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Downstream of Hearing Loss: A Population-Based Multistate Analysis of Lifetime Risk and Years Lived with Hearing Loss, Dementia and Their Comorbidity in Finland

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Key points:

- Individuals with hearing loss at age 60 live approximately one additional year with dementia compared to those without hearing loss.
- The lifetime risk of dementia is about 1.5 times higher for individuals with hearing loss at age 60.
- Female sex and higher levels of education are associated with a greater number of years and a higher lifetime risk of hearing loss, dementia and their comorbidity due to longer exposure to age-related diseases.
- These findings highlight the importance of early identification and management of hearing loss as a potential strategy for reducing dementia burden.

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Authors' contributions

Study conception and design: DS, AL, KK, PM, MM; Data management: DS, KK; Methodology: DS, AL; Formal analysis and investigation: DS, AL; Visualization: DS; Writing - original draft preparation: DS; Writing - review and editing: DS, AL, KK, PM, MM; Supervision: AL, MM; all authors read and approved the final manuscript.

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Conflict of interest

No conflicts of interest.

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Abstract

Background: Hearing loss (HL) is a major modifiable risk factors of dementia, yet gaps persist regarding its association with years lived with dementia, lifetime risks differences by HL status, and sociodemographic disparities.

Methods: Using Finnish register data on all residents aged 60–99 from 2009–2019 (N=1,987,876; 16,439,107 person-years) and discrete-time multistate modeling, we calculated age-specific transition probabilities between five states – healthy, HL, dementia, comorbidity (both HL and dementia), and death, stratified by sex and education. We then estimated state-specific expectancies and lifetime risk.

Results: At age 60, males and females in the overall population were expected to live 3.39 and 3.61 years with HL, and 1.09 and 1.85 years with dementia, respectively. Lifetime risk of HL was 22.7% for both sexes; dementia risk was 21.4% for males and 31.0% for females. When examining subpopulations defined by origin state at age 60, those who were healthy could expect 1.10 (males) and 1.89 (females) years with dementia. Meanwhile, those with HL at age 60: 1.90 years (males) and 2.82 years (females) with both HL and dementia (comorbidity). Their lifetime risk of comorbidity was 33.5% (males) and 42.9% (females) – about 1.5 times higher than the dementia risk for those starting healthy. Higher education was associated with longer life, more years across all states, and higher lifetime risks.

Conclusions: HL at age 60 is associated with a substantial redistribution of remaining life toward dementia and comorbidity. Early HL detection and management may offer a public health opportunity to reduce dementia burden.

Introduction

Dementia represents a significant global health challenge, with the number of people living with dementia projected to increase to 153 million by 2050 [1]. It is among the leading causes to disability burden [2] and has far-reaching social and economic consequences for families and societies at large [3]. Age-related hearing loss (HL) is another prevalent condition in aging populations [4], with well-documented associations with social withdrawal, loneliness, and depression [5,6]. Notably, there is increasing evidence linking HL to cognitive decline [7] and dementia [8].

HL is associated with cognitive decline across multiple cognitive domains, as well as an increased risk of cognitive impairment and dementia incidence [9]. Maharani *et al.* [10] found that older adults with hearing impairment had lower episodic memory scores and were at a greater risk of

cognitive impairment. Similarly, Matthews *et al.* [11] demonstrated that individuals who consistently experienced poorer or worsening hearing had a more rapid cognitive decline. Impaired hearing is also linked to neurodegeneration relevant to dementia [12].

Differences by sex/gender exist for both health outcomes. HL disproportionately affects men [13,14], while women have a higher lifetime risk of dementia [15]. Social inequalities also play a critical role in shaping the landscape of both HL and dementia. Individuals with lower educational attainment are more susceptible to both HL and dementia [16,17].

Despite extensive literature documenting HL as a modifiable risk factor of dementia, three critical knowledge gaps remain unaddressed. First, current health expectancy research has focused primarily on estimates for HL [18,19] and dementia [20,21] as individual conditions, leaving unclear how many years individuals live with comorbidity – that is having both HL and dementia. Second, despite the importance of understanding lifetime risk – the probability an individual will develop a condition during their lifespan – current research lacks comparative estimates of dementia lifetime risk between individuals with and without HL. Third, while both conditions independently vary by education and sex, we have limited insight into how these sociodemographic factors may compound vulnerabilities in the HL-dementia relationship. To address these gaps, our study leverages Finnish population-level register data to provide comprehensive estimates of years lived with HL, dementia, and their comorbidity, as well as lifetime risks, by sex and education – revealing critical insights for identifying increased-risk populations and informing targeted interventions.

Data and Methods

Data and Study Population

This study used population register data covering all permanent residents in Finland. We restricted individuals to those aged 60-99 during years 2009-2019. The restriction is due to the age pattern of health outcomes considered. We linked annual population register information with the Death Register for dates of death using personal identification codes assigned to all permanent residents. Similarly, we integrated population register information with data from various national health records: Finnish Drug Reimbursement Register (available from 1995, though anti-dementia medications only appear from 2000 onward), which included medication purchases and

reimbursements, provided by the Social Insurance Institution of Finland, as well as the Care Register for Health Care, from which we utilized hospitalization data (1987-2019) and specialized care visits (1998-2019), maintained by the National Institute for Health and Welfare. To be included in the multistate calculation, individuals needed to contribute to person-years in at least two calendar years. Following exclusions, the final analytical sample comprised 1,987,876 individuals, contributing to 16,439,107 person-years. Supplementary Figure S1 illustrates the analytical sample derivation process.

Dementia

The Drug Reimbursement and Care registries were used to determine the year of dementia onset. Dementia was identified based on several criteria, including eligibility for reimbursement of Alzheimer's disease medication (disease code 307), the purchase of state-reimbursed Alzheimer's disease medication (Anatomical Therapeutic Chemical [ATC] code N06D), and records from inpatient and specialized outpatient care registries where dementia was listed as a primary or additional diagnosis. Diagnoses were classified according to the International Classification of Diseases, 9th Revision (ICD-9) for the years 1987–1995 (codes 290, 291.2, 292.8C, 294.1A, 331.0, 331.1, and 437.8A) and the 10th Revision (ICD-10) for the years 1996–2019 (codes F00–F03, F05.1, and G30). The use of a combination of Finnish hospital care and medication reimbursement registers to identify cases of dementia has previously been validated [22] and employed in empirical investigations [23]. The year of dementia onset was determined by identifying the earliest recorded occurrence in these registries for individual persons.

