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SOCIOECONOMIC FACTORS

Income differences in mortality: a register-based follow-up study of three million men and women

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Objectives	We analyse whether the relationship between net household income and mortality form a continuous linear gradient or is curvilinear, assess the attenuation of this association after adjusting for confounding and reverse causality, and assess the strength of the association by age and cause of death.
Design and setting	Prospective study of mortality in Finland among all men and women over 30 years old. Information on household income and sociodemographic factors was from the records of the Finnish tax authorities and the 1990 census. Income data were available for more than 95% of the cohort. Follow-up was by record linkage to death certificates in 1991–1996; altogether about 261 000 deaths.
Results	The all-cause mortality ratio between the lowest and the highest household income decile is 2.37 (95% CI : 2.30–2.44) among men and 1.73 (95% CI : 1.67–1.80) among women. Adjusting for household structure, spouse's economic activity, social class, education and own economic activity attenuates the relationship by 61% among men and 52% among women. The association between income and mortality is mainly linear before and after adjusting for confounding, and the association is strong for all 5-year age groups below 60–64 years, after which it declines rapidly in strength.
Conclusions	The mainly linear nature of the relationship and the strong attenuation after adjustment for other socioeconomic factors and economic activity status, and the age pattern of the relationship indicate that a large part of the relationship is unlikely to be due to direct causal effects of poverty and material hardship. Rather, income seems to be related to accumulation of factors that increase mortality over the whole range of incomes.

Keywords	Income, mortality, cause of death, confounding
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Poverty and material hardship have been argued to be a main underlying cause of social inequalities in mortality and morbidity.[1–3] However, relatively few analyses of the relationship between income and mortality at the individual level are available, and in those that exist income data are often unreliable or missing for a large part of the sample, or they lack a complete and reliable mortality follow-up.

The evidence so far indicates that income in adulthood is strongly associated with morbidity and mortality.[4–13] However, interpretation of the association is hampered by confounding by other aspects of socioeconomic status causally preceding income; it is plausible to argue that income, especially individual income, is partly determined by previously achieved educational qualifications and occupational status, and that these factors may be more fundamental determinants of mortality than income as such. Income would be either mediating the effects of education and social class on mortality, or be only spuriously related to mortality. If this were the case, any attempts to reduce income differences in mortality are best achieved, for example,

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by guaranteeing more equal educational outcomes, rather than redistribution of income.

Furthermore, income, more so than occupational class and particularly education, may be partly determined by pre-existing ill-health. In working age, poor health may lead to early retirement and a consequent loss of income, and it simultaneously also predicts mortality. Thus, in a seminal work on socioeconomic differences in mortality in the US Kitagawa and Hauser summarize: '... the basic presupposition in studies of socioeconomic differentials in mortality is that socioeconomic status has an effect on mortality. In the case of income differentials, however, this causal pathway is complicated by a reverse path (or reverse causality [our addition]) in which the approach of death itself is the cause of decreased income during the years preceding death'.[4]

The effects of confounding and reverse causality on the income and mortality association can be minimized in at least three different ways. First, appropriate measures of income should be used. Household disposable income per consumption unit should be preferred over individual income, as this measure can partly overcome biases related to confounding and reverse causality, and more accurately measures consumption possibilities and poverty. Second, it is necessary to analytically adjust for several other socioeconomic variables that precede income and economic activity. Previous analyses indicate that the mortality and morbidity differences between income groups are greatly reduced, but by no means abolished, after such adjustments are made.[6–7,9,12,14]

Third, the shape of the relationship between income in adulthood and mortality can also be used to assess the nature of the relationship. For our purposes two main shapes can be discerned: (1) A curvilinear relationship where mortality increases particularly rapidly at lower levels of income; (2) A linear relationship where mortality increases at a constant rate with declining income. A curvilinear relationship is consistent with poverty and material circumstances being a major determinant of poor health, and improving the incomes of the poorest would lead to the greatest improvements in mortality. A linear relationship is more consistent with accumulation of factors that increase mortality over the whole range of incomes and corresponds with similar findings concerning occupation-based social class and education. Previous evidence on the shape of the mortality curve is not consistent, as both linear and curvilinear associations have been observed.[6–7,9–14]

Confounding and particularly reverse causation are likely to be especially severe in analyses of working-age populations. Thus, further analyses by age may also provide valuable insights to the relevance of confounding, as income levels beyond retirement age are less related to economic activity. Furthermore, little evidence of the relationship between income and cause-specific mortality is available although the potential independent effects of income on mortality may be particularly strong for some causes of death.

The main aim of our analyses is to assess whether household disposable income per consumption unit in adulthood—a measure of current material well-being and poverty—is independently related to mortality or whether the effects are more likely to reflect confounding by other socioeconomic factors and economic activity status. In Finland, linkage of census records, death records, and records of tax authorities for the total population by means of a unique personal identification code provide an excellent source of data to study this relationship. With these data we aim specifically to: (1) analyse whether the relationship between net household income and age-adjusted mortality forms a continuous linear gradient or is curvilinear, (2) assess how much of this relationship is attenuated after adjusting for household structure, economic activity and other measures of socioeconomic status, (3) assess the strength of the association by age and cause of death.

