

Supplementary materials

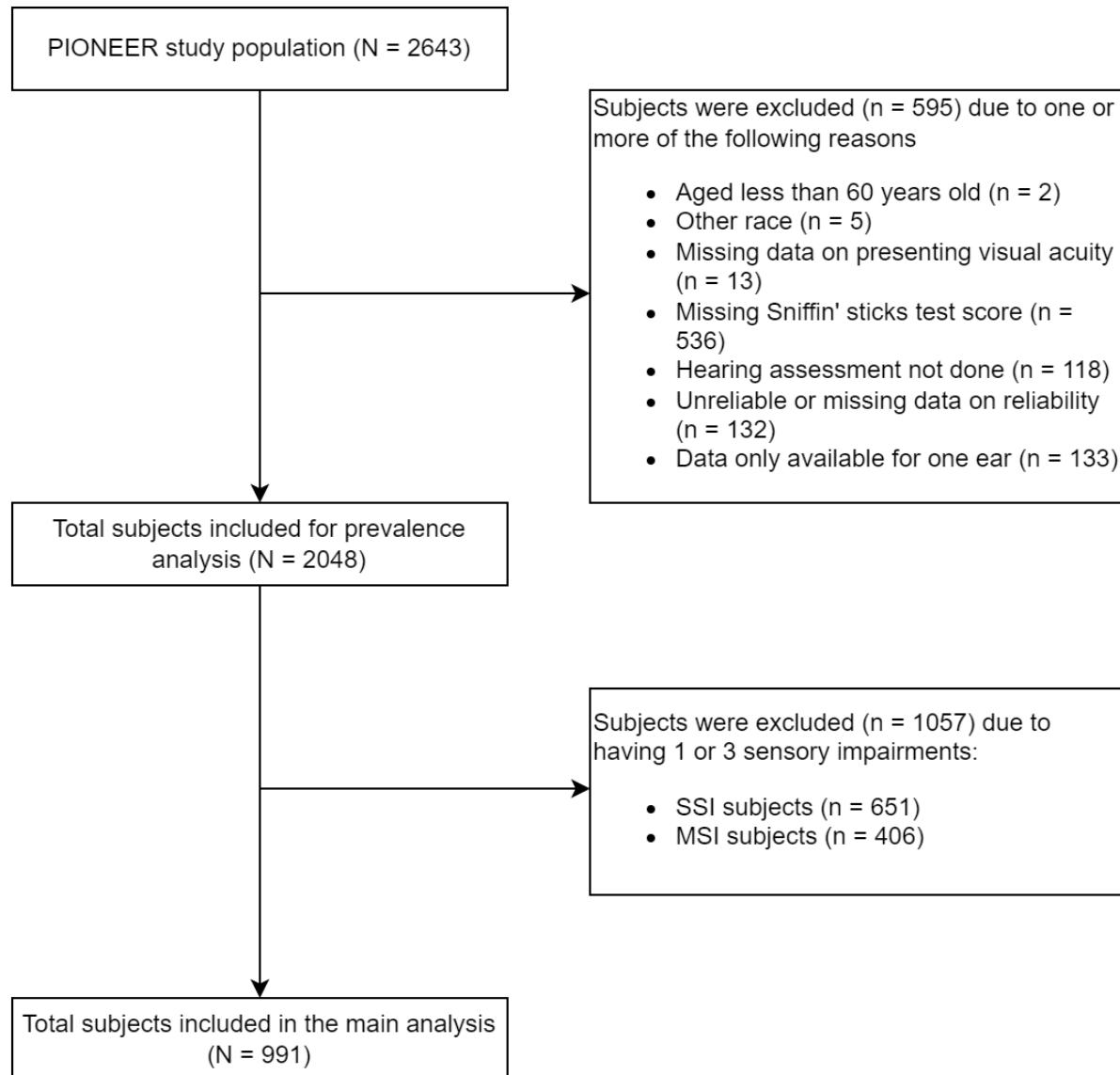
Supplement 1

In short, 6377 individuals received study invitation letters after being carefully selected from a national database. Study recruitment officers visited these individuals at home to ascertain eligibility and agreement to participate. Of the 6377 invited, 1015 (15.9%) were classified as 'uncontactable' because of invalid address(s), were unresponsive to ≥ 3 home visit attempts, and/or living in residences that were inaccessible because of security restrictions. In addition, 648 (10.2%) individuals were excluded because of incarceration, death, residence abroad or in a nursing home; while a further 994 (15.6%) were deemed ineligible because they were terminally ill, bedridden, or otherwise unable to give informed consent due to severe cognitive (assessed using 6 item Cognitive Impairment Test (6-CIT))⁷⁹, hearing impairment or muteness. Of the remaining 3720 (69.4%) eligible individuals, 1055 refused (28.33%), 23 (0.62%) were undecided and a total of 2643 (71.05%) participated in the study. Reasons for refusal were lack of interest (n=895, 84.9%) or time needed to participate in the study (n=159, 15.1%). Compared to participants (n=2,643), non-participants (n=1,054) were older ($p<0.001$), more likely to be female ($p<0.001$), and Chinese ($p<0.001$). About 54.8% of the sample was female, and 49.8%, 25.1%, 25.0% were Chinese, Indians, and Malays, respectively.

Supplement 2

Additional analysis with different VI and HI definitions. VI = PDVA worse than 20/40 ($> 0.3 \text{ logMAR}$) in the worst eye. HI = PTA $> 25 \text{ dB}$ in the worst ear.

Figure S1: Subject flowchart of PIONEER study population for the additional analysis



Supplementary Tables

1. **Table S1.** Demographic, systemic, socioeconomic characteristics and patient reported outcomes of participants in the PIONEER study, stratified by DS1 status (NSI, DS1).