Hearing Loss

Hearing loss (HL) was identified using data from inpatient and specialized outpatient Care registries for the years 1996-2019. Identification was based on either a documented diagnosis of conductive and sensorineural HL (ICD-10 code H90), other and unspecified HL (ICD-10 code H91), or evidence of hearing aid use, including fitting and adjustments of devices (ICD-10 codes Z45.3, Z46.1, Z97.4). This coding strategy optimizes both etiological comprehensiveness, by capturing a wide range of HL pathophysiology, and sensitivity, by supplementing clinical diagnoses with hearing aid utilization codes to identify functionally significant cases that might

otherwise be missed in register data. The earliest recorded occurrence was considered the year of HL onset.

Sociodemographic variables

Information on sex, age, and educational attainment was provided in the population register of Statistics Finland. Age was a continuous variable measured in completed years. Educational attainment was determined based on the highest qualification achieved and classified according to the International Standard Classification of Education (ISCED-2011) as follows: tertiary (levels 5–8), secondary (levels 3–4), and no qualifications (levels 0–2).

Analytical Approach

This study employs discrete-time Markov chain multistate models analyzing transitions across five states: healthy, HL, dementia, comorbidity, and death. Health states are defined by the presence or absence of HL and dementia; thus, the 'healthy' state denotes the absence of diagnoses for both conditions, rather than overall health. The 'comorbid' state refers specifically to the co-occurrence of HL and dementia. Multistate models allow us to calculate years of remaining life at age 60 expected in these health states during 2009-2019, differentiate the mortality patterns associated with each health state, and estimate the lifetime risk of developing morbidity through various progression pathways (illustrated in Supplementary Figure S2).

In Markov chain multistate models, the estimation of health expectancies and lifetime risks relies on transition probabilities, which quantify the likelihood of movement between health states. Age-specific transition probabilities were obtained non-parametrically from the empirical data by tabulating proportions of movements from origin to destination states and calculated for each age stratifying by sex and education. The use of full-population data allows for direct calculation of transition probabilities without relying on statistical modeling or distributional assumptions, thereby providing robust estimates based entirely on observed transitions.

The sex and education specific matrices were used to derive the corresponding fundamental matrices [24]. By means of the transition matrices and the corresponding fundamental matrices, we compute state-specific expectancies, conditioned and unconditioned on starting state, and life time risks, conditioned on starting state.

State expectancies are a weighted sum of conditional expected durations in a given state. To account for the mid-period transition assumption, a half-year correction of 0.5 was subtracted from the sum of transitions between states before applying the starting distribution weights. To mitigate noise from small sample sizes, starting distribution weights were calculated using a 5-year age interval of 60-65 over the period 2009-2019. Lifetime risk was calculated as a cumulative probability of ever transitioning into a specific state from a given state of origin. More technical details are available in existing literature [15,25].

Confidence intervals were obtained using a non-parametric bootstrap approach [26]. Due to computational constraints with the full population, we generated 200 resamples from a 5% random subsample by resampling individual trajectories, estimated the length of the confidence intervals based on this subsample, and obtained the length of the total population confidence intervals by scaling the 5% sub-sample by factor of 1/sqrt(20), as the total population is 20 times the 5% sub-sample. We constructed the confidence intervals by applying the length symmetrically around the point estimate.

Data management and preparation were conducted using Stata version 18.0, while all statistical analyses were implemented in R version 4.4.0.

Results

Descriptive Statistics

The total sample size was 905,394 males and 1,082,482 females, and the analysis was based on 7,332,239 and 9,106,868 person-years, respectively (Table 1). A total of 460,482 deaths were observed during the study period. On average, females and those with no educational qualifications were represented by older ages.

Mortality risk increased exponentially with age, exhibiting notable sex differences (Figure 1). Males consistently demonstrated higher death transition probabilities regardless of origin state. Individuals with dementia or comorbidity exhibited substantially higher mortality than those healthy or with HL alone, though HL did not increase mortality risk compared to healthy individuals.

Sex-specific patterns emerged across health transitions. Females showed higher probabilities of transitioning from healthy to dementia and from HL to comorbidity, with differences pronounced after age 80. Males showed higher probabilities of transitioning from healthy to HL and from dementia to comorbidity, with consistent differences across all ages. For both sexes, transition probabilities into comorbidity were consistently higher among individuals with pre-existing HL compared to those healthy or with pre-existing dementia (Figure 1).

Table 1. Sample characteristics of adults aged 60-99 in Finland upon their entry into the sample, 2009-2019 by sex and educational attainment level

	Males				**Females**			
	No qualifications	**Secondary**	**Tertiary**	**Total**	**No qualifications**	**Secondary**	**Tertiary**	**Total**
Age, mean	68.7	63.4	64.5	65.9	72.1	64.9	64.1	67.9
State, N (%)								
Healthy	333,763 (86.9)	263,997 (91.7)	213,780 (91.5)	811,540 (89.6)	415,820 (84.2)	303,828 (91.1)	234,005 (92.0)	953,653 (88.1)
Hearing Loss	33,159 (8.6)	19,269 (6.7)	15,646 (6.7)	68,074 (7.5)	39,924 (8.1)	21,356 (6.4)	15,539 (6.1)	76,817 (7.1)
Dementia	14,089 (3.7)	3,824 (1.3)	3,457 (1.5)	21,370 (2.4)	32,861 (6.7)	7,633 (2.3)	4,184 (1.6)	44,678 (4.1)
Comorbid	3,004 (0.8)	742 (0.3)	664 (0.3)	4,410 (0.5)	5,528 (1.1)	1,124 (0.3)	682 (0.3)	7,334 (0.7)
Total	384,015 (*42.4*)	287,832 (*31.8*)	233,547 (*25.8*)	905,394 (100)	494,133 (*45.7*)	333,941 (*30.9*)	254,408 (*23.5*)	1,082,482 (100)

Note: Percentages are to be interpreted as column-wise percentages, with the exception of the final row Total, which provides educational composition for males and females.