Methods

This study linked death records in the period 1991–1996 to the 1990 census records of Finnish men and women aged 30 and over; altogether almost 3 million people.[15] Deaths are classified according to the Finnish edition of the Ninth Revision of the International Classification of Diseases and Causes of Death. Only about 0.5% of deaths could not be linked to census records. Data on 1990 household incomes were made available by the Finnish tax authorities. Altogether men in our study population lived about 8.14 million person-years, and experienced about 131 000 deaths; the corresponding figures among women were 9.57 million and 130 000 deaths. Statistics Finland carried out the linkage of data sets by means of personal identification codes.

We use household disposable income per consumption unit as our income measure. It comprises all taxable income received by the family members, including wages, capital income and taxable income transfers, but excludes taxes. The information on different sources of income comes from the registers of the Finnish Tax Administration and the Social Insurance Institution. Income data were available for more than 95% of the sample. Different weights are used for adults and children in the calculation of household consumption units. The first adult in the family corresponds to one consumption unit and all others over 18 years of age 0.7 units. Children under 18 years of age equal 0.5 consumption units. In the analyses we use income deciles with cut-points calculated from the combined data for men and women.

Both the study subjects and their spouse's economic activity was assessed on the basis of the longest held status in the 12-month period preceding the 1990 census. Five categories were used: employed, unemployed, retired (disability or old age pension), students, and people whose source of income is not known.

Household structure is based on information on the number of adults and under 18 year old members of the household. For the purposes of this study the following classification was used: (1) single, (2) married or cohabiting couple, (3) other adult households with two or more members, (4) adult and children, (5) couple and children, (6) other household with two or more adults and children and (7) other and unknown.

Educational categories were based on the highest completed educational degree or certificate. The five categories ranged from basic education to university degree. Seven social classes were used: upper white collar, lower white collar, skilled manual, unskilled manual, farmers, other self-employed and others. The unemployed and retired people were classified according to their previous occupations; housewives were categorized according to the occupation of the head of the household.

The deaths and person-years were cross-tabulated according to year, income decile and other variables of interest. Statistical analyses were based on the Poisson regression model, with the cell in the cross-tabulation taken as the unit of analysis. Age

was adjusted in 5-year intervals. The parameters of the Poisson models are presented as 'mortality ratios', with those in the highest decile being the reference group. The mortality ratio has a straightforward percentage interpretation, e.g. a group with a ratio of 1.25 has a 25% higher mortality than the reference group.[16]

In all graphical presentations of the data the income deciles are placed on the x-axis at the mean income of each decile. This leads to the lowest and the highest income decile being somewhat apart from the other deciles. A continuous regression line on these data is then fitted, and deviations from linearity are estimated by separately fitting dummy variables for each income decile. We estimate the fraction of variation in mortality between the income deciles explained by the continuous regression line by calculating $100*[(LL_C-LL_0)/(LL_D-LL_0)]$, where LL_0, LL_C and LL_D are the log-likelihoods for the models with terms for age, age and continuous income, and age and income dummies respectively.

To summarize the data in the Tables we also estimated the increase in mortality per income decile by estimating a continuous linear regression coefficient (the slope in the Tables) for income when deciles were assigned values 1–10. The slope is the factor of increase in mortality for each step (decile) down the income ladder, e.g. a slope of 1.05 indicates that mortality increases, on average, by 5% from one decile to the next. Each decile corresponds to about a 10 000 FIM (about 1680 euro) increment in income. In fitting the models we first adjust for household compositional factors, and subsequently for confounding by other socioeconomic factors preceding income in causal order, and finally for own economic activity—which is partly a measure of pre-existing ill-health. All regression analyses were carried out in STATA.[17]

Results

The relative all-cause mortality ratio between the lowest and the highest household income decile is 2.37 among men and 1.73 among women (Table 1). The relationship between income and total mortality is monotonic and quite linear for both men and women. We estimate that about 96% of the variation in mortality between the income deciles is accounted for by the linear trend. Mortality increases by a factor (see the slope in Table 2) of 1.09 for each decile down the income ladder among men, and 1.06 among women. However, both the poorest, and in particular the wealthiest, income decile have somewhat higher mortality than expected on the basis of the linear trend.

Adjusting for household structure and spouse's economic activity attenuates the age-adjusted income and mortality relationship by about 23% ([1.094–1.072]/[1.094–1]) among men and 15% among women (Table 2); additional adjustment for social class and education reduces the relationship by about 31% and 28%, and further adjustment for own economic activity by 61% and 52% as compared to the initial age-adjusted association for men and women respectively.

