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Socioeconomic Inequalities

Education-related inequalities in cause-specific mortality: first estimates for Australia using individual-level linked census and mortality data

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Abstract

Background: Socioeconomic inequalities in mortality are evident in all high-income countries, and ongoing monitoring is recommended using linked census-mortality data. Using such data, we provide the first estimates of education-related inequalities in cause-specific mortality in Australia, suitable for international comparisons.

Methods: We used Australian Census (2016) linked to 13 months of Death Registrations (2016–17). We estimated relative rates (RR) and rate differences (RD, per 100 000 person-years), comparing rates in low (no qualifications) and intermediate (secondary school) with high (tertiary) education for individual causes of death (among those aged 25–84 years) and grouped according to preventability (25–74 years), separately by sex and age group, adjusting for age, using negative binomial regression.

Results: Among 13.9 M people contributing 14 452 732 person-years, 84 743 deaths occurred. All-cause mortality rates among men and women aged 25–84 years with low education were 2.76 [95% confidence interval (CI): 2.61–2.91] and 2.13 (2.01–2.26) times the rates of those with high education, respectively. We observed inequalities in most causes of death in each age-sex group. Among men aged 25–44 years, relative and absolute inequalities were largest for injuries, e.g. transport accidents [RR = 10.1 (5.4–18.7), RD = 21.2 (14.5–27.9)]). Among those aged 45–64 years, inequalities were greatest for chronic diseases, e.g. lung cancer [men RR = 6.6 (4.9–8.9), RD = 57.7 (49.7–65.8)] and ischaemic heart disease [women RR = 5.8 (3.7–9.1), RD = 20.2 (15.8–24.6)], with similar patterns for people aged 65–84 years. When grouped according to preventability, inequalities were large for causes amenable to behaviour change and medical intervention for all ages and causes amenable to injury prevention among young men.

Conclusions: Australian education-related inequalities in mortality are substantial, generally higher than international estimates, and related to preventability. Findings highlight opportunities to reduce them and the potential to improve the health of the population.

Key words: Australia, health inequalities, socioeconomic position, education, mortality, cause-specific mortality, linked data

Key Messages

- Using linked Australian Census (2016) and Death Registrations (2016-17), we provide the first estimates of education-related inequalities in cause-specific mortality for Australia, broadly suitable for international comparisons.
- Among men aged 25-44 years, inequalities were largest for injuries, with mortality rates among those with low education six to ten times the rates of those with high education. Among the middle and older age groups, inequalities were largest for chronic diseases, where mortality rates among those with low education were between two and seven times the rates of those with high education.
- In 2016-17, around half of all deaths for men and one-third of deaths for women aged 25-84 years were associated with less than tertiary education. The majority of these excess deaths were attributable to leading causes.
- The substantial inequalities seen in preventable deaths highlight ongoing opportunities to reduce inequalities in mortality and to improve the overall health of the Australian population.
- Australian inequality estimates are generally higher than those for comparable countries and earlier time periods, but further standardization of methods and reporting would enhance the validity of such comparisons.

Background

Death rates in high-income countries, including Australia, have decreased substantially over recent decades,[1] but clear inverse socioeconomic gradients in mortality persist.[2–5] Understanding the reasons for these inequalities, including identifying causes of death with the largest contribution to these differences, is crucial for informing strategies to reduce health inequalities and improving the overall health of the population. This requires accurate measurement and ongoing monitoring of inequalities in cause-specific mortality, including the ability to compare inequalities across countries and over time.

The Organisation for Economic Cooperation and Development (OECD) recommends measuring inequalities using longitudinal, census-linked-to-mortality data, with education as the socioeconomic indicator.[6] Many high-income countries, including most European countries, monitor inequalities using this approach and have shown that inequalities vary substantially by cause of death. Consistent with the notion that inequalities reflect unequal distribution of resources required to protect and promote good health, inequalities are larger for causes of death amenable to prevention, including injury, causes linked to smoking and excessive alcohol consumption and causes amenable to medical care, compared with other causes of death.[7,8]

In Australia, routine estimates of inequalities in cause-specific mortality are based on area-level measures of socioeconomic position (SEP). This approach, most commonly using Socio-Economic Indexes for Areas (SEIFA) Index of Relative Socio-Economic Disadvantage (IRSD) quintiles,[9–12] makes it difficult to compare inequality estimates with other countries. Further, this method misclassifies people in regard to their individual-level SEP because of the heterogeneity within statistical areas on which these measures are based (in Australia, inequality estimates are based on areas containing an average of approximately 10 000 people).[9–12] This typically results in lower estimates of inequalities compared with those based on individual-level measures.[13] Whereas individual-level SEP measures are not collected in mortality data in Australia, recent developments in linkage of national data has led to the availability of these data through linkage with census data.

Thus, in line with international standards, education-related inequalities in mortality can be quantified.

The aim of this study was to quantify, for the first time, relative and absolute education-related inequalities in cause-specific mortality, including the leading causes of death and causes categorized according to preventability, for Australia, using census-linked-to-death data.

Methods

We used linked 2016 Census of Population and Housing and 2016–17 Death Registrations to create a cohort study of the resident population of Australia, followed up for 13 months for cause-specific mortality.