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Table S1. Demographic, systemic, socioeconomic characteristics and patient reported outcomes of participants in the PIONEER study, stratified by DSI status (NSI, DSI).

Characteristics	NSI (N=137)	DSI ¹ (N=854)	Overall (N=991)
	Mean (SD) or n (%)		
Age (year)	65.7 (4.9)	73.6 (7.9)	72.5 (8.0)
Female gender	94 (68.6)	453 (53.0)	547 (55.2)
Race			
Chinese	69 (50.4)	422 (49.4)	491 (49.5)
Malay	32 (23.4)	233 (27.3)	265 (26.7)
Indian	36 (26.3)	199 (23.3)	235 (23.7)
Low socioeconomic status	8 (5.8)	154 (18.0)	162 (16.3)
Living alone	7 (5.1)	90 (10.5)	97 (9.8)
BMI categories			
Underweight	9 (6.6)	44 (5.2)	53 (5.3)
Normal	38 (27.7)	228 (26.7)	266 (26.8)
Overweight/Obese	90 (65.7)	580 (67.9)	670 (67.6)
Smoking status			
Never smoked or past smoker	129 (94.2)	743 (87.0)	872 (88.0)
Current smoker	7 (5.1)	86 (10.1)	93 (9.4)
Alcohol frequency			
None	109 (79.6)	715 (83.7)	824 (83.1)
≤ 4 days/week	11 (8.0)	67 (7.8)	78 (7.9)
> 4 days/week	2 (1.5)	22 (2.6)	24 (2.4)
Polypharmacy	13 (9.5)	195 (22.8)	208 (21.0)
Any systemic condition	130 (94.9)	838 (98.1)	968 (97.7)
Systemic conditions			
Diabetes	32 (23.4)	302 (35.4)	334 (33.7)
Hypertension	103 (75.2)	738 (86.4)	841 (84.9)
Dyslipidaemia	119 (86.9)	692 (81.0)	811 (81.8)
CVD	9 (6.6)	149 (17.4)	158 (15.9)
CKD	3 (2.2)	169 (19.8)	172 (17.4)
Multimorbidity	37 (27.0)	357 (41.8)	394 (39.8)

1. DSI subjects consists of 29 (3.4%) VI+OI subjects, 476 (55.7%) VI+HI subjects, and 349 (40.9%) OI+HI subjects. BMI: Body Mass Index; BP: Blood Pressure; CKD: Chronic Kidney Disease; CVD: Cardiovascular Disease; DSI: Dual Sensory Impairment; HI: Hearing Impairment; NSI: No Sensory Impairment; OI: Olfactory Impairment; SD: Standard Deviation; VI: Visual Impairment

Table S2. Weighted prevalence of DSI, stratified by age, gender and ethnicity in the PIONEER study.