The relative increase in mortality by household income is strongest for alcohol poisonings and alcohol-related diseases and suicide for both men and women (Table 3). Also other

Table 1 Age-adjusted relative mortality rates for all causes of death, 95% CI and average incomes by income decile. Men and women aged ⩾30 years

	Men		Women		Men & women
Decile	RR[a]	95% CI	RR	95% CI	**Average income (FIM)**
1. decile	1.00		1.00		121 596
2. decile	1.13	1.09–1.17	1.05	1.00–1.10	87 844
3. decile	1.24	1.20–1.28	1.13	1.09–1.19	76 264
4. decile	1.36	1.31–1.40	1.22	1.17–1.27	67 895
5. decile	1.50	1.45–1.55	1.28	1.23–1.33	60 918
6. decile	1.63	1.58–1.68	1.33	1.27–1.38	54 461
7. decile	1.78	1.73–1.83	1.41	1.36–1.46	47 958
8. decile	1.95	1.90–2.01	1.47	1.42–1.53	41 432
9. decile	2.02	1.96–2.08	1.51	1.46–1.57	35 134
10. decile	2.37	2.30–2.44	1.73	1.67–1.80	18 807

[a] Relative mortality rate.

Table 2 Income slope of mortality by age for all causes of death and 95% CI in different regression models. Men and women aged ⩾30 years

	Men			Women		
Adjusted for	Slope[a]	95% CI	**% reduction in excess mortality[b]**	Slope[a]	95% CI	**% reduction in excess mortality[b]**
(a): Age	1.094	1.091–1.096		1.060	1.057–1.062	
(b): (a) + Household structure and spouse's economic activity	1.072	1.070–1.075	23	1.051	1.048–1.053	15
(c): (b) + Social class and education	1.065	1.062–1.068	31	1.043	1.040–1.046	28
(d): (c) + Economic activity	1.037	1.034–1.039	61	1.029	1.026–1.033	52

[a] The slope is the estimated continuous linear regression coefficient for income when deciles were assigned values 1–10. The slope is the factor of increase in mortality for each step (decile) down the income ladder.

[b] Per cent reduction in excess mortality between models (a) and (b) is obtained from the two slopes in the following way: $100 \times [(a-b)/(a-1)]$. Per cent reduction for all other models in reference to model (a) have been calculated correspondingly.

Table 3 Income slope[a] of mortality by cause of death. Men and women aged ⩾30 years

	Men			Women			Men	Women
Cause of death	No. of deaths	Age-adjusted	Fully adjusted[b]	No. of deaths	Age-adjusted	Fully adjusted[b]	% reduction in excess mortality after adjustment[c]	
All causes (ICD 000–999)	130 713	1.094	1.037	130 228	1.060	1.029	60.6	51.7
All diseases	116 941	1.085	1.038	123 915	1.058	1.031	55.3	46.6
Neoplasms (ICD 140–239)	30 096	1.054	1.026	28 135	1.017	1.001	51.9	94.1
Lung (ICD 162)	8712	1.126	1.069	2145	1.017	0.992	45.2	147.1
Breast (ICD 174)	–	–	–	4408	0.986	0.983	–	–[d]
Prostate (ICD 185)	4032	1.004	1.000	–	–	–	–[d]	–
Female reproductive (ICD 179,180,182,183)	–	–	–	3093	1.038	1.020	–	49.5
Stomach (ICD 151)	2192	1.057	1.029	1887	1.043	1.009	49.1	79.1
Colon (ICD 153)	1382	1.002	1.018	1930	1.004	1.005	–[d]	–[d]
Other cancers	13 778	1.032	1.010	14 672	1.023	1.002	68.8	91.3
Circulatory diseases (ICD 390–459)	61 543	1.085	1.039	67 085	1.073	1.046	54.1	37.0
Ischaemic heart disease (ICD 410–414)	40 737	1.093	1.044	36 278	1.083	1.053	52.7	36.1
Cerebrovascular diseases (ICD 430–438)	12 037	1.055	1.023	19 039	1.047	1.028	58.2	40.4
Other cardiovascular diseases	8769	1.091	1.038	11 768	1.089	1.055	58.2	38.2
Respiratory diseases (ICD 460–519)	10 380	1.143	1.078	8576	1.099	1.063	45.5	36.4
Alcohol-related diseases[e]	3438	1.174	1.072	782	1.183	1.068	58.6	62.8
Other diseases	11 484	1.096	1.039	19 337	1.055	1.023	59.4	58.2
Accidents and violence	13 772	1.155	1.058	6313	1.092	1.030	62.6	67.4
Suicide	4579	1.116	1.043	1458	1.103	1.039	62.9	62.1
Alcohol poisonings	1929	1.283	1.130	461	1.189	1.087	54.1	54.0
Other accidents and violence	7264	1.147	1.050	4394	1.072	1.024	66.0	66.7

[a] The slope is the estimated continuous linear regression coefficient for income when deciles were assigned values 1–10. The slope is the factor of increase in mortality for each step (decile) down in the income ladder.