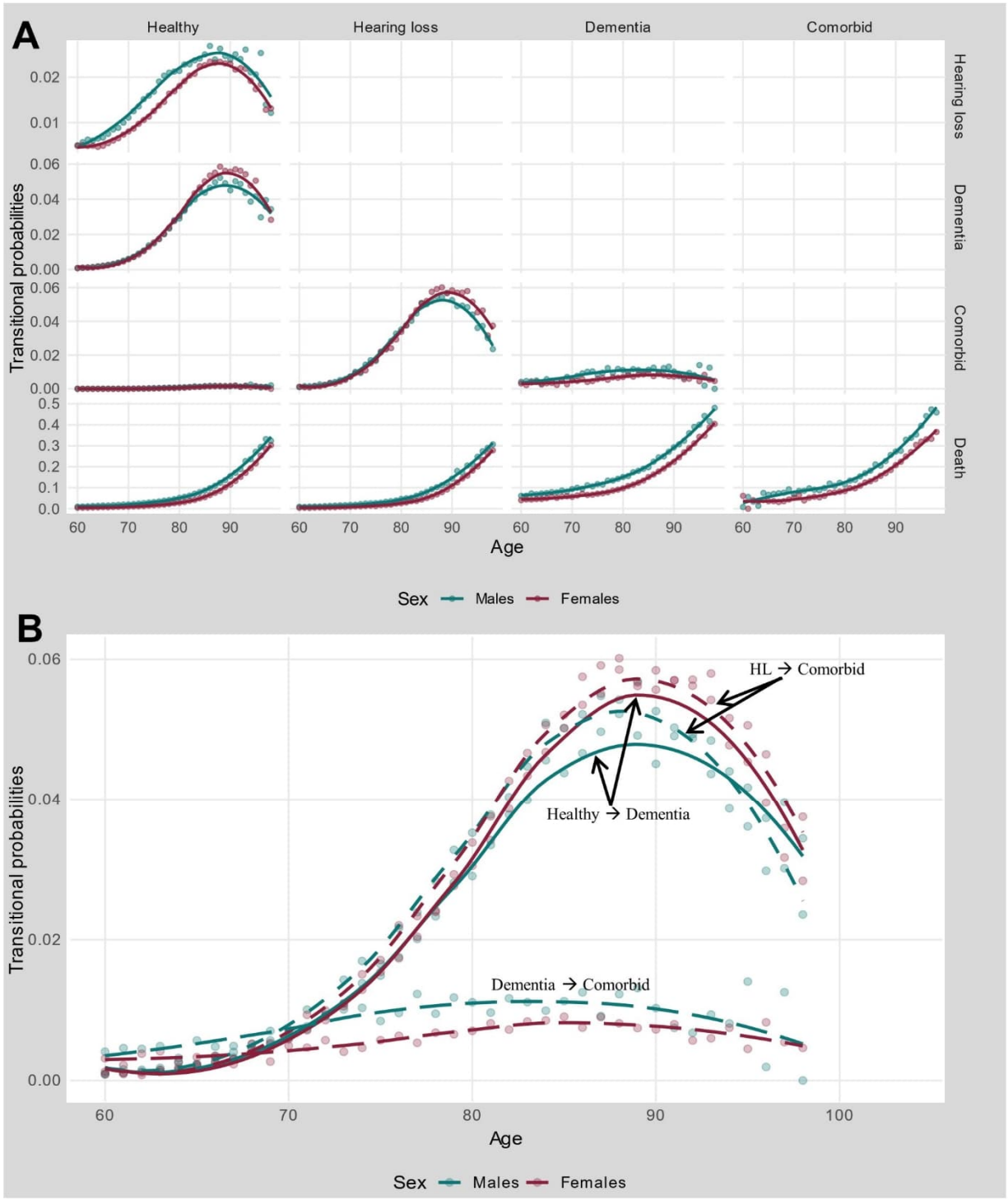

Figure 1. Sex-specific transition probabilities.
Panel A presents sex-specific transition probabilities across age from origin states to destination states, excluding transitions within the same state.
Panel B compares selected transition probabilities by sex.
Source: Author's calculations based on population register data of all Finns aged 60–99 from 2009 to 2019.
Note: Smoothing lines were applied using the LOESS method for readability, while multistate life tables were constructed using transitional probabilities, derived from observed transitions across single-year age groups.

Patterns across educational attainment levels were less consistent. See Supplementary Figure S3 for education-specific estimates.

Life and Health Expectancies

Remaining life expectancy at age 60 was 21.40 for males and 25.41 for females, reflecting a female survival advantage (Table 2). The figures are consistent with Human Mortality Database [27] for 2010-2019, which reported 21.85 for males and 25.94 for females. This deviation is to be expected because our study was restricted to age 99.

Remaining years of life were partitioned into expected time spent in each of the four health states. At age 60, males could expect to spend 16.39 years without either of the conditions, 3.39 with HL, 1.09 with dementia and 0.53 with comorbidity. Females at the same age could expect to spend 19.25 years healthy, 3.61 with HL, 1.85 with dementia, and 0.71 with comorbidity.

The longer life expectancy of females resulted in longer healthy life, as well as, more years lived with HL, dementia, and their co-occurrence, compared to males. Education also extended remaining life expectancy, increasing both healthy years and time spent in morbid states. Specifically, tertiary education when compared to no educational qualifications increased life expectancy by 3.51 years for males and 2.48 for females, while also extending time spend with HL, dementia, or both by approximately one year for each sex.

Expected years lived with dementia differed markedly by health status at age 60. Specifically, these are conditional expectancies representing the number of years an individual can expect to live given their health state at age 60. Males with HL at age 60 could expect 22.19 years on average (Table 2), of which 1.90 would be spent with co-occurring HL and dementia (Table3). Females could expect 25.85 years on average, of which 2.82 would be spent with co-occurring HL and dementia. Those who were healthy (free from HL and dementia) at age 60 had a similar total life expectancy (21.43 years for males and 25.46 years for females), but approximately one year less with dementia: 1.10 years for males and 1.89 years for females. A complete list of conditional expectancies can be found in Supplementary Table S1.

