5.065	<0.001
Behavioral visual acuity	Pinhole-corrected logMAR	75.328	<0.001	1.121	0.581	32.425	<0.001
Refractive error	Pinhole-corrected – habitual-corrected logMAR	1.462	0.109	0.925	0.702	1.903	0.112
Vision asymmetry	logMAR difference between eyes	6.660	<0.001	0.689	0.031	3.761	<0.001
Vision disease diagnosis	Diagnosed with macular degeneration, glaucoma, or current cataract	2.509	<0.001	0.938	0.406	1.726	<0.001
Wearing visual correction for test	Does not wear glasses						
	Wore glasses to habitual test	1.286	0.017	0.831	0.024	1.271	0.187
	Did not wear prescribed glasses	1.031	0.792	0.917	0.333	0.902	0.608
Use of visual aid	Uses vision aid(s)	2.709	<0.001	1.105	0.263	2.234	<0.001
Multimorbidity	#chronic conditions	1.076	<0.001	1.067	<0.001	1.111	<0.001
Cognition	Executive function (PC1 score)	1.000	0.995	0.996	0.844	0.959	0.288
	Memory (PC2 score)	0.982	0.527	1.048	0.047	0.982	0.690
Retirement status	Retired						
	partly retired	1.059	0.587	1.135	0.131	0.930	0.684
	not retired	1.145	0.134	1.110	0.168	1.271	0.121
Driving status	Drives at least occasionally	0.561	<0.001	1.190	0.102	0.601	0.002
Living situation	Lives alone (ref. lives with others)	0.702	<0.001	0.905	0.167	0.823	0.147
Life space index	Composite score	1.000	0.822	0.996	0.011	0.991	0.005
Social participation	Types of activities	0.955	0.101	0.980	0.369	0.918	0.100

Social participation	Participation frequency	0.976	0.667	0.979	0.673	1.045	0.657
Social participation	Social network index	0.999	0.954	1.017	0.268	1.015	0.628
Perceived social isolation	Perceived availability of social support	0.993	<0.001	0.998	0.083	0.995	0.049
Perceived social isolation	Feels lonely at least sometimes	1.244	0.002	1.053	0.411	0.961	0.748
Intercept		0.412	0.060	0.038	<0.001	0.076	0.001

RRR = relative risk ratio. Statistically significant results in bold.

Table S6: Missing data.

Variable of interest	N with complete data	N missing	% missing
Age	30,097	0	0.00
Sex	30,097	0	0.00
BPTA (mid-range, 10 dB HL)	29,062	1,035	3.44
Pinhole VA logMAR	29,385	712	2.37
Self-report HD	30,069	28	0.09
Self-report VD	30,078	19	0.06
Ear asymmetry	28,192	1,905	6.33
Eye asymmetry	29,172	925	3.07
Better-eye refractive error	26,472	3,625	12.04
Trouble hearing in noise	30,024	73	0.24
Vision pathology diagnosis	25,515	4,582	15.22
Visited eye care professional	28,705	1,392	4.63
Wore prescribed vision correction for test	30,096	1	<0.01
Vision aid use	30,092	5	0.02
Hearing aid use	30,095	2	0.01
PC1 (Executive function)	25,051	5,046	16.77
PC2 (Memory)	25,051	5,046	16.77
Multimorbidity	28,166	1,931	6.42
Cultural background	30,081	16	0.05
Education	30,022	75	0.25
Income	28,156	1,941	6.45
Life space index	30,044	53	0.18
Social participation types	30,034	63	0.21
Social network index	29,982	115	0.38
Social support availability	30,007	90	0.30
Social participation frequency	30,025	72	0.24
Retirement status	29,987	110	0.37
Driving status	27,561	2,536	8.43
Lives alone	30,054	43	0.14
Feeling lonely	29,976	121	0.40