Data sources and sample

Data came from the Multi-Agency Data Integration Project (MADIP), a partnership among Australian Government agencies to link administrative and survey data, including data relating to demographic characteristics and health. Underpinning MADIP data is a Person Linkage Spine, used to create a person-level identification key by linking data from three administrative databases, together resulting in virtually complete coverage of the resident population[4]: the Medicare Enrolments Database (records for those covered by Medicare, Australia's universal health insurer); the Social Security and Related Information database (records for those receiving government benefits); and the Personal Income Tax database (records for those who lodge a tax return). The Spine is the dataset to which all other data sources are linked and contains basic demographic information only. In this study, the 2016 Census was linked with Death Registrations via the Spine. Linkage was performed using deterministic and probabilistic methods, using name, full date of birth, address and sex, with linkage rates of 92% for the Census and 97% for deaths.[14]

The scope of the 2016 Census was usual residents of Australia on the night of 9 August 2016, living in private and non-private dwellings.[15] It had an estimated person response rate of 94.8%, with some variation in response by ethnicity and location.[16] We included all usual residents aged 25-84 years whose census record was linked to the Spine. Death Registrations data available through the MADIP contained information on month and year of death occurrence, and underlying cause of death for all deaths registered in Australia in the 2016 and 2017 calendar years.[17] Death Registrations data were complete until August 2017, allowing for an almost 13-month follow-up period.

Variables

Education

We derived highest level of education from two census variables: highest year of school completed (from ≤Year 8 to Year 12 or equivalent) and highest non-school qualification (from no non-school qualification, to postgraduate degree). We created three education categories, corresponding to International Standard Classification of Education (ISCED) categories[18]: low education (no secondary school graduation or other qualification, ISCED levels 0-2); intermediate education (secondary graduation with/without other non-tertiary qualifications, ISCED levels 3-5); and high education (tertiary qualification, irrespective of secondary school level, ISCED levels 6-8). Missing data on education (5.3%) were imputed using single imputation with ordered logistic regression (Supplementary File 1, available as Supplementary data at *IJE* online).

Cause of death

Underlying cause of death was coded according to the International Classification of Diseases and Related Health Problems, Tenth Revision (ICD-10) and grouped using the Australian Bureau of Statistics method of identifying leading causes of death[19] (Supplementary File 2, Table S2.1 contains ICD-10 codes, available as Supplementary data at *IJE* online). We obtained leading causes directly from complete Death Registrations using deaths occurring in the study time period (i.e. August 2016-August 2017). We further grouped causes by broad cause (circulatory diseases, cancers, external causes, infectious diseases and other causes, Supplementary File 2, Table S2.2, available as Supplementary data at *IJE* online) and preventability, based on established methods, which included amenable causes (three groups: amenable to behaviour change, to medical intervention, to injury prevention) and non-preventable causes (Supplementary File 2, Table S2.3, available as Supplementary data at *IJE* online).[7] As only month and year of death were available in the Death Registrations data in MADIP, all deaths were assumed to have occurred on the 15th day of the month.

Covariates

Age at census, in years, and sex were obtained from the Census.

Analysis

Preceding our main analysis, we performed data validation analyses to assess potential selection bias from excluding people without a census record and incomplete linkage (Supplementary File 3, available as Supplementary data at *IJE* online). First, we compared all-cause and cause-specific mortality rates, produced using the analysis file with official national estimates, and estimates produced using complete Death Registrations (numerator) and the 2016 mid-year estimated resident population (denominator). Second, we estimated socioeconomic inequalities using SEIFA IRSD (the area-based measure of SEP), comparing estimates produced using the analysis file with those produced using complete Death Registrations and the 2016 mid-year estimated resident population.

In our main analysis, we estimated relative and absolute education-related inequalities for the 10 leading causes of death for each sex-age group, and for causes grouped according to preventability. All analyses were performed separately for men and women and by broad age group.

To quantify relative inequalities in death rates (deaths/person-years), we used negative binomial regression, due to over-dispersion in the data, to estimate relative rates (RR) with 95% confidence intervals (CIs) for low and for intermediate compared with high education, focusing on estimates of low vs high education. For each person, person-years-at-risk was the time from the date of the Census (9 August 2016) to the date of death or end of the study period (31 August 2017), whichever occurred first. Analyses were age-adjusted, using 5-year age groups.

To estimate absolute inequalities in death rates, we estimated rate differences (RD) per 100 000 person-years, using high education as the reference group. Given that absolute death rates were underestimated in our study (Supplementary File 3, Tables S3.3-S3.4, available as Supplementary data at *IJE* online), we maximized external validity of the RDs by estimating the education-specific mortality rates by applying the relevant RRs (described above) to age-sex specific mortality rates for Australia, calculated using data from complete 2016 Death Registrations and the 2016 mid-year estimated resident population.[20] We also estimated the number of annual excess deaths associated with less than tertiary education, by multiplying the RDs by the age-sex-specific usual resident population in 2016 with low and intermediate education and summing them.

We also report the relative index of inequality (RII). The RII converts a categorical measure to a continuous measure based on the proportion of people in each education category, and can be interpreted as the ratio of the mortality rates predicted for those on the hypothetical lowest and highest points on the continuous measure.[21]

In supplementary analyses, we quantified inequalities in broad causes of death, and ranked individual causes by magnitude of relative inequalities, including all leading causes of death and other causes with at least 50 deaths recorded in the analysis file within the relevant age-sex group.

Analyses were conducted through the Australian Bureau of Statistics (ABS) virtual DataLab using Stata 15.[22] Ethics approval for this study was granted by the Australian National University Human Research Ethics Committee (reference 2016/666). We notified ABS of this ethics approval as part of a formal application to access the linked dataset in the ABS Virtual Datalab.