Table 2. Overall and state-specific life expectancies (LE) at age 60, and LE by starting state (healthy, hearing loss (HL), dementia, or comorbidity), by sex and educational level in Finland (2009–2019), with 95% confidence intervals

	Population-level		By education					
	Males	**Females**	**Males**			**Females**		
			No qualifications	Secondary	Tertiary	No qualifications	Secondary	Tertiary
Life and Health Expectancies *Unconditional on starting state*								
Overall LE	21.40 [21.37-21.43]	25.41 [25.38-25.44]	20.20 [20.15-20.25]	21.48 [21.42-21.54]	23.71 [23.63-23.79]	24.56 [24.51-24.61]	25.76 [25.69-25.83]	27.04 [26.95-27.13]
Healthy LE	16.39 [16.35-16.43]	19.25 [19.22-19.28]	15.66 [15.61-15.71]	16.14 [16.08-16.20]	18.10 [18.04-18.16]	18.84 [18.79-18.89]	19.33 [19.27-19.39]	20.27 [20.19-20.35]
LE with HL	3.39 [3.36-3.42]	3.61 [3.58-3.64]	3.00 [2.97-3.03]	3.70 [3.65-3.75]	3.81 [3.75-3.87]	3.18 [3.14-3.22]	3.83 [3.78-3.88]	4.17 [4.10-4.24]
LE with dementia	1.09 [1.08-1.10]	1.85 [1.84-1.86]	1.06 [1.05-1.07]	1.09 [1.06-1.12]	1.21 [1.18-1.24]	1.88 [1.86-1.90]	1.85 [1.82-1.88]	1.89 [1.85-1.93]
LE with Comorbidity	0.53 [0.52-0.54]	0.71 [0.70-0.72]	0.48 [0.47-0.49]	0.56 [0.54-0.58]	0.59 [0.56-0.62]	0.67 [0.66-0.78]	0.75 [0.73-0.77]	0.71 [0.68-0.74]
Life expectancy *Conditional on starting state at age 60*								
Healthy	21.43 [21.40-21.46]	25.46 [25.43-25.49]	20.25 [20.20-20.30]	21.50 [21.43-21.57]	23.74 [23.66-23.82]	24.63 [24.58-24.68]	25.81 [25.75-25.87]	27.08 [26.99-27.17]
HL	22.19 [22.09-22.29]	25.85 [25.75-25.95]	21.06 [20.90-21.22]	22.41 [22.21-22.61]	24.19 [23.99-24.39]	25.00 [24.82-25.18]	26.11 [25.93-26.29]	27.35 [27.15-27.55]
Dementia	10.67 [10.41-10.93]	14.13 [13.86-14.41]	10.23 [9.82-10.63]	10.72 [10.32-11.13]	11.61 [11.05-12.16]	13.72 [13.27-14.18]	14.06 [13.60-14.52]	14.99 [14.36-15.62]
Comorbidity	12.82 [12.30-13.34]	16.07 [13.92-18.23]	12.08 [9.94-14.22]	13.13 [11.18-15.09]	13.47 [11.22-15.72]	15.45 [12.88-18.01]	15.84 [15.84-15.84]	17.84 [17.29-18.40]

Note: All expectancies are in years. Life expectancies conditional on a starting state are based on trajectories of subpopulations defined by the state they occupy at age 60.

Table 3. Remaining years in healthy state, with hearing loss (HL), dementia, or comorbidity for two subpopulations: starting healthy or with HL at age 60, with corresponding 95% confidence intervals

Remaining years in destination states:	**Males**		**Females**	
	Starting Healthy (92.5%)	**Starting with HL** (5.8%)	**Starting Healthy** (93.2%)	**Starting with HL** (95.7%)
Healthy	17.52 [17.49-17.55]	-	20.53 [20.50-20.56]	-
HL	2.37 [2.35-2.39]	20.29 [20.20-20.38]	2.46 [2.44-2.48]	23.03 [22.93-23.13]
Dementia	1.10 [1.08-1.11]	-	1.89 [1.87-1.90]	-
Comorbidity	0.44 [0.43-0.44]	1.90 [1.86-1.93]	0.58 [0.57-0.58]	2.82 [2.77-2.86]

Note: the numbers in brackets (%) indicate the proportion of each subpopulation aged 60–65 within the full population – i.e., their prevalence. These proportions, along with those for dementia and comorbidity states at age 60–65, were used as weights to calculate population averages.
Empty cells represent impossible transitions, as HL and dementia are modelled as mutually exclusive and irreversible states (Supplementary Figure S2). Transitions from these states are only possible toward comorbidity.

Lifetime Risk

The lifetime risk of developing HL from a healthy state was identical between sexes, despite females having lower age-specific incidence probability (22.7%, Figure 2). Partial risk between ages 60-80 was twice larger in males than females (16.5% vs. 8.3%, respectively), suggesting that females' longer survival allows them to accumulate similar lifetime risk despite lower age-specific incidence probabilities (see Supplementary Materials Table S2). Furthermore, females exhibited significantly higher lifetime risk of developing dementia from a healthy state compared to males (21.4 for males vs. 31.0% for females, Figure 2). The lifetime risk of developing comorbidity directly from a healthy state was relatively low but still higher among females.

In addition to these sex-specific patterns, the health state at age 60 was also associated with differences in lifetime dementia risk. Among individuals starting out healthy at age 60, the lifetime risk of developing dementia was 21.4% for males and 31.0% for females. In contrast, for those already experiencing HL at age 60, the risk of transitioning to comorbid state was notably higher – 33.5% for males and 42.9% for females.