[b] Adjusted for age, family structure, own and spouse's economic activity, social class and education.

[c] Per cent reduction in excess mortality is obtained from the age-adjusted slope (a) and the fully-adjusted slope (b) in the following way: 100 * [(a – b)/(a – 1)].

[d] Not calculated for models where age-adjusted slope is less than 1.01.

[e] Alcohol psychosis, alcoholism, alcoholic liver diseases, alcoholic pancreatitis, alcoholic cardiomyopathy, alcoholic polyneuropathy and alcoholic gastritis.

accidents and violence, respiratory diseases and lung cancer showed particularly large differences. For most causes of death the attenuation of the relationship after full adjustment was about 40–70% among both men and women, but some variability to this was observed with regard to different cancer sites.

For all diseases, the effects of the adjustment for household structure, spouse's economic activity, social class, education, and own economic activity are large among the 30–64 year olds—about 70% for both men and women—but relatively small among the over 64 year olds (Figure 1). Among 30–64 year old women there is a slight indication of a curvilinear relationship at low incomes. However, among both women and men aged 30–64 most of the non-linearity is a flattening of the curve at high levels of income.

For accidental and violent causes of death we observe some curvilinearity in the relationship among 30–64 year old men and women, particularly at high levels of income. For women we also observe a threshold between the 6th and 7th decile. For older women the relationship between income and accidental and violent mortality is very modest. Again the relationships are strongly attenuated after adjustment.

To assess further the possibility of reverse causation—the possibility that the approach of death itself is the cause of decreased income during the years preceding death—we analysed the strength of the income and mortality association in 5-year age groups. Particular attention should be paid to changes in the association between income and mortality around retirement age, and comparing the age pattern of excess mortality by income to that of social class. To achieve this we first calculated the sex- and age-specific relative mortality rates for dichotomized social class (manual versus non-manual). After this we dichotomized income so that for each sex and age group the distribution of income and social class were as similar as possible. These results are presented in Figure 2; among men and women the association of income and total mortality is strong for all 5-year age groups below 60–64 years, after which the association declines rapidly in strength. This contrasts with the association between social class—here assessed in terms of manual/non-manual mortality ratio—and total mortality, which declines steadily from the age of about 40–44 years.

Discussion

The results of this study can be summarized in five points: (1) Among Finnish over 30 year olds all-cause mortality ratio between the lowest and the highest household income decile is 2.37 among men and 1.73 among women. (2) Adjusting for household structure, spouse's economic activity, social class,

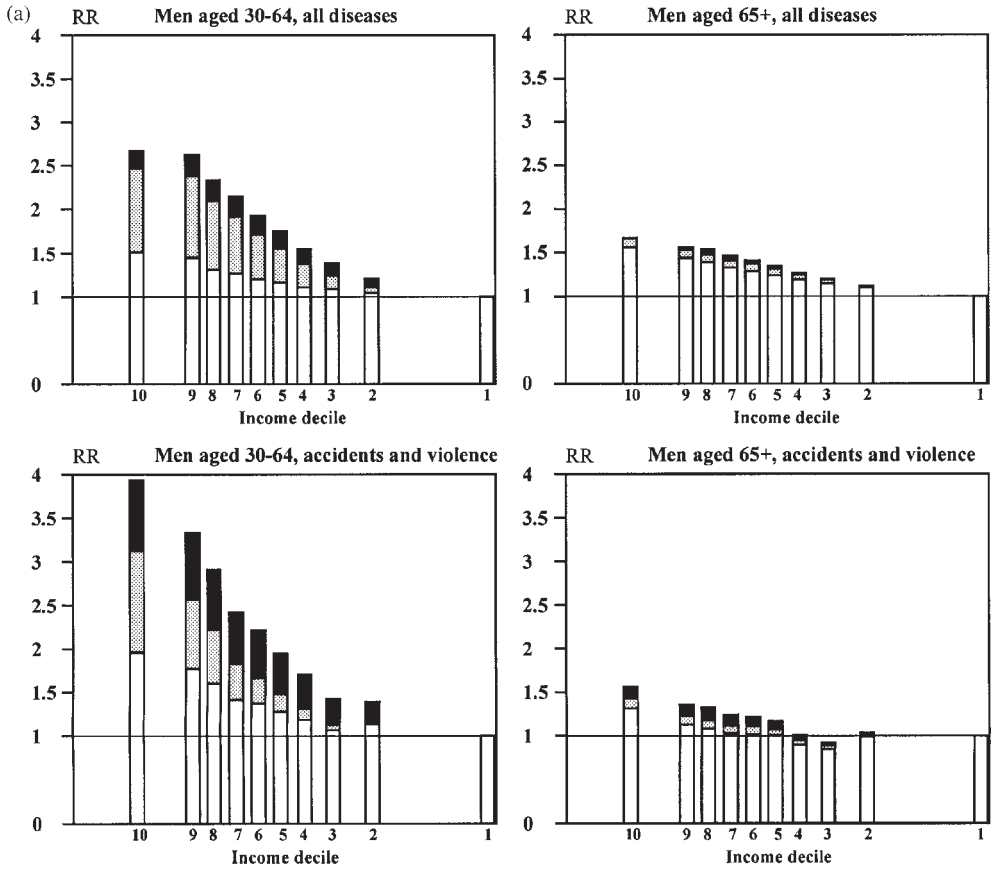

Figure 1a Relative cause-specific mortality rate by income decile in the different regression models. Men aged 30–64 and 65+