Results

There were 15 562 042 census records for usual residents of Australia aged 25-84 years[23] (Figure 1). After excluding

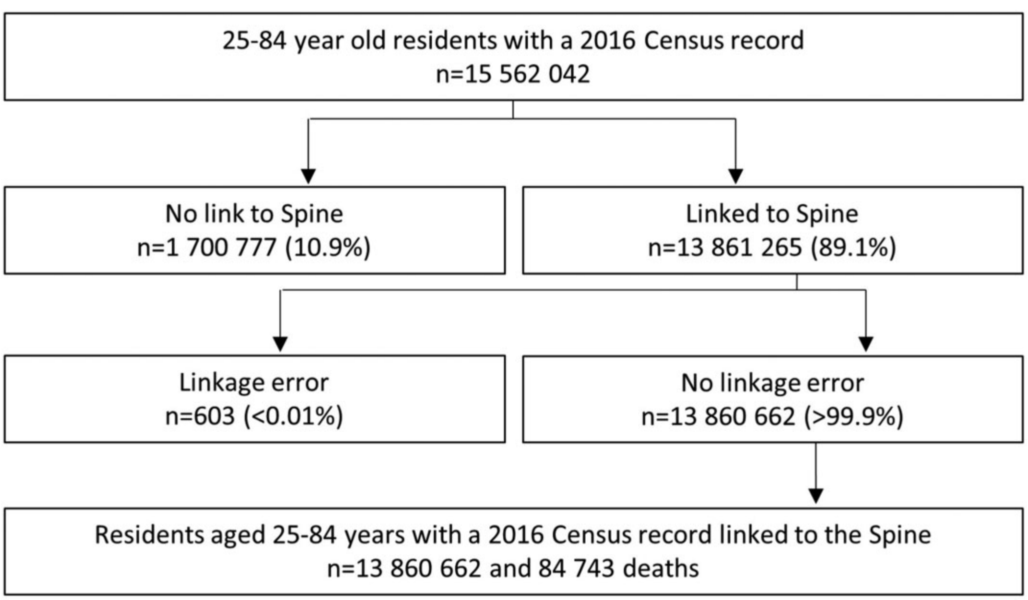

Figure 1 Study flow diagram

records which did not link to the Person Linkage Spine (n = 1 700 777, 11%) and records linked in error (*n* = 603, <0.01%), our final sample included 13 860 662 residents aged 25-84 years (87% of the in-scope population, see Supplementary File 3, Table S3.1, available as Supplementary data at *IJE* online[20]) among whom there were 84 743 deaths (85% of deaths in this age group; 98% of deaths occurring between ages 25-86 years linked to the Spine, Supplementary File 3, Table S3.2, available as Supplementary data at *IJE* online). After imputation, 26.8% of the sample had low, 47.9% had intermediate and 25.3% had high levels of education (Supplementary File 1, Table S1.3, available as Supplementary data at *IJE* online).

In general, validation analyses provided support for use of the analysis file to quantify education-related inequalities in mortality, as area-level estimates produced using the analysis file were comparable to estimates produced using complete Death Registrations. The exception to this was among younger women where inequality estimates were underestimated in the analysis file (Supplementary File 3, available as Supplementary data at *IJE* online).

Inequalities in all-cause mortality

All-cause mortality rates were higher in those with lower levels of education: the age-adjusted all-cause mortality RR (low versus high education) was 2.76 (95% CI: 2.61, 2.91) among men aged 25-84 [RD = 697 per 100 000 person-years (655-739)], and 2.13 (2.01, 2.26) among women of the same age [RD = 350 per 100 000 person-years (322-378) (Supplementary File 4, Tables S4.1-S4.2, available as Supplementary data at *IJE* online)], see Tables 1 and 2 for age-stratified results.

Inequalities in leading causes of death

With few exceptions, those with lower levels of education had higher mortality rates for leading causes of death (Tables 1 and 2). The magnitude of relative and absolute inequalities varied substantially by cause and by age and sex.

For men aged 25–44 years, relative and absolute inequalities were largest for external causes of death, although there was considerable uncertainty in the estimates due to small numbers of deaths (total deaths = 2499, Table 1). This included deaths from land transport accidents, accidental poisoning and suicide (RRs ranged from 6.10 to 10.1, RDs from 21.2 to 42.7 per 100 000 person-years, Table 1). Relative inequalities among younger men were also large for ischaemic heart disease and cirrhosis of the liver (RRs were between 5 and 6), although absolute inequalities were small (i.e. <12 per 100 000 person-years). There was little evidence of inequalities for brain cancer and colorectal cancer among young men. Due to concerns regarding internal validity, inequality estimates for women aged 25-44 are presented as Supplementary material only and should be interpreted with caution (Supplementary File 3, Table S3.6, available as Supplementary data at *IJE* online).

For men and women aged 45-64 years, relative and absolute inequalities were largest for cancer of the trachea, bronchus and lung, ischaemic heart disease, cerebrovascular disease, cirrhosis and other liver diseases, and chronic lower respiratory disease (RRs for these causes ranged from 3.00 to 33.4; RDs from 11.0 to 68.0 per 100 000 person-years) (Tables 1 and 2). Relative inequalities were also substantial for colorectal cancer, cancer of the pancreas and, lymphoma and leukaemias for men and breast cancer for women, although absolute differences were smaller relative to other causes.

In the 65-84 year old age group also, the largest relative and absolute inequalities were observed in chronic diseases (Tables 1 and 2). This included chronic lower respiratory disease, cancer of the trachea, bronchus and lung, ischaemic heart disease, cerebrovascular disease and diabetes (RRs ranged from 1.85 to 6.82, RDs from 39.2 to 240 per 100 000 person-years). Among people of this age, absolute and relative inequalities in dementia and Alzheimer's disease were also considerable.