Age group	All (N = 2048)		Gender				Ethnicity						
			Male (N = 919)		Female (N = 1129)		Chinese (N = 992)		Malay (N = 582)		Indian (N = 474)		
	n	Weighted, % (95% CI)	n	Weighted, % (95% CI)	n	Weighted, % (95% CI)	n	Weighted, % (95% CI)	n	Weighted, % (95% CI)	n	Weighted, % (95% CI)	
VI+OI													
60-69	16	2.5 (1.3, 4.3)	4	0.7 (0.1, 2.5)	12	4.3 (2.1, 7.7)	10	2.8 (1.4, 5.1)	3	1.2 (0.2, 3.5)	3	1.5 (0.3, 4.5)	
70-79	8	1.5 (0.6, 3.1)	3	1.2 (0.2, 4.1)	5	1.7 (0.5, 4.1)	6	1.6 (0.6, 3.5)	1	0.5 (0.0, 2.9)	1	0.6 (0.0, 3.5)	
≥ 80	5	1.1 (0.3, 2.8)	3	2.1 (0.4, 6.2)	2	0.5 (0.0, 2.4)	4	1.2 (0.3, 3.2)	0	-	1	0.6 (0.0, 3.5)	
P-trend		P-trend = 0.102		P-trend = 0.940		P-trend = 0.033		P-trend = 0.167		P-trend = 0.171		P-trend = 0.541	
Total	29	2.0 (1.2, 3.1)	10	1.0 (0.4, 2.2)	19	2.9 (1.6, 4.8)	20	2.2 (1.3, 3.5)	4	0.9 (0.2, 2.4)	5	1.2 (0.3, 3.0)	
VI+HI													
60-69	165	18.6 (15.4, 22.2)	68	17.7 (13.2, 22.9)	97	19.5 (15.0, 24.7)	64	17.8 (14.0, 22.2)	62	23.1 (18.1, 28.7)	39	20.2 (14.7, 26.6)	
70-79	178	26.0 (22.1, 30.1)	60	20.0 (14.6, 26.3)	118	31.2 (25.8, 37.0)	98	26.3 (21.9, 31.1)	44	24.6 (18.5, 31.6)	36	23.7 (17.1, 31.3)	
≥ 80	133	27.3 (22.2, 32.8)	60	27.9 (20.9, 35.9)	73	26.9 (20.0, 34.7)	73	28.1 (22.3, 34.4)	29	20.8 (13.9, 29.3)	31	23.7 (16.4, 32.3)	
P-trend		P-trend = 0.003		P-trend = 0.090		P-trend = 0.008		P-trend = 0.005		P-trend = 0.800		P-trend = 0.053	
Total	476	22.0 (19.7, 24.4)	188	19.5 (16.3, 23.1)	288	24.1 (21.0, 27.5)	235	21.8 (19.2, 24.7)	135	23.2 (19.6, 27.2)	106	21.5 (17.6, 25.9)	
OI+HI													
60-69	104	11.7 (9.2, 14.7)	70	17.0 (12.7, 22.1)	34	6.6 (4.0, 10.2)	40	11.1 (8.1, 14.8)	32	12.9 (9.0, 17.6)	32	17.3 (12.1, 23.5)	
70-79	134	19.6 (16.1, 23.4)	72	23.5 (17.7, 30.0)	62	16.2 (12.1, 21.0)	70	19.6 (15.6, 24.1)	32	17.7 (12.4, 24.1)	32	21.7 (15.4, 29.0)	
≥ 80	111	18.7 (14.8, 23.1)	61	23.7 (17.6, 30.8)	50	15.5 (10.6, 21.5)	57	18.4 (14.0, 23.4)	30	21.7 (14.6, 30.3)	24	19.2 (12.6, 27.4)	
P-trend		P-trend <0.001		P-trend = 0.076		P-trend <0.001		P-trend <0.001		P-trend <0.001		P-trend = 0.156	
Total	349	15.0 (13.1, 17.0)	203	19.6 (16.4, 23.2)	146	10.8 (8.7, 13.2)	167	14.7 (12.5, 17.1)	94	15.0 (12.0, 18.4)	88	18.6 (14.9, 22.9)	