The full height of the bars shows the age, household structure and spouse's economic activity adjusted for relative mortality rates. Attenuation of the relative rates after further adjustment for social class and education is shown by the dark grey sections, and further adjustment for own economic activity by the light grey sections.

The relative mortality rates of the income deciles are placed on the x-axis at the mean income of each decile.

education and own economic activity attenuates the relationship by 61% among all men and 52% among all women; the attenuation is even stronger among 30–64 year olds. (3) The association between income and mortality is mainly linear before and after adjusting for confounding. (4) Among men and women the association of income and total mortality is strong for all 5-year age groups below 60–64 years, after which the association declines rapidly in strength. (5) The association between income and mortality is strongest for respiratory diseases, alcohol-related causes of death, accidents and violence and lung cancer.

The results of this study are in several respects more reliable than those obtained before. First, because the information on all sources of family income, taxes and the complex measure of household composition are based on the registers of the Finnish Tax Administration and the Statistics Finland, our results are not affected by self-report biases. Second, our household income data cover more than 95% of the Finnish population, and thus bias related to missing information is also very small. Many previous studies have missing information on income for up to one-third of the population, and are also limited to non-institutional populations. Third, the cause-specific mortality follow-up for our data is based on linkage to the national register of death certificates. This allows for a complete and unbiased linkage of all deaths to the census records and income information.

Income and mortality in working age

For 30–64 year old men and women a major part of the relationship between income in adulthood and mortality disappears when family structure and other measures of socioeconomic status, and especially own economic activity are adjusted for. This is in accordance with the proposition that confounding accounts for much of the association between income and mortality. In particular, the strong attenuation after adjusting for own economic activity indicates that reverse causality plays a major role in creating an association between income and mortality. Reverse causality implies that unmeasured pre-existing poor health may, for example, lead to early retirement and a consequent loss of income, and simultaneously also predicts mortality.

However, attempts to remove the effects of reverse causality (poor health leading to low income) by adjusting for economic

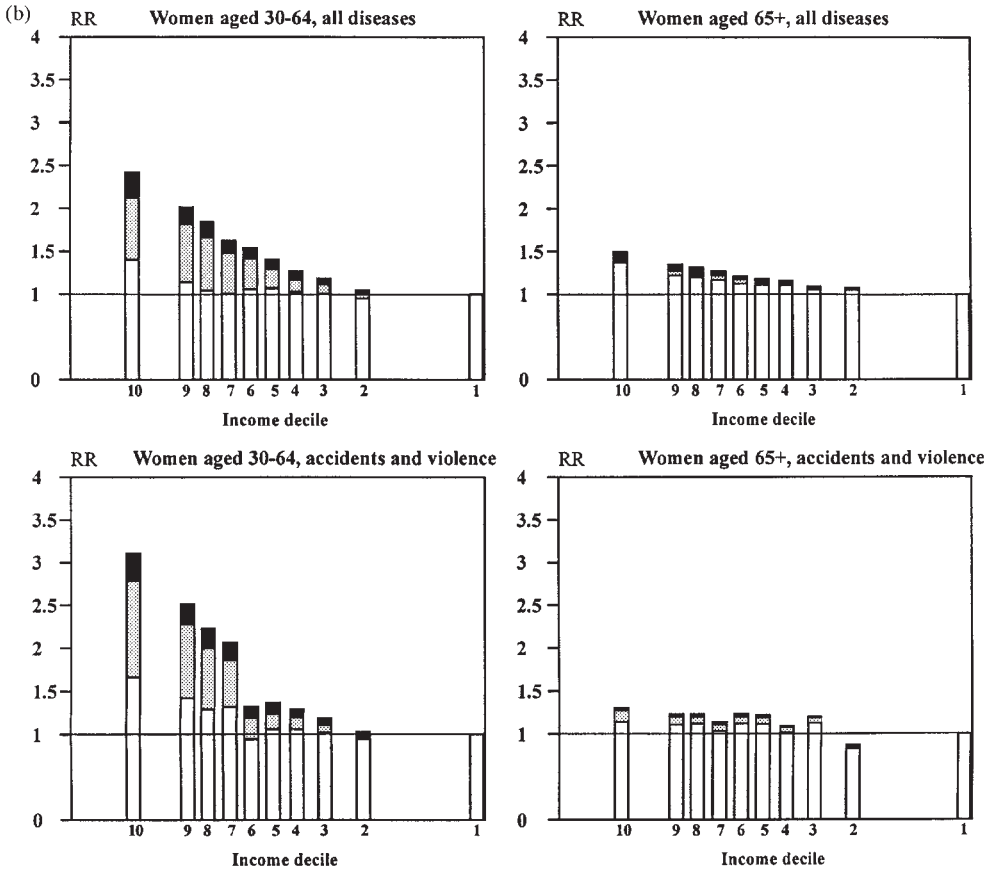

Figure 1b Relative cause-specific mortality rate by income decile in the different regression models. Women aged 30–64 and 65+