Among men, the estimated number of excess deaths associated with less than tertiary education from all causes in the 1-year period (2016–17) was 2121 for those aged 25-44, 6344 for those 45-64 and 13 943 among those aged 65-84, equivalent to 62%, 50% and 37% of all deaths in each age group, respectively (Table 1). The estimated number of excess deaths from the 10 leading causes accounted for 71%, 57% and 66% of all excess deaths for those aged 25-44 years, 45-64 years and 65-84 years, respectively. Among women, the number of excess deaths from all causes was 3129 for those aged 45-64 and 8710 for those aged 65-84, equivalent to 39% and 32% of all deaths among the two age groups, respectively (Table 2). The estimated number of excess deaths from the 10 leading causes was 1646 (53% of the total number of excess deaths from all causes) for women aged 45-64 and 5724 (66%) among women aged 65-84.

Inequalities in causes according to preventability

For men and women in each age group, relative inequalities were largest for causes of death amenable to behaviour change (Figure 2, Supplementary File 4, Tables S4.3-S4.4, available as Supplementary data at *IJE* online);

Table 1 Number of deaths, mortality rates, and absolute and relative inequality estimates based on education for leading causes of death, among Australian men aged 25–84 years by age group, 2016-17

	Crude numbers			Crude mortality rate		Expected number of deaths in population	Age-adjusted mortality rate (per 100 000 py)			Rate difference (per 100 000 py)	Number of excess deaths	Rate ratio	Relative index of inequality
	High education	Intermediate education	Low education	Total sample (per 100 000 py)	Total population (per 100 000 people)		High education	Intermediate education	Low education	Low vs high education		Low vs high Education	
Age group 25-44													
Sample, *n* (%)	877 508 (31%)	1 551 747 (56%)	358 340 (13%)										
Person-years	917 594	1 622 158	374 378										
Deaths													
1. Suicide	64	383	161	20.9	24.8	848	8.37	28.3	51.1	42.7 (34.5-50.8)	562	6.10 (4.56-8.15)	9.17 (6.55-12.8)
2. Accidental poisoning	32	122	104	8.85	14.6	497	5.61	12.4	45.6	40.0 (29.8-50.3)	305	8.13 (5.32-12.4)	18.4 (10.3-32.9)
3. Land transport accidents	13	116	55	6.31	10.2	349	2.34	11.7	23.6	21.2 (14.5-27.9)	269	10.1 (5.42-18.7)	15.0 (7.72-29.2)
4. Ischaemic heart disease	23	80	53	5.35	5.80	198	2.82	5.49	14.4	11.6 (7.49-15.8)	102	5.12 (3.12-8.41)	9.08 (4.64-17.8)
5. Symptoms signs ill-defined conditions	n.p.	30	20	1.96	2.23	76	0.87	2.13	5.97	5.11 (2.40-7.81)	46	6.87 (2.90-16.3)	13.4 (4.37-41.0)
6. Brain cancer	16	57	n.p.	2.81	2.67	91	1.70	3.36	2.16	0.46 (-1.20-2.11)	33	1.27 (0.55-2.90)	1.81 (0.75-4.38)
7. Cirrhosis and other diseases of the liver	n.p.	40	13	1.99	2.14	73	0.62	2.73	3.43	2.82 (0.87-4.76)	52	5.57 (1.98-15.6)	6.94 (2.39-20.2)
8. Colorectal cancer	16	52	13	2.78	2.70	92	1.71	3.14	3.26	1.55 (-0.42-3.51)	34	1.90 (0.91-3.96)	2.47 (1.04-5.86)
9. Assault	n.p.	11	n.p.	0.79	1.96	67	0.82	1.68	5.95	5.13 (1.13-9.14)	39	7.26 (1.96-26.9)	16.8 (2.78-101)
10. Diabetes	n.p.	22	26	1.68	1.76	60	0.12	1.46	7.01	6.89 (4.18-9.61)	56	58.9 (7.99-434)	119 (29.0-488)
10. Lymphoma and leukaemias	15	21	14	1.72	1.61	55	1.56	1.23	3.3	1.74 (-0.24-3.72)	2	2.11 (0.99-4.52)	2.26 (0.74-6.90)
All causes	290	1441	768	84.7	101	3446	38.8	105	236	197 (176-218)	2121	6.08 (5.22-7.08)	10.2 (8.42-12.4)

(Continued)