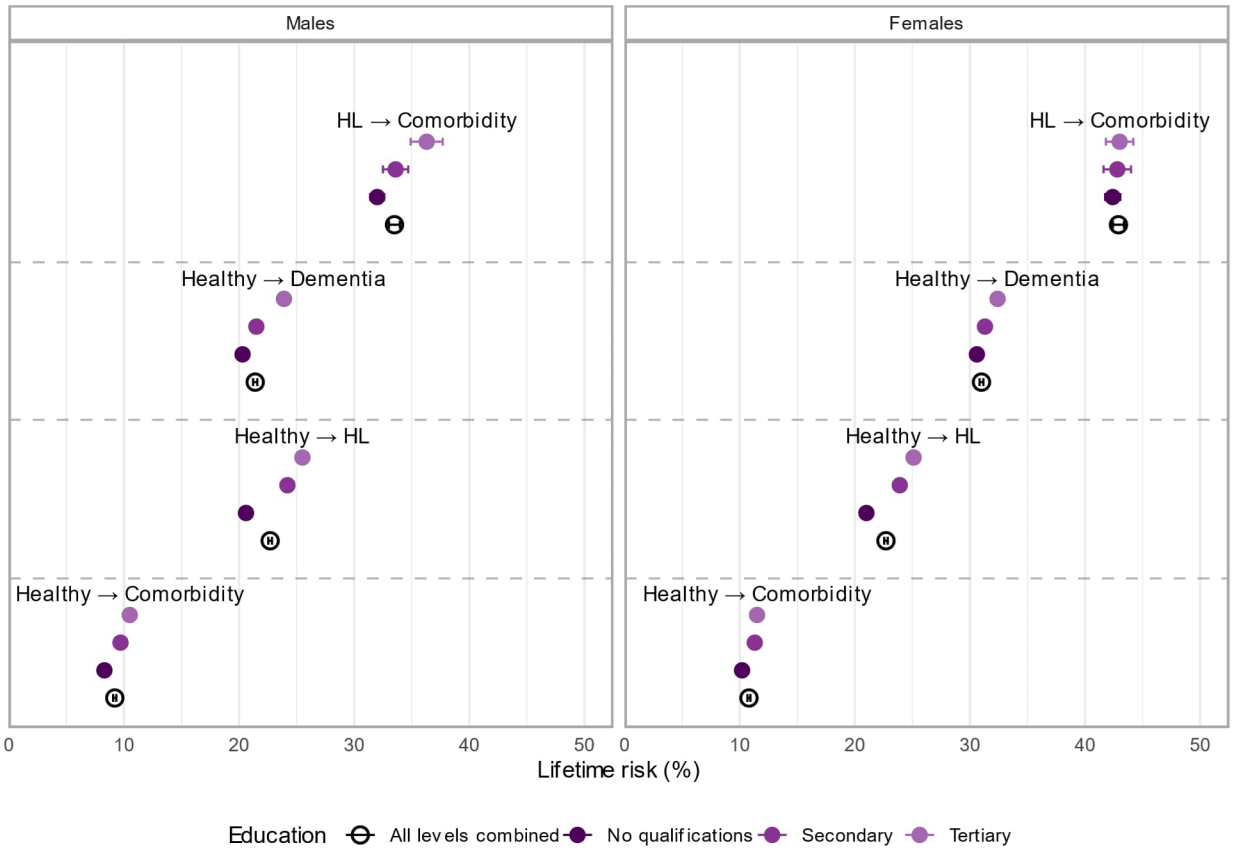

Figure 2. Lifetime risks by sex and education.
Points represent the estimated lifetime risk (%) of transitioning from the given origin state (e.g., Healthy or HL) to another health state. Bars indicate 95% confidence intervals.

Finally, educational attainment revealed additional gradients in lifetime dementia risk. For males, the lifetime risk of developing dementia from a healthy state increased progressively with education, from 20.3% (no educational qualifications) to 23.9% (tertiary education). A similar pattern emerged for females, with dementia risk increasing from 30.6% to 32.4% across educational categories. Similar educational gradients were observed for other transitions, particularly for males, where the effect of education appears more pronounced than for females.

Discussion

Hearing loss (HL) is increasingly recognized as a key target for dementia prevention, due to both its modifiability and prevalence in older adults [28]. However, we lacked clear understanding on whether and how the presence of HL should inform expectations about future years lived with dementia and the lifetime risk of dementia to support clinical decision-making. Our study

investigated how many years individuals live with HL, dementia, and their comorbidity, differential lifetime risks between exposure groups, and sociodemographic group differences.

We find several important patterns. First, individuals with HL at age 60 can expect to live approximately one additional year with dementia compared to those without HL, despite similar overall remaining life expectancy. This represents a substantial increase in the burden of dementia associated with pre-existing HL. Our finding on survival aligns with previous literature showing that HL does not reduce overall life expectancy [19,29], despite its association with various adverse health outcomes [30,31]. While West and Lynch [19] attributed this finding – which contradicts earlier literature linking HL to increased mortality risk [32] – to the possibility of recovery from hearing impairment in their survey-based data, our results emerge in a different context. We employ diagnosed HL, which relies on individuals recognizing difficulty of hearing and seeking healthcare. As such, it is more likely to capture persistent or non-recoverable HL compared to self-reported assessments – particularly at younger ages – where overestimation is common [33]. Both methodological approaches converge on the conclusion that HL does not reduce remaining life years, with our findings specifically indicating a redistribution of years toward increased time spent with dementia.

Second, we find that the higher dementia incidence associated with HL [34-36] comes with a substantially higher lifetime risk of developing dementia. This represents an approximate 12 percentage point increase, or 1.5 times higher, lifetime risk of dementia associated with HL at age 60, a clinically meaningful difference that persists across both sexes. This increase in lifetime risk is consistent with the growing body of empirical evidence supporting HL as an important precursor of cognitive decline and dementia pathology [10-12].

However, it is important to note that only about 6 percent of males and females at ages 60-65 in the Finnish population of this study were diagnosed with HL (as compared to 19 percent among males and 14 percent among females at ages 80-85), which likely reflects a subset with more severe or symptomatic impairments that prompt clinical attention. This early-onset (midlife) HL may therefore imply an early clinical marker of elevated neurodegenerative vulnerability rather than two isolated age-related morbidities. In line with this, Kim et al. [37] reported that the middle-aged individuals demonstrate higher risk of dementia associated with hearing impairment than the older-aged groups, underscoring greater significance of HL when it manifests at relatively younger ages.