Weighted prevalences are calculated with sampling weights specific to each age group, gender and ethnicity to adjust for oversampling and post-stratification weights to align to the population distribution based on the 2020 Singapore Census. P-trend will not be computed for counts less than 5 in any age group or if the total count is less than 20.

CI: Confidence Interval; DSI: Dual Sensory Impairment; HI: Hearing Impairment; OI: Olfactory Impairment; VI: Visual Impairment

Table S3A. Factors associated with DSI (VI+HI)

Risk factor	Model		Dominance analysis	
	OR (95% CI)	P-value	Contribution ¹ (%)	Rank ²
Age (year)	1.18 (1.13, 1.25)	<0.001	65.9	1
Gender			1.0	9
Female	Reference	NA		
Male	0.90 (0.50, 1.65)	0.74		
Race			1.4	7
Chinese	Reference	NA		
Malay	1.55 (0.78, 3.11)	0.209		
Indian	1.27 (0.64, 2.54)	0.495		
Low socioeconomic status			14.6	2
No	Reference	NA		
Yes	2.33 (1.01, 6.08)	0.061		
Living alone			1.7	6
No	Reference	NA		
Yes	1.66 (0.63, 4.87)	0.329		
BMI categories			1.0	8
Normal	Reference	NA		
Underweight	0.41 (0.12, 1.32)	0.133		
Overweight/Obese	0.81 (0.42, 1.54)	0.534		
Smoking status			3.0	5
Never or past smoker	Reference	NA		
Current smoker	3.25 (1.14, 10.91)	0.038		
Alcohol frequency			0.0	10
None	Reference	NA		
≤ 4 days/week	0.98 (0.41, 2.46)	0.963		
> 4 days/week	2.19 (0.45, 16.59)	0.375		
Polypharmacy			3.8	4
No	Reference	NA		
Yes	1.55 (0.69, 3.68)	0.302		
Multimorbidity			7.6	3
No	Reference	NA		
Yes	1.64 (0.88, 3.10)	0.126		

1: Contribution is the standardized dominance statistics in the dominance analysis from the model.

2. The ranks of each predictor are ranked from predictors with the greatest contribution to the least.

Low Socioeconomic Status: Having primary or lower education and individual monthly income < SGD2000; BMI categories: BMI < 18.5 kg/m² as underweight, BMI between 18.5 and 22.9 kg/m² (inclusive) as normal, BMI ≥ 23 kg/m² as overweight/obese; Polypharmacy: Taking ≥ 5 medications (exclude supplements or vitamins); Multimorbidity: Having more than or equal to 3 systemic conditions (diabetes, hypertension, dyslipidemia, CVD, CKD)

BMI: Body Mass Index; CI: Confidence Interval; CKD: Chronic Kidney Disease; CVD: Cardiovascular Disease; DSI: Dual Sensory Impairment; HI: Hearing Impairment; OR: Odds Ratio; VI: Visual Impairment

Table S3B. Factors associated with DSI (OI+HI)