The full height of the bars shows the age, household structure and spouse's economic activity adjusted for relative mortality rates. Attenuation of the relative rates after further adjustment for social class and education is shown by the dark grey sections, and further adjustment for own economic activity by the light grey sections.

The relative mortality rates of the income deciles are placed on the x-axis at the mean income of each decile.

activity may possibly be over-adjustment. The time spent in different economic activity statuses, income history and onset of illness are not measured and the dynamics of these variables cannot be accurately assessed. Thus the attenuation of the income effect after adjustment for economic activity may also partly reflect the causal effects of low income on health.

By examining the shape of the income and mortality relationship further insight may be gained. An American study[9] has indicated that the relationship between income and mortality may be strongly curvilinear, i.e. income is more strongly related to mortality at low rather than high incomes. Such observations, if replicated, strengthen the argument for the causal effects of low incomes and material hardship on mortality. However, the association between income and mortality among Finnish men and women is mainly linear both before and after adjusting for confounders. Similar linear associations have been observed for occupation based social class and education. The most consistent non-linearity is the modest flattening of the relationship at very high incomes.

Relative socioeconomic inequalities in mortality have repeatedly been found to decrease by age among both men and women,[6] but the analyses presented here indicate that the association of income and total mortality is strong for all 5-year age groups below 60–64 years, after which the association declines rapidly in strength. This contrasts with the association between social class and mortality, which declines quite steadily from the age of about 40–44 years. This suggests that the effects of reverse causality are particularly strong at later working ages, say 45–64 years. Further analyses of these data (not presented here) show that adjusting for economic activity is particularly strong at these ages.

Income and mortality over the age of 64 years

Among participants over the age of 64 years almost all are economically inactive and reverse causality is thus less plausible. Hence, this age group should most clearly show the unconfounded effects of income on mortality. Among the over 64 year olds income differences in mortality are much smaller than in working age. Furthermore, the relationship at older ages is linear, and we can observe very little evidence for threshold effects. Adjusting for confounders reduces the strength of the relationship slightly, but the shape remains unaffected. Overall,