Table 1 Continued

	Crude numbers			Crude mortality rate		Expected number of deaths in population	Age-adjusted mortality rate (per 100 000 py)			Rate difference (per 100 000 py)	Number of excess deaths	Rate ratio	Relative index of inequality
	High education	Intermediate education	Low education	Total sample (per 100 000 py)	Total population (per 100 000 people)		High education	Intermediate education	Low education	Low vs high education		Low vs high Education	
Age group 45-64													
Sample, *n* (%)	573 069 (22%)	1 351 836 (53%)	636 401 (25%)										
Person-years	598 784	1 411 203	663 234										
Deaths													
1. Ischaemic heart disease	137	643	576	50.7	57.5	1675	27.5	52.9	95.6	68.1 (57.9-78.3)	875	3.48 (2.85-4.24)	4.95 (3.91-6.25)
2. Cancer of trachea, bronchus and lung	52	397	426	32.7	35.9	1045	10.4	32.0	68.1	57.7 (49.7-65.8)	743	6.57 (4.87-8.86)	9.35 (6.86-12.7)
3. Suicide	80	285	185	20.6	22.6	657	14.6	22.1	31.0	16.4 (10.9-22.0)	233	2.13 (1.63-2.77)	2.62 (1.88-3.63)
4. Cirrhosis and other diseases of the liver	37	213	205	17.0	18.7	546	7.13	17.0	33.4	26.3 (20.8-31.7)	338	4.68 (3.27-6.70)	6.75 (4.56-9.98)
5. Colorectal cancer	74	241	208	19.6	20.6	600	13.7	18.4	31.9	18.2 (12.9-23.6)	202	2.33 (1.79-3.04)	3.31 (2.37-4.62)
6. Chronic lower respiratory disease	n.p.	131	215	13.1	13.6	396	0.97	10.3	32.5	31.5 (25.5-37.5)	368	33.4 (13.5-82.7)	33.2 (18.4-60.0)
7. Liver cancer	33	157	153	12.8	14.6	424	6.71	13.0	25.2	18.5 (13.7-23.3)	229	3.76 (2.56-5.51)	5.59 (3.61-8.65)
8. Lymphoma and leukaemias	65	187	123	14.0	14.1	411	11.4	13.5	17.8	6.41 (2.20-10.61)	78	1.56 (1.15-2.11)	1.83 (1.24-2.70)
9. Cancer of the pancreas	53	165	116	12.5	13.3	387	9.88	12.5	18.2	8.27 (3.53-13.0)	99	1.84 (1.29-2.62)	2.28 (1.44-3.60)
10. Cerebrovascular disease	32	131	137	11.2	12.6	368	6.30	10.7	22.8	16.5 (12.0-21.0)	184	3.61 (2.45-5.34)	5.93 (3.73-9.42)
10. Accidental poisoning	12	101	99	7.93	12.6	366	3.10	11.3	24.3	21.2 (16.1-26.3)	276	7.82 (4.29-14.2)	10.3 (5.89-17.9)
All causes	1117	5040	4575	401	437	12731	219	399	724	505 (462-547)	6344	3.30 (3.01-3.62)	4.75 (4.23-5.35)

(Continued)

Table 1 Continued

	Crude numbers			Crude mortality rate		Expected number of deaths in population	Age-adjusted mortality rate (per 100 000 py)			Rate difference (per 100 000 py)	Number of excess deaths	Rate ratio	Relative index of inequality
	High education	Intermediate education	Low education	Total sample (per 100 000 py)	Total population (per 100 000 people)		High education	Intermediate education	Low education	Low vs high education		Low vs high Education	
Age group 65-84													
Sample, *n* (%)	203 080 (15%)	650 789 (47%)	522 337 (38%)										
Person-years	210 969	673 366	536 490										
Deaths													
1. Ischaemic heart disease	317	1745	2445	317	306	4698	173	269	413	240 (208-272)	2035	2.38 (2.09-2.72)	3.03 (2.60-3.53)
2. Cancer of trachea, bronchus and lung	152	1165	1479	197	202	3112	82.6	188	275	193 (170-215)	1842	3.33 (2.79-3.98)	3.51 (2.94-4.20)
3. Chronic lower respiratory disease	64	798	1420	161	146	2252	34.1	120	232	198 (179-217)	1728	6.82 (5.24-8.86)	7.21 (5.75-9.04)
4. Cerebrovascular disease	138	705	995	129	127	1958	79.6	112	169	89.5 (70.4-109)	735	2.12 (1.76-2.57)	2.71 (2.19-3.35)
5. Dementia and Alzheimer's disease	86	502	1148	122	115	1767	52.1	79.8	189	137 (118-157)	965	3.63 (2.87-4.60)	6.68 (5.19-8.58)
6. Prostate cancer	165	742	811	121	118	1810	90.6	113	135	44.9 (27.9-61.8)	417	1.49 (1.26-1.77)	1.63 (1.35-1.96)
7. Colorectal cancer	138	638	750	107	107	1641	72.8	98.2	133	60.4 (44.9-75.9)	522	1.83 (1.52-2.20)	2.16 (1.77-2.63)
8. Lymphoma and leukaemias	158	659	624	101	100	1545	83.6	100	108	24.5 (8.8-40.1)	259	1.29 (1.08-1.54)	1.31 (1.08-1.60)
9. Diabetes	80	434	750	89.0	88.7	1364	45.3	69.5	134	88.2 (73.0-103)	667	2.95 (2.32-3.75)	4.49 (3.49-5.77)
10. Cancer of the pancreas	104	344	400	59.7	57.0	876	51.8	50.3	68.1	16.3 (4.25-28.4)	80	1.32 (1.06-1.63)	1.67 (1.29-2.17)
All causes	2767	14181	19 048	2533	2458	37 785	1551	2201	3202	1651 (1503-1799)	13943	2.06 (1.93-2.20)	2.62 (2.40-2.85)

Sample mortality rates are estimated using the analysis file. Population mortality rates are estimated using complete Death Registrations using deaths occurring in 2016 and the estimated resident population on 30 June 2016. If sample rates are lower than the population rate, more deaths than population have been underestimated. If sample rates are higher than the rate in the population, population numbers are underestimated relative to number of deaths. Sample rates for ages x to x + n more precisely refer to ages x + 0.5 to x + n + 0.5; this is because of data linkage. The effect of this on the reported rate ratios is negligible. Education-specific mortality rates, rate differences and excess deaths are estimated by applying relative rates to the 2016 population mortality rate. Number of excess deaths have been estimated using the estimated resident population on 30 June 2016. Relative rates and the relative index of inequality are estimated with the analysis file. Expected number of deaths is estimated using the crude mortality rate in the population times the estimated resident population within each age-sex-group on 30 June 2016. 'Symptoms signs ill-defined conditions' is often used as a temporary code for deaths undergoing coronial investigation. Diabetes and lymphoma/leukaemias were equal 10th leading causes among men aged 25–44 years. Cerebrovascular disease and accidental poisoning were equal 10th leading cause of death among men aged 45-64 years.

py, person-years; n.p. indicates that the number is <10 and has been suppressed.