Third, our findings reveal important sociodemographic patterns in health expectancy and lifetime risk. While females live longer than males, their extended lifespan includes not only more healthy years but also more years with morbidities, including dementia. Female disadvantage extends to lifetime risks – females face approximately 10 percentage points higher lifetime dementia risk regardless of HL status. This reflects the female-male health–survival paradox: women outlive men but spend greater proportions of their lives with disability and chronic illness, including dementia [38,39].

Educational gradients were also evident: individuals with higher educational attainment experienced expanded morbid life expectancy and increased lifetime risks of HL, dementia, and their comorbidity, despite spending more years healthy. This pattern likely reflects differential survival—higher education extends lifespans but increases cumulative exposure to age-related morbidities. This pattern is not unique to HL or dementia. Studies show more-educated older adults have higher disability prevalence than less-educated counterparts [40]. These patterns likely reflect a broader phenomenon of trends where the longevity benefits are partly accompanied by expansion of years lived with disability rather than compressing them [41].

This study benefits from comprehensive Finnish register data covering all residents aged 60–99 and a 10-year follow-up, minimizing attrition and selection issues common in panel data. However, selection bias may persist. Diagnostic likelihood may vary by education, with higher-educated individuals more likely to seek care, potentially leading to underdiagnosis in lower-educated groups and underestimation of educational inequalities.

Furthermore, our conceptual framework considered irreversible HL, yet some cases of HL may be reversible or mitigated through interventions. Hearing aids represent a common intervention, but their efficacy in reducing dementia risk remains contested. While some observational studies suggest potential cognitive benefits [42], consistent evidence supports hearing aid advantages only among individuals already at high dementia risk [43,44]. Our identification strategy, incorporating both HL diagnoses and hearing aid utilization codes, enhances sensitivity to clinically relevant HL but complicates interpretation, as hearing aid use may simultaneously indicate HL severity and potentially modify its effects on dementia.

In conclusion, HL is more than a sensory impairment – it predicts cognitive aging. Our findings show that individuals with HL at age 60 not only live longer with dementia but face a substantially

higher lifetime risk of developing it. These burdens are not evenly distributed: females and those with higher education spend more years navigating both HL and dementia, reflecting the complex interplay of longevity and increased exposure to age-related conditions. Together, these findings have significant implications for clinical practice, patient care, and public health policy, suggesting that early identification and management of HL represents a valuable opportunity for modifying dementia trajectories across population subgroups.

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Number of references: 44

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Supplementary Materials
Downstream of Hearing Loss: A Population-Based Multistate Analysis of Lifetime Risk and Years Lived with Hearing Loss, Dementia and Their Comorbidity in Finland

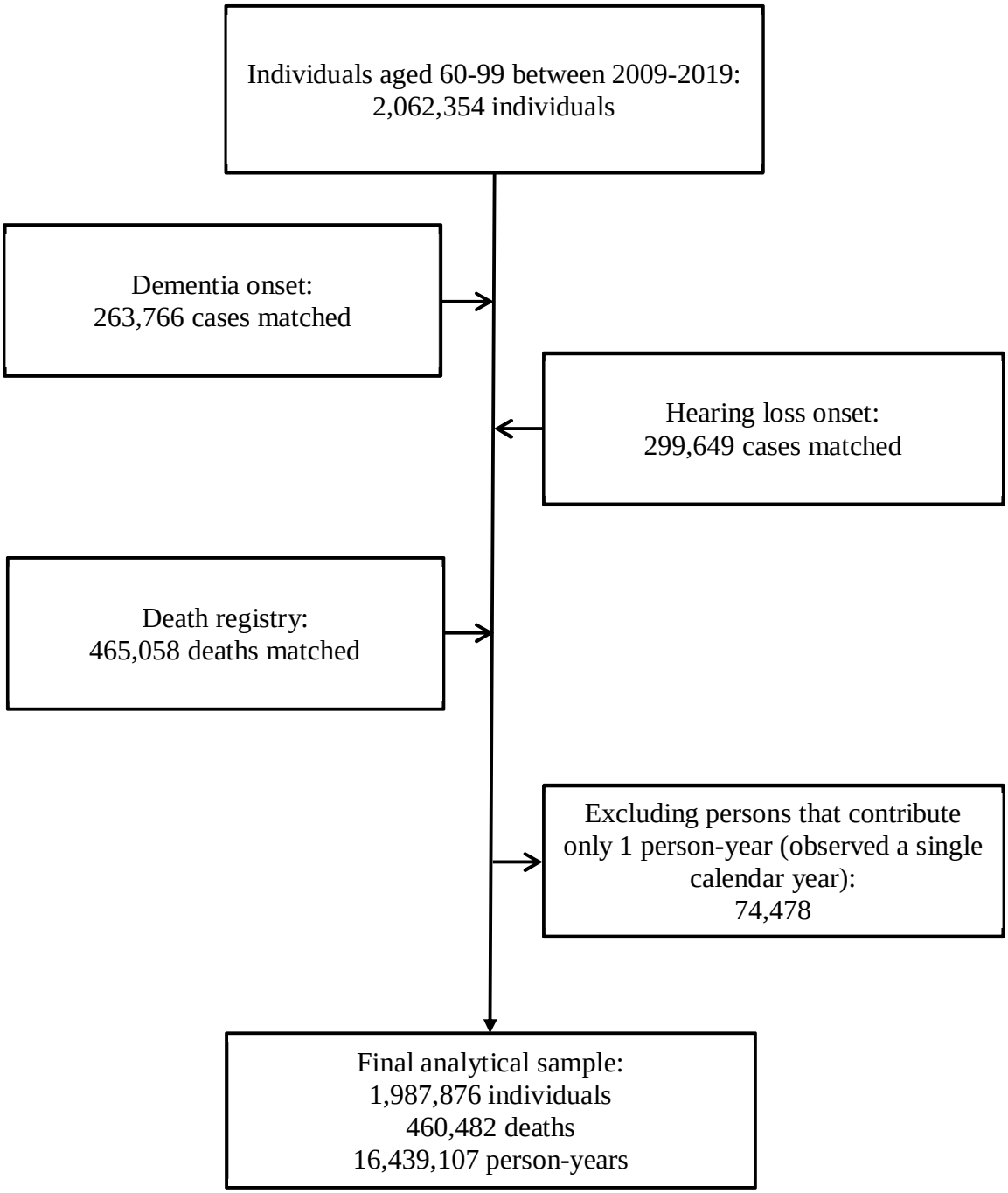

Figure S1. Flow chart of analytical sample derivation.