Risk factor	Model		Dominance analysis	
	OR (95% CI)	P-value	Contribution ¹ (%)	Rank ²
Age (year)	1.22 (1.15, 1.30)	<0.001	70.9	1
Gender			13.3	2
Female	Reference	NA		
Male	2.74 (1.47, 5.21)	0.002		
Race			0.4	9
Chinese	Reference	NA		
Malay	1.19 (0.57, 2.52)	0.647		
Indian	1.11 (0.53, 2.31)	0.786		
Low socioeconomic status			0.4	10
No	Reference	NA		
Yes	1.22 (0.43, 3.72)	0.712		
Living alone			1.5	7
No	Reference	NA		
Yes	1.39 (0.48, 4.49)	0.557		
BMI categories			0.9	8
Normal	Reference	NA		
Underweight	0.44 (0.12, 1.57)	0.207		
Overweight/Obese	0.83 (0.40, 1.69)	0.607		
Smoking status			3.5	4
Never or past smoker	Reference	NA		
Current smoker	2.83 (0.97, 9.67)	0.072		
Alcohol frequency			1.6	6
None	Reference	NA		
≤ 4 days/week	0.71 (0.28, 1.83)	0.466		
> 4 days/week	1.12 (0.21, 8.97)	0.902		
Polypharmacy			4.3	3
No	Reference	NA		
Yes	1.79 (0.75, 4.50)	0.200		
Multimorbidity			3.2	5
No	Reference	NA		
Yes	1.07 (0.52, 2.19)	0.853		

1: Contribution is the standardized dominance statistics in the dominance analysis from the model.

2. The ranks of each predictor are ranked from predictors with the greatest contribution to the least.

Low Socioeconomic Status: Having primary or lower education and individual monthly income < SGD2000; BMI categories: BMI < 18.5 kg/m² as underweight, BMI between 18.5 and 22.9 kg/m² (inclusive) as normal, BMI ≥ 23 kg/m² as overweight/obese; Polypharmacy: Taking ≥ 5 medications (exclude supplements or vitamins); Multimorbidity: Having more than or equal to 3 systemic conditions (diabetes, hypertension, dyslipidemia, CVD, CKD)

BMI: Body Mass Index; CI: Confidence Interval; CKD: Chronic Kidney Disease; CVD: Cardiovascular Disease; DSI: Dual Sensory Impairment; HI: Hearing Impairment; OI: Olfactory Impairment; OR: Odds Ratio

Table S4. Associations between DSI and patient-reported outcomes.

PRO	Exposure	Estimate ¹ (95% CI)	P-value	Overall marginal effect (95% CI)	Change (%)
EQ-5D-5L					
	NSI	Reference	NA	NA	NA
	VI+OI	0.014 (-0.033, 0.061)	0.560	0.014 (-0.033, 0.061)	1.53
	VI+HI	-0.021 (-0.045, 0.003)	0.091	-0.021 (-0.045, 0.003)	-2.26
	OI+HI	0.002 (-0.023, 0.027)	0.864	0.002 (-0.023, 0.027)	0.24
Life space mobility					
	NSI	Reference	NA	NA	NA
	VI+OI	-0.064 (-0.431, 0.303)	0.732	-0.064 (-0.430, 0.302)	-1.38
	VI+HI	-0.132 (-0.319, 0.054)	0.164	-0.132 (-0.318, 0.054)	-2.86
	OI+HI	-0.137 (-0.333, 0.059)	0.171	-0.137 (-0.333, 0.059)	-2.96
Low IADL status					
	NSI	Reference	NA	NA	NA
	VI+OI	OR: 1.590 (0.294, 6.731)	0.552	0.053 (-0.132, 0.238)	46.91
	VI+HI	OR: 1.811 (0.838, 4.282)	0.15	0.070 (-0.017, 0.157)	62.67
	OI+HI	OR: 1.450 (0.645, 3.532)	0.387	0.041 (-0.048, 0.131)	36.46
Falls					
	NSI	Reference	NA	NA	NA
	VI+OI	OR: 0.638 (0.170, 1.932)	0.458	-0.072 (-0.246, 0.103)	-28.37
	VI+HI	OR: 0.584 (0.325, 1.061)	0.074	-0.084 (-0.182, 0.014)	-33.17
	OI+HI	OR: 0.771 (0.422, 1.426)	0.402	-0.044 (-0.148, 0.061)	-17.13
Hospitalisations					
	NSI	Reference	NA	NA	NA
	VI+OI	OR: 0.910 (0.043, 7.115)	0.936	-0.005 (-0.116, 0.106)	-8.58
	VI+HI	OR: 1.645 (0.575, 5.941)	0.392	0.031 (-0.032, 0.094)	59.09
	OI+HI	OR: 1.333 (0.447, 4.939)	0.631	0.017 (-0.046, 0.079)	31.04
Osteoporosis					
	NSI	Reference	NA	NA	NA
	VI+OI	OR: 0.112 (0.006, 0.600)	0.039	-0.239 (-0.367, -0.111)	-83.44
	VI+HI	OR: 1.274 (0.737, 2.246)	0.394	0.047 (-0.060, 0.154)	15.90