Table 2 Number of deaths, mortality rates, and absolute and relative inequality estimates based on education for leading causes of death, among Australian women aged 45-84 years by age group, 2016-17

	Crude numbers			Crude mortality rate		Expected number of deaths in population	Age-adjusted mortality rate (per 100 000 py)			Rate difference (per 100 000 py)	Number of excess deaths	Rate ratio	Relative index of inequality
	High education	Intermediate education	Low education	Total sample (per 100 000 py)	Total population (per 100 000 people)		High education	Intermediate education	Low education	Low vs high education		Low vs high education	
Age group 45-64													
Sample, *n* (%)	671 789 (25%)	1 211 635 (45%)	824 955 (30%)										
Person-years	702 081	1 265 756	860 976										
Deaths													
1. Breast cancer	168	382	309	30.4	30.4	921	25.0	31.0	34.0	8.99 (3.59-14.4)	163	1.36 (1.12-1.64)	1.49 (1.16-1.91)
2. Cancer of trachea, bronchus and lung	72	245	377	24.5	25.2	762	11.8	21.6	41.5	29.7 (23.8-35.6)	404	3.52 (2.68-4.61)	5.69 (4.05-7.98)
3. Colorectal cancer	68	188	160	14.7	14.3	434	10.1	15.1	16.7	6.61 (3.05-10.2)	128	1.65 (1.24-2.20)	1.83 (1.28-2.64)
4. Ischaemic heart disease	24	110	204	12.0	13.0	395	4.18	10.32	24.4	20.2 (15.8-24.6)	268	5.83 (3.74-9.08)	10.76 (6.46-17.9)
5. Chronic lower respiratory disease	11	85	252	12.3	10.7	323	1.61	6.52	24.2	22.6 (18.5-26.7)	274	15.0 (8.06-28.0)	36.6 (20.1-66.9)
6. Suicide	32	108	85	7.95	7.83	237	4.42	8.25	10.1	5.65 (2.87-8.44)	103	2.28 (1.49-3.48)	2.73 (1.60-4.64)
7. Ovarian cancer	66	101	97	9.33	7.76	235	8.37	6.92	8.45	0.08 (-2.56-2.72)	−19	1.01 (0.74-1.38)	1.07 (0.68-1.67)
8. Cerebrovascular disease	34	77	134	8.66	9.51	288	5.54	6.88	16.6	11.1 (7.62-14.5)	120	3.00 (2.05-4.38)	5.82 (3.48-9.75)
9. Cancer of the pancreas	43	99	103	8.66	8.02	243	6.16	7.64	10.13	3.97 (1.22-6.73)	56	1.64 (1.14-2.36)	2.01 (1.24-3.26)
10. Cirrhosis and other diseases of the liver	18	70	112	7.07	7.83	237	2.96	6.27	14.1	11.2 (7.98-14.4)	147	4.78 (2.86-7.99)	8.70 (4.73-16.0)
All causes	995	2804	3519	259	262	7927	158.4	235.6	386	227 (202-252)	3129	2.44 (2.21-2.68)	3.46 (3.04-3.94)

(Continued)

Table 2 Continued

	Crude numbers			Crude mortality rate		Expected number of deaths in population	Age-adjusted mortality rate (per 100 000 py)			Rate difference (per 100 000 py)	Number of excess deaths	Rate ratio	Relative index of inequality
	High education	Intermediate education	Low education	Total sample (per 100 000 py)	Total population (per 100 000 people)		High education	Intermediate education	Low education	Low vs high education		Low vs high education	
Age group 65-84													
Sample, *n* (%)	185 930 (12%)	465 778 (31%)	856 466 (57%)										
Person-years	193 558	483 988	886 110										
Deaths													
1. Ischaemic heart disease	106	486	1695	146	140	2311	71.0	113	171	100 (81.9-118)	1138	2.41 (1.96-2.97)	3.07 (2.45-3.85)
2. Dementia and Alzheimer's disease	96	397	1538	130	123	2030	71.2	93.0	152	80.4 (60.1-101)	853	2.13 (1.69-2.68)	3.11 (2.37-4.08)
3. Chronic lower respiratory disease	69	386	1526	127	118	1945	42.1	84.9	154	112 (96.4-127)	1249	3.66 (2.84-4.72)	5.01 (3.87-6.48)
4. Cancer of trachea, bronchus and lung	131	495	1275	122	124	2042	76.6	111	142	65.1 (48.0-82.3)	775	1.85 (1.52-2.25)	2.10 (1.68-2.62)
5. Cerebrovascular disease	92	409	1292	115	111	1841	64.7	97.4	130	65.8 (48.3-83.3)	772	2.02 (1.60-2.54)	2.35 (1.82-3.04)
6. Breast cancer	125	342	759	78.4	78.3	1294	70.8	73.8	82.5	11.8 (-2.08-25.6)	124	1.17 (0.96-1.41)	1.28 (1.02-1.61)
7. Colorectal cancer	96	289	733	71.5	73.8	1220	61.9	67.6	80.1	18.2 (4.01-32.4)	197	1.29 (1.04-1.61)	1.48 (1.14-1.92)
8. Lymphoma and leukaemias	85	280	596	61.5	59.3	981	50.2	60.4	61.1	10.8 (-1.41-23.1)	151	1.22 (0.96-1.54)	1.17 (0.89-1.55)
9. Diabetes	44	144	641	53.0	54.4	900	31.1	35.7	70.3	39.2 (26.7-51.7)	386	2.26 (1.63-3.14)	4.08 (2.77-6.01)
10. Cancer of the pancreas	76	203	490	49.2	48.2	797	43.5	43.6	51.9	8.41 (-2.68-19.5)	78	1.19 (0.93-1.53)	1.39 (1.03-1.88)
All causes	1741	6217	18 780	1710	1662	27 474	1135	1432	1916	781.1 (669-893)	8710	1.69 (1.56-1.83)	2.13 (1.91-2.38)