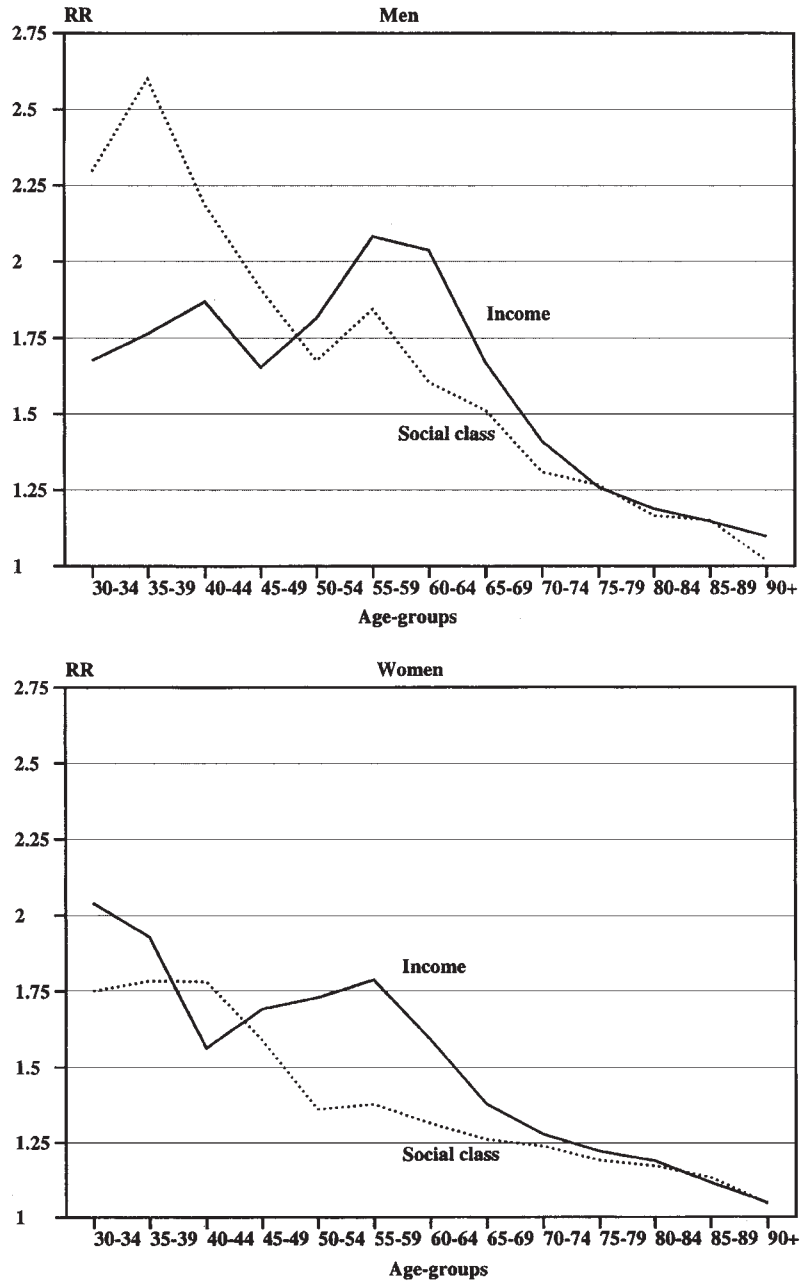

Figure 2 Age-specific relative mortality rates by income and social class for all causes of death by 5-year age groups. Men and women aged 30 and over

Social class is classified as manual/non-manual. Income is categorized into two groups so that for each sex by age group the distribution of income and social class are as similar as possible.

older men and women—among whom most deaths occur—determine the linear form of the income and mortality relationship for the total population.

It could be posited that high incomes at ages above 65 years are related to a financial imperative to work; the meaning of income would change after this age because those with small assets have to work to maintain a decent standard of living. This is unlikely to explain the falling ability of income to predict mortality, because in these data (1) only less than 20% and 2% of men aged 65–69 and 70–74 work, (2) of the 65–69 year olds who work, the majority are better educated and of higher social groups, i.e. they are hardly groups with the smallest assets.

Macro-social determinants and international variation in the association between income and mortality

In the late 1980s income inequalities in Finland, as in other Nordic countries, were lower than in other European countries.[18,19] In the early 1990s, the period covered by this study, Finland suffered a severe economic crisis. Economic output declined for 3 years and the bankruptcy rate doubled.[20] Unemployment rate increased from less than 4% in 1990 to about 18% in 1994.[20,21] However, because of the redistributive effects of the welfare state, income inequalities have increased only slightly towards the end of the study period. Finland is still among the countries with smallest income inequalities. There is also little evidence of increasing poverty or social exclusion. The adherence to the 'Nordic (or Scandinavian) welfare state model' may go some way in explaining the non-existence of a curvilinear association between current income and mortality in Finland; societies with relatively small income inequality, and low prevalence of poverty and social exclusion may have been able to avoid the emergence of a low paid under-class with particularly high mortality.

Systematic evidence of the relationship between income and mortality is scarce in most other countries. However, results from the US show a curvilinear relationship between income and mortality, even after adjustment for confounders.[9] These results from the US data may be compromised by poorer coverage and less reliable linkage to death registration. Nevertheless, it is possible that current income has a stronger independent and curvilinear effect on health and mortality in countries were income inequalities are large, e.g. the US, and where access to cash benefits and social services are not provided 'universally'. The experience of Finland is probably highly applicable to all Nordic countries and to other North-West European countries with a good social security coverage, but also seem a relevant contrast to countries that fall outside this regime. However, further research evidence on the association between income and mortality is needed in countries with different social policy arrangements, and with different prevalence of poverty.

Conclusion

Household income in adulthood is strongly related to mortality among Finnish men and women. The causes of this relationship are not easy to establish, especially at working ages. The mainly linear nature of the relationship and the strong attenuation after other socioeconomic factors and economic activity status were adjusted for, and the age pattern of the relationship indicate that a large portion of the relationship is unlikely to be due to direct causal effects of current poverty and material hardship. Rather, current income seems to be related to long term accumulation of factors that increase mortality over the whole range of incomes. This accumulation may, for example, be related to material hardship in the parental home, but also to adverse educational, occupational and labour market careers.

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KEY MESSAGES

- The relative all-cause mortality ratio between the lowest and the highest current household income decile is 2.37 (95% CI : 2.30–2.44) among men and 1.73 (95% CI : 1.67–1.80) among women.
- Adjusting for household structure, own and spouse's economic activity, social class and education attenuates the income-mortality relationship by 61% among men and 52% among women.
- The association between income and mortality is mainly linear before and after adjusting for confounding.
- Together these results indicate that the relationship between current income and mortality is unlikely to be due to direct causal effects of poverty, but that income is related to accumulation of factors, e.g. adverse educational or occupational experiences, or poverty in childhood, that increase mortality over the whole range of incomes.
- Income may have a stronger independent and curvilinear effect on mortality in countries were income inequalities are large and where access to benefits and social services are not provided 'universally'.