Supplementary Materials
Downstream of Hearing Loss: A Population-Based Multistate Analysis of Lifetime Risk and Years Lived with Hearing Loss, Dementia and Their Comorbidity in Finland

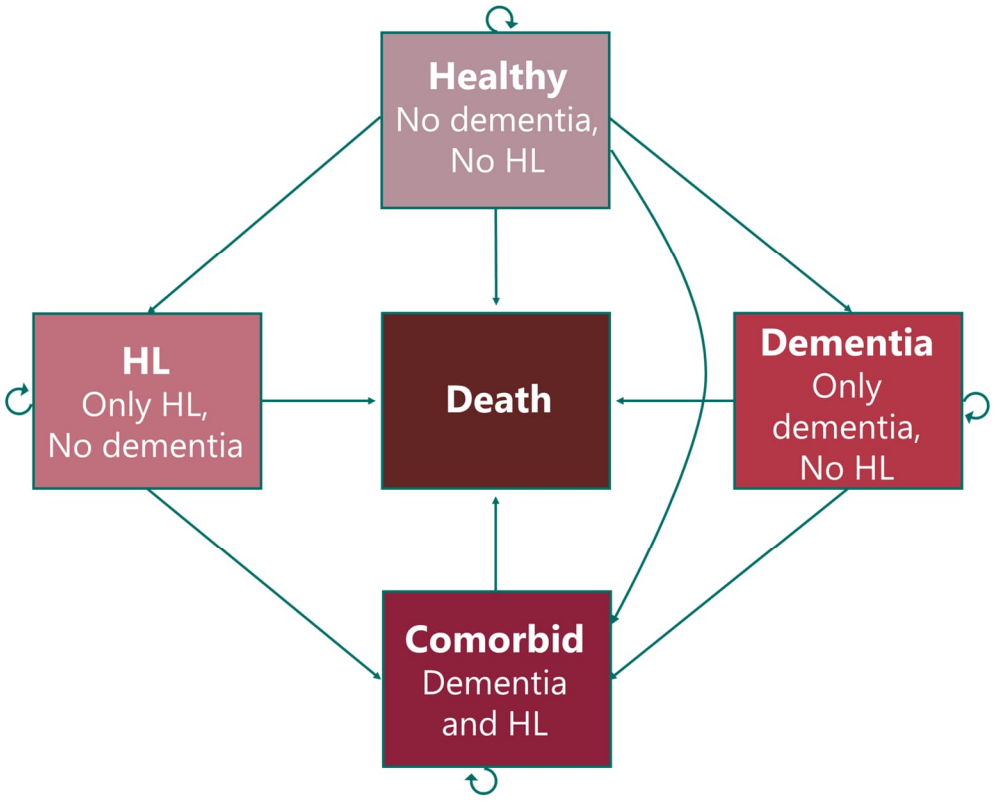

Figure S2. State space of the Markov multistate model and possible transitions across the states.
Note: HL = hearing loss.
We calculated transition probabilities non-parametrically as tabulated proportions of movements between states across 1-year age groups, stratified by sex and education. Since the disease progression of hearing loss and dementia is irreversible, we define these transitions as non-recoverable.

Supplementary Materials
Downstream of Hearing Loss: A Population-Based Multistate Analysis of Lifetime Risk and Years Lived with Hearing Loss, Dementia and Their Comorbidity in Finland