Sample mortality rates are estimated using the analysis file. Population mortality rates are estimated using complete Death Registrations using deaths occurring in 2016 and the estimated resident population on 30 June 2016. If sample rates are lower than the population rate, more deaths than population have been underestimated. If sample rates are higher than the rate in the population, population numbers are underestimated relative to number of deaths. Sample rates for ages x to x + n more precisely refer to ages x + 0.5 to x + n + 0.5; this is because of data linkage. The effect of this on the reported rate ratios is negligible. Education-specific mortality rates, rate differences and excess deaths are estimated by applying relative rates to the 2016 population mortality rate. Number of excess deaths have been estimated using the estimated resident population on 30 June 2016. Relative rates and the relative index of inequality are estimated with the analysis file. Expected number of deaths is estimated using the crude mortality rate in the population times the estimated resident population within each age-sex-group on 30 June 2016. Results are not presented for women aged 25–44 years due to concerns about the internal validity of the data for this group. They are available in Supplementary File 3 Table S3.6, available as Supplementary data at *IJE* online, but should be interpreted with caution.

n.p. indicates that the number is <10 and has been suppressed.

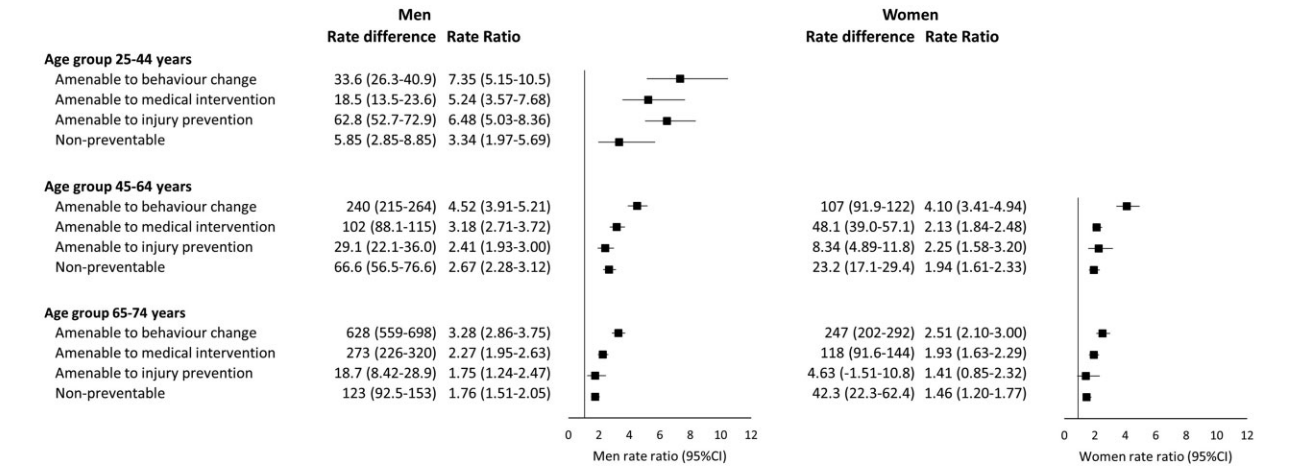

Figure 2 Absolute (per 100 000 person-years) and relative inequality estimates based on education (low versus high) for causes of death according to preventability among men aged 25-74 years and women aged 45-74 years by age group, Australia 2016–17. Rate ratio is plotted. Number of deaths, excess deaths and relative index of inequality for all age-sex groups are available in Supplementary 4, Tables S4.3-S4.4, available as Supplementary data at *IJE* online. Results are not presented here for women aged 25-44 years due to concerns about the internal validity of the data for this group. They are in Supplementary File 3, Table S3.6, available as Supplementary data at *IJE* online, but should be interpreted with caution

absolute inequalities were also generally largest for deaths amenable to behaviour change, with the exception of younger men, where absolute inequalities were largest for causes amenable to injury prevention. That inequalities were generally larger for preventable causes was also evident when all causes of death were ranked by the magnitude of relative inequalities (Supplementary File 4, Tables S4.5-S4.6, available as Supplementary data at *IJE* online). However, small numbers of deaths limited the precision of estimates for some causes.

Discussion

We observed substantial education-related inequalities in mortality among the resident population of Australia aged 25–84 years. For men and women, mortality rates for people with low education were more than twice those of people with high education. Among younger men, absolute and relative inequalities were largest for injuries, where mortality rates among those with no educational qualifications were between 6-fold (suicide) and 10-fold (land transport accidents) those of people with a tertiary education. Among middle and older age men and women, relative and absolute inequalities were largest for chronic diseases, particularly for smoking-related causes, where mortality rates among those with the lowest education were between 2-fold and 7-fold those with the highest education, and 2-fold to 4-fold for cardiovascular diseases. As expected, relative and absolute inequalities were generally larger for preventable compared with non-preventable causes, and were large for causes amenable to behaviour change and medical intervention across all age groups, and for causes amenable to injury prevention among young men.