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Commentary: Income and health: why are curves so appealing?

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In this issue of the *International Journal of Epidemiology* Martikainen *et al*.[1] report a *linear* relationship between household income and subsequent mortality. The linear trend accounts for '96% of the variation between income deciles'. Departures from linearity at the top and bottom of the income range are modest and variable—the most consistent being a flattening of the relationship at very high incomes. These results contrast markedly with the most directly comparable study of Backlund *et al*.[2] which found pronounced curvilinearity, flattening at much lower income levels.

The first point to stress about this difference is that it is very unlikely to be due to statistical artefacts or methodological differences between the studies. Both studies have huge sample sizes with very high response rates. Whilst income data are frequently problematic, particularly at the top and bottom of the range, both results are consistent with other findings from their respective countries. In short, we can be confident that they reflect a real difference and one which may be informative about the underlying causal processes at work.

The importance of the finding can be illustrated in the context of the income inequality debate. This was sparked by Richard Wilkinson's assertion that relative income is more important for health than absolute income in developed societies,[3] and has given a new lease of life to research in the area. Although many of the resulting studies have used aggregate data, those based on individual-level data are inherently more informative.[4,5] One reason is that studies employing only aggregate data are unable to distinguish between the various competing hypotheses. Gravelle has also argued that a relationship between income inequality and health at the aggregate level could simply be an 'artefact' of a curvilinear relationship between income and health at the individual level.[6] With such a relationship the effects of income are greater at lower levels. Of two countries with the same average income, that with greater income inequality will have more people at both lower and higher incomes, but the 'health loss' at lower incomes will be greater than the 'health gain' at higher incomes. So the average health of the more unequal society will be lower. With a more linear relationship the losses and gains would tend to balance each other. Thus the shape of the relationship plays a critical role in the debate. Unfortunately, few studies have addressed it directly.

Whilst Wilkinson, himself, is agnostic about the shape of the relationship,[3] others are less so. Wagstaff and van Doorslaer[4] assert that, in addition to four studies explicitly cited, 'the multitude of other studies … suggest a concave relationship at the individual level between health and income'. In terms of

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mortality, the study by Martikainen *et al*. directly contradicts this. For health more generally, we have suggested that there is no single relationship between health and income. In a study of 14 health measures,[7] we found that the relationship to income varied according to the aspect of health considered as well as by age and sex. Now having clear evidence that the relationship of income with mortality varies between countries, we might speculate that associations with health also vary between countries.

If this is the case, we should be wary of relying too heavily on the evidence from a single country. A large proportion of the literature is based on data from the USA, but this may not be generalizable to other countries. Relative to other developed countries, the USA has high levels of income inequality whereas Finland has low levels. This leads the authors to suggest that the shape of the relationship may depend on the level of income inequality: higher income inequality corresponding to more curvilinear relationships and lower inequality to more linear relationships.

This line of reasoning, elaborated by Ellison,[8] turns Gravelle's formulation on its head. Instead of the association between income inequality and health (at the aggregate level) being an 'artefact' of a curvilinear relationship at the individual level, rather the curvilinear individual relationship is the result of income inequality within the society. The reason, put succinctly by Davey Smith,[9] is that 'Income inequality goes hand in hand with underinvestment in human resources'.

The absence of a steep curve at lower incomes in Finland is largely attributed by the authors to the protective effect of the Finnish welfare state which pre-empts 'the emergence of a low paid underclass with particularly high mortality'. Implicit in this explanation is the notion of the curvilinear relationship as somehow the natural state which will tend to arise unless preventive measures are taken.

Why, we might ask, does the curvilinear relationship seem so appealing? There are several possible reasons. One is simply a carry over from the clear non-linearity that appears, for example between GDP and life expectancy, when a full range of countries is included. Wilkinson maintains that for 'developed' societies the curve has flattened so much that there is no longer any relationship. Others disagree. In an interesting variation on this theme, Ellison[8] speculates that the effect of high income inequality is to reduce the poorest individuals' income to the part of the relationship where the relationship becomes non-linear again.

Another possible reason lies in the intuitive appeal of the law of diminishing returns. Typically, this might be explained as follows: an increase of £1000 per month in household income will buy more 'health benefit' for a household where the current income is £1000 than for one where the current income is £4000. This seems self-evident. For some it suggests that an equal proportionate increase in income might confer the same health benefit and hence that log income would be a better predictor of health.[10]

However, there may be a flaw in the reasoning. Currently wealthy households will, in general, have had the health benefits of a lifetime of affluence, including the material, social and cultural benefits that go with it, and vice versa for currently poor households. Altering current income could have little or no impact on the effects of the prior life course. Re-formulating an example of diminishing returns in terms of alternative life courses dilutes the intuitive appeal.

Ultimately, the shape of the relationship (or relationships) between income and health, is an empirical question. Martikainen *et al*. call for further research on this in a wider range of countries. I, for one, second that.

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