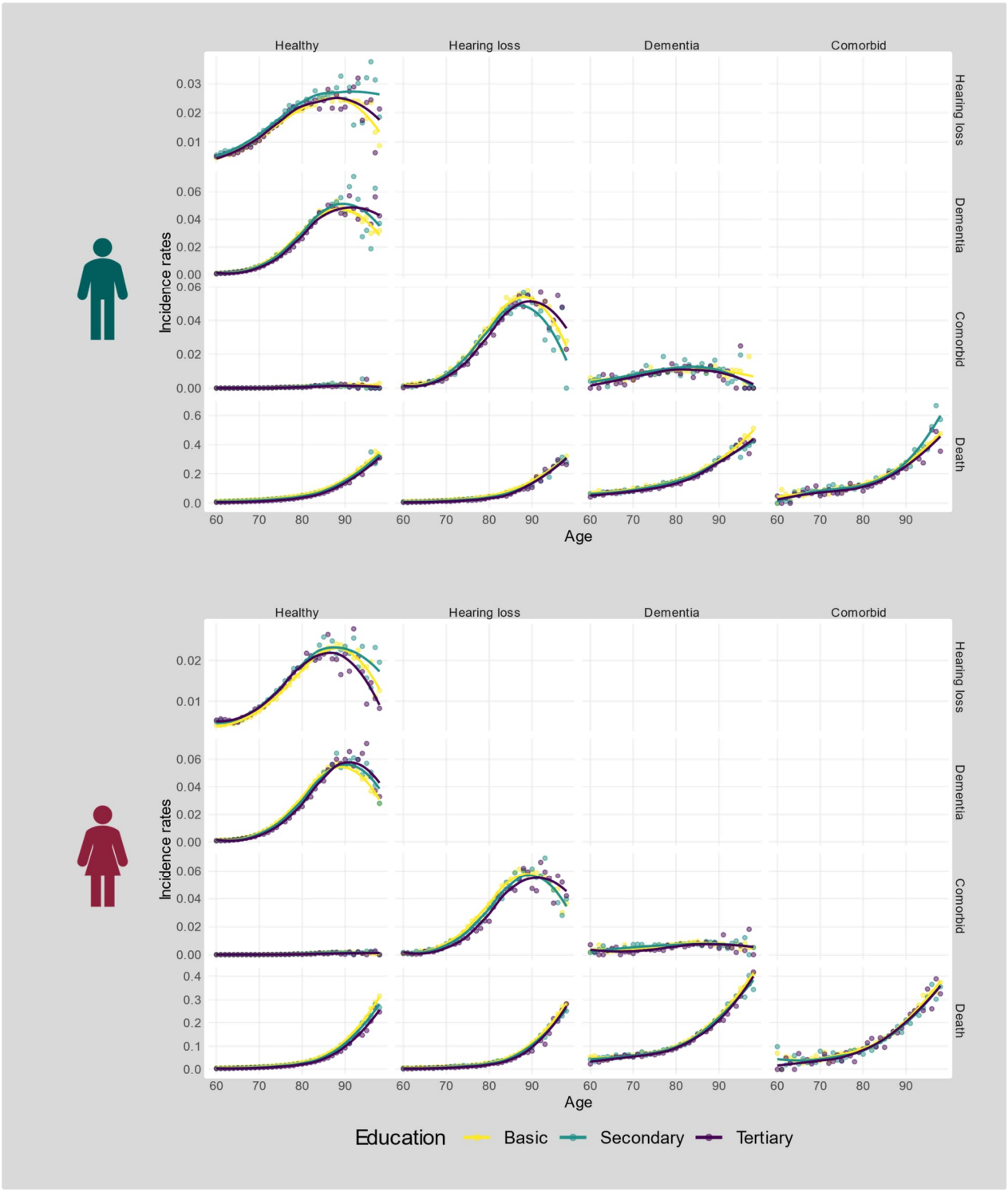

Figure S3. Education-specific transition probabilities across age from origin states to destination states, excluding transitions within the same state, stratified by sex.
Source: Author's calculations based on population register data of all Finns aged 60–99 from 2009 to 2019.
Note: Smoothing lines were applied using the LOESS method for readability, while multistate life tables were constructed using non-smoothed estimates. Age 99 is omitted from the graph for readability, as all individuals in this age group transition to the absorbing state of death.

Supplementary Materials
Downstream of Hearing Loss: A Population-Based Multistate Analysis of Lifetime Risk and Years Lived with Hearing Loss, Dementia and Their Comorbidity in Finland

Table S1. Conditional Life and Health Expectancies.
To obtain the unconditional expectancies (AVERAGE), which do not depend on the initial state individuals start in, we computed weighted averages of the conditional expectancies. For each population stratum of interest, the weights were determined based on the starting state distribution at 60-65.

A. Remaining Life Expectancy

Sex	Education	start.Healthy_60	start.HL_60	start.Dem_60	start.Comorb_60
Males	Population	21.40	22.19	10.67	12.82
Males	Basic	20.25	21.06	10.23	12.08
Males	Secondary	21.50	22.41	10.72	13.13
Males	Tertiary	23.74	24.19	11.61	13.47
Females	Population	25.46	25.85	14.13	16.07
Females	Basic	24.63	25.00	13.72	15.45
Females	Secondary	25.81	26.11	14.06	15.84
Females	Tertiary	27.08	27.35	14.99	17.84

B. Remaining Healthy Life Expectancy

Sex	Education	start.Healthy_60
Males	Population	17.52
Males	Basic	16.72
Males	Secondary	17.34
Males	Tertiary	19.25
Females	Population	20.53
Females	Basic	19.99
Females	Secondary	20.68
Females	Tertiary	21.65

C. Remaining Life Expectancy with Hearing Loss

Sex	Education	start.Healthy_60	start.HL_60
Males	Population	2.37	20.29
Males	Basic	2.08	19.22
Males	Secondary	2.60	20.52
Males	Tertiary	2.76	22.11
Females	Population	2.46	23.03
Females	Basic	2.20	22.17
Females	Secondary	2.63	23.24
Females	Tertiary	2.90	24.66

Continued in the next page

Supplementary Materials
Downstream of Hearing Loss: A Population-Based Multistate Analysis of Lifetime Risk and Years Lived with Hearing Loss, Dementia and Their Comorbidity in Finland

D. Remaining Life Expectancy with Dementia

Sex	Education	start.Healthy_60	start.Dem_60
Males	Population	1.10	10.10
Males	Basic	1.05	9.65
Males	Secondary	1.10	10.11
Males	Tertiary	1.23	11.08
Females	Population	1.89	13.47
Females	Basic	1.89	13.06
Females	Secondary	1.90	12.35
Females	Tertiary	1.94	14.43

E. Remaining Life Expectancy with Comorbidity

Sex	Education	start.Healthy_60	start.HL_60	start.Dem_60	start.Comorb_60
Males	Population	0.44	1.9	0.57	12.82
Males	Basic	0.4	1.84	0.58	12.08
Males	Secondary	0.46	1.89	0.61	13.13
Males	Tertiary	0.5	2.08	0.53	13.47
Females	Population	0.58	2.82	0.66	16.07
Females	Basic	0.55	2.82	0.67	15.45
Females	Secondary	0.61	2.87	0.71	15.84
Females	Tertiary	0.58	2.69	0.56	17.84

Supplementary Materials
Downstream of Hearing Loss: A Population-Based Multistate Analysis of Lifetime Risk and Years Lived with Hearing Loss, Dementia and Their Comorbidity in Finland

Table S2. Lifetime risk using different index ages.

Lifetime risk	Men	Women
Index age = 70		
Lifetime risk of dementia (from healthy)	24.60	33.53
Lifetime risk of comorbidity (from hearing loss)	35.91	44.24
Lifetime risk of hearing loss (from healthy)	20.72	20.26
Lifetime risk of comorbidity (from healthy)	8.63	9.73
Index age = 80		
Lifetime risk of dementia (from healthy)	26.04	33.49
Lifetime risk of comorbidity (from hearing loss)	33.88	41.27
Lifetime risk of hearing loss (from healthy)	15.26	15.71
Lifetime risk of comorbidity (from healthy)	5.97	6.99
Index age = 90		
Lifetime risk of dementia (from healthy)	16.13	20.97
Lifetime risk of comorbidity (from hearing loss)	18.48	23.52
Lifetime risk of hearing loss (from healthy)	8.46	8.31
Lifetime risk of comorbidity (from healthy)	1.98	2.23
Partial risk for ages 60-80, index age = 60		
Lifetime risk of dementia (from healthy)	10.86	20.97
Lifetime risk of comorbidity (from hearing loss)	15.26	23.52
Lifetime risk of hearing loss (from healthy)	16.48	8.31
Lifetime risk of comorbidity (from healthy)	2.49	2.29