	OI+HI	OR: 0.735 (0.406, 1.346)	0.312	-0.055 (-0.162, 0.053)	-18.75
Frailty	NSI	Reference	NA	NA	NA
	VI+OI	OR: 0.623 (0.030, 4.386)	0.683	-0.033 (-0.174, 0.108)	-34.29
	VI+HI	OR: 1.535 (0.626, 4.356)	0.379	0.040 (-0.042, 0.122)	42.90
	OI+HI	OR: 0.947 (0.366, 2.782)	0.916	-0.004 (-0.085, 0.076)	-4.56
Sarcopenia	NSI	Reference	NA	NA	NA
	VI+OI	OR: 1.290 (0.476, 3.405)	0.608	0.055 (-0.157, 0.266)	14.95
	VI+HI	OR: 1.164 (0.702, 1.950)	0.559	0.033 (-0.077, 0.142)	8.88
	OI+HI	OR: 1.255 (0.742, 2.141)	0.400	0.049 (-0.065, 0.163)	13.32

1. For PROs EQ-5D-5L, and life space mobility, the estimates are coefficients derived from linear regression models. The remaining PROs are odds ratios (OR) derived from logistic regression models.

All models are adjusted for age, gender, ethnicity, low socioeconomic status, living alone, smoking status, polypharmacy and multimorbidity.

CI: Confidence Interval; DSI: Dual Sensory Impairment; EQ-5D-5L: EuroQoL 5-dimension 5-level; HI: Hearing Impairment; IADL: Instrumental Activities of Daily Living; NSI: No sensory impairment; OI: Olfactory Impairment; OR: Odds Ratio; PRO: Patient-Reported Outcome; VI: Visual Impairment

Table S5. Associations between DSI and costs using two-parts model.

Outcome	Exposure	First part		Second part		Overall marginal effect (95% CI)
		OR (95% CI)	P-value	Cost Ratio (95% CI)	P-value	
Healthcare cost						
	Robust	Reference	NA	Reference	NA	NA
	VI+OI	0.83 (0.31, 2.11)	0.701	1.77 (0.41, 12.63)	0.473	138.51 (-433.94, 710.96)
	VI+HI	0.57 (0.35, 0.93)	0.024	2.49 (1.07, 5.51)	0.031	184.36 (-81.54, 450.25)
	OI+HI	0.51 (0.31, 0.86)	0.011	3.55 (1.43, 8.34)	0.003	322.87 (-22.25, 668.00)

In the two-parts model, the first part results were odds ratios from logistic regression models and the second part results were cost ratios (exponentiated coefficients) from gamma generalised linear models with a log-link function for healthcare cost.

All models are adjusted for age, gender, ethnicity, low socioeconomic status, living alone, smoking status, polypharmacy and multimorbidity.

CI: Confidence Interval; DSI: Dual Sensory Impairment; HI: Hearing Impairment; NSI: No Sensory Impairment; OI: Olfactory Impairment; OR: Odds Ratio; PRO: Patient-Reported Outcome; VI: Visual Impairment