This study is the first to comprehensively report on cause-specific education-related inequalities in Australia. Compared with the most recent national estimates of inequalities (for the period 2009-11) using area-level measures of SEP, our education-based inequality estimates are substantially larger for all-cause and cause-specific mortality.[10] Our estimates are also higher than previous estimates of education-related inequalities reported for all-cause[5] and selected causes of death[24] in Australia for 2011-12. These differences likely reflect, at least in part, methodological differences as well as changes in the composition of educational groups over time (Supplementary File 5, available as Supplementary data at *IJE* online).

Our inequality findings for Australia are broadly consistent with those reported for other countries, in that inequalities are larger for preventable than non-preventable deaths.[7,8,25–27] Notably, however, our RR estimates are generally larger in magnitude than those reported for other high-income countries,[7,8,25–27] although estimates of similar magnitude have been reported in other advanced welfare states.[5,25,26] Many studies do not report RIIs, despite this being the recommended method for international comparisons.[6] However, our RIIs were generally higher than those reported for those aged 35-79 years in European countries covering the period from 1990s to the early 2000s and for New Zealand in the period 2006-11,[4,28] although direct comparisons remain difficult given that previously reported RIIs are generally not age stratified. The fact that the relative inequality estimates observed in this study are generally larger than observed in comparable countries may reflect, at least in part, a greater concentration of disadvantage among those with lower levels of education in Australia[29,30] and/or larger socioeconomic differences in risk factors in Australia compared with other countries (e.g. in Australia, the absolute difference in the prevalence of current daily smoking between those with high versus low education is 17%[31] compared with the OECD average of 7%[32]) They may also reflect, in part, methodological and reporting differences. Although it would be an immense undertaking, recommendations for standardized reporting of inequalities, including sex-age-stratified RIIs, may aid international comparisons and ongoing monitoring of inequalities over time, and Australia now has the data to be able to contribute to these comparisons. Nevertheless, differences in linkage methodologies and data quality may continue to limit comparisons.

Understanding the mechanisms by which education-related inequalities in mortality occur is critical to ensure that policies are implemented to mitigate them. It was not possible with the data used in this paper to examine specific mechanisms or solutions to reduce inequalities in Australia, but our findings provide insights on areas to target. Among the younger age group, inequalities were largest for external causes of deaths and causes amenable to injury prevention. Although the number of deaths in the younger age group was low, the considerable absolute inequalities in injury-related deaths highlights the potential for further reductions. Among the older age groups, inequalities were greatest for chronic diseases, particularly for causes associated with smoking and alcohol/substance use. Virtually all behaviour-related risk factors are more prevalent among those of lower compared with higher SEP in Australia.[31] Our findings further underscore the need for interventions to reduce the disproportionately high prevalence of risk factors among those of lower SEP, including strategies which recognize and address the upstream determinants of these risk factors. We also observed substantial inequalities in cause-specific mortality amenable to medical intervention. This included cancers amenable to screening and diseases amenable to acute medical care, such as cardiovascular diseases.[33] While not all deaths in this group of causes could have been avoided with better health care, inequalities in health care are well documented in Australia,[5,34,35] and addressing them is likely part of the solution.

Using linked Census and Death Registrations we had information on 87% of the population of interest, with virtually complete (98%) ascertainment of deaths among those in the sample. Given this, we did not apply a weighting strategy. This is likely to be a valid approach for the middle and older age groups, where our mortality rates compared favourably with estimates from the complete population. However, weights may have improved absolute estimates for younger age groups, where rates in the sample were up to 60% lower for some causes relative to the full population. We addressed this issue by generating absolute inequality estimates by applying RRs to external population-based mortality rates estimated using complete Death Registrations , but this method relies on the strong assumption that the RRs are internally valid. The key threat to internal validity is the potential for selection bias; 13% of the population were excluded from the analysis (due to not completing the Census or not linking to the Spine) and selection bias will occur if exclusion is related to both exposure (education) and the outcome (risk of dying). There was evidence of this in younger women, where the validation analysis showed women in low area-level SEP groups who went on to die in the following year were more likely to be excluded from the study compared with other women in this age group, resulting in underestimates of inequality. Such bias was not evident for other age-sex groups; however, given that our validation relied on an area-level measure of SEP, not education, we cannot exclude the possibility. We measured mortality occurring over a 13-month follow-up period, resulting in small numbers of deaths, particularly for younger age groups and for less common causes of death, limiting the precision of some of our estimates. Longer follow-up periods may be needed for more reliable estimates. Furthermore, delays in death registrations may have contributed to lower mortality rates among younger age groups, which may be improved with updated data. Finally, we did not account for migration or deaths occurring outside of Australia. Given our relatively short follow-up period, it is unlikely that this had a material effect on our estimates.

Conclusions

Using linked census mortality data enabled valid estimates of education-related inequalities in mortality in Australia, broadly suitable for international comparisons. Standardizing the reporting of census-mortality analyses would further enhance the ability to compare estimates across time and countries, although differences in linkage methods and data quality may continue to impede comparisons.

Education-related inequalities are substantial in Australia and evident for most causes of death. The absolute and relative inequalities are largest for preventable deaths, in particular deaths due to injury in younger adults and deaths from preventable cancers and cardiovascular diseases among middle and older age adults. These findings highlight opportunities to reduce health inequalities in

Australia and the marked potential to improve the overall health of the population.

Supplementary Data

Supplementary data are available at *IJE* online.

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Data Availability

Data as part of the Multi-Agency Data Integration Project are available for approved projects to approved government and non-government users at [https://www.abs.gov.au/websitedbs/D3310114.nsf/home/Statistical+Data+Integration+-+MADIP].

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Conflict of Interest

None declared.

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