Worsening trends in disease accumulation and health inequalities among middle-aged and older adults in Scotland: cross-cohort analysis using health-linked data from the Scottish Longitudinal Study

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Abstract

Background: In the United Kingdom, rising prevalence of multimorbidity is coinciding with stagnation in life expectancy. We investigate patterns of disease accumulation and how they vary by birth cohort, social and environmental inequalities in Scotland, a country which has long suffered from excess mortality and poorer health outcomes relative to its neighbours.

Methods: Using a dataset which links census data from 1991, 2001 and 2011 to disease registers and hospitalization data, we follow cohorts of adults aged 30-69 years for 18 years.

We model physical and mental disease accumulation using linear mixed effects models.

Findings: Younger born cohorts experience higher levels of chronic disease accumulation compared to their predecessors at the same ages. Moreover, in more recently born cohorts we observe socioeconomic status disparities emerging earlier in the life course, which widen over time and with every successive cohort. Patterns of chronic conditions are also changing, and the most common diseases suffered by later born cohorts are cancer, hypertension, asthma, drug and alcohol problems and depression.

Interpretation: We recommend policies which target prevention of chronic disease in working age adults, considering how and why certain conditions are becoming more prevalent across time and space.

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Keywords: multimorbidity, ageing, Scotland, birth cohort patterns, longitudinal analysis

Research in context

Evidence before this study Evidence from the UK suggests that the incidence and prevalence of multimorbidity (the same individual having more than one chronic disease) is increasing over time, which is partly attributable to population ageing. At the same time, gains in life expectancy in the UK have stalled, which in Scotland are partly attributable to rising mortality among working-age males. In the US and Canada multimorbidity rates are higher among recently-born cohorts at the same age, suggesting an earlier and more rapid onset of multimorbidity in younger cohorts. Evidence from UK and Scottish birth cohort studies using self-reported measures of health suggests the same patterns. However, a larger sample size and administrative data are required to provide more detail of demographic and socioeconomic patterns between different cohorts, provide a longitudinal picture of multimorbidity trajectories, and to explore the illnesses that might be driving earlier onset.

Added value of this study This study investigates 18-year multimorbidity trajectories using a representative sample of middle-aged and older Scottish adults, aged 30-69 years. It uses census data which provides a comprehensive picture of socioeconomic deprivation and housing status, linked to hospitalization and disease registers over an 18-year period. Recently born cohorts experience higher levels of chronic disease accumulation compared to their predecessors at the same ages. Moreover, in more recently born cohorts we observe socioeconomic status disparities emerging earlier in the life course, which widen over time and with every successive cohort. Patterns of chronic conditions are also changing, and the most common diseases suffered by later born cohorts are cancer, hypertension, asthma, drug and alcohol problems and depression.

Implications of all the available evidence In some high-income countries, chronic diseases are being diagnosed earlier in the life course. This suggests a worsening of population health among middle-aged adults. The conditions which drive earlier onset of chronic disease might vary between settings, just as the reasons for stalling life expectancy vary. We recommend policies which target prevention of chronic disease in working age adults, considering how and why certain conditions are becoming more prevalent across time and space.

Introduction

More individuals suffer from multiple simultaneous chronic diseases, or multimorbidity, during their lifespan than previously [1], partly as a result of population ageing. In England, the prevalence of individuals having 2 or more chronic diseases increased between 2004-2019 from 31% to 53% [2]. For individuals, multimorbidity is associated with poorer quality of life and higher incidence of mortality [3,4]. Moreover, future projections of multimorbidity anticipate it causing profound challenges for health systems, including increased costs and greater levels of unpaid informal care to meet growing gaps in state-funded social care [1,5]. Survey-based longitudinal research from North America and the UK suggests an earlier onset and higher prevalence of multimorbidity among younger born cohorts compared to older cohorts at corresponding ages [6–9]. This study investigates the issue in Scotland, where there is high prevalence of multimorbidity, whether this is measured using data from primary care, secondary care or social care receipt [10–12].

Scotland has long been the subject of epidemiological attention due to its comparatively high mortality rates relative to the rest of the United Kingdom and other Western European nations [13]. Recently, and in common with other high-income countries [14], there has been a downturn in population health, most evident in stalled life expectancy [15]. In this respect, Scottish mortality trends display similar patterns to those observed in the US [16], with an increase in cardiovascular mortality and 'deaths of despair', which include drug-related deaths [17]. In England and Wales, stalls in mortality improvements, or even reversals are particularly observable at older ages [18], while in Scotland, mortality among middle-aged men and those over 65 years contribute most to stalling life expectancy [17]. It has been suggested that austerity measures following the 2008 recession are the most likely contributory cause [14,15]. These have led to cuts in social welfare including reducing the value of unemployment and disability benefits, and reductions in the provision of social care at older ages. Austerity policies are likely to have implications for the onset and accumulation of chronic disease, as well as mortality.

It has been noted before, using self-reported cohort data that younger Scottish cohorts suffer higher multimorbidity [19], but the sample size and detail of administrative data linked to census data are needed for a comprehensive picture. Explanations for this pattern are currently unclear, with some suggesting increasing obesity rates as a key contributor [9,15]. Other studies have shown that early onset cancer rates are increasing [20], which would contribute to the accumulation of more disease in younger cohorts. In Scotland, adjustment for health behaviours does not explain multimorbidity differentials in cohort study data [19]. It is also unclear whether socioeconomic inequalities, which are particularly stark and apparently widening in Scotland [21], affect cohort trends in multimorbidity.

To address this gap, this study aimed to investigate 18-year multimorbidity trajectories of middle-aged and older adults, aged 30-69 years using linked census-administrative data in Scotland. We address the following research questions:

- How do disease accumulation trajectories vary according to age, gender and birth cohort?
- Do socio-demographic and socio-economic inequalities differ between birth cohorts?

Method

Data and sample

We used data from the Scottish Longitudinal Study (SLS), which links three Scottish censuses (1991, 2001, and 2011) to a range of administrative data sources for a 5.3% sample of the Scottish population [22]. In this study, SLS was linked to the national diabetes register (covering January 1st- 1997-31st August 2019) the cancer registry (covering January 1st 1980-31st August 2019), in-and outpatient hospitalization (SMR01, SMR04 covering January 1st 1997-31st August 2019). We selected a cohort of 124,612 SLS participants who were aged 30-69 years when they responded to the Scottish census in 2001. We observe participants from 1st April 2001 (when the census was conducted), until 31st July 2019, or until they die, or exit from the study due to emigration.

Chronic disease identification

There is great variability in how multimorbidity is measured in longitudinal studies [23], and the incidence is sensitive to the number of conditions considered [24]. Using a recently developed consensus list of conditions [25] we extracted disease presence, order and month of first being recorded for 44 conditions (see list, relevant ICD10 codes and prevalence in Supplementary Table S1). Any diagnosis from the diabetes register (Types 1 and 2) was also included. In the case of the same disease being recorded more than once across these records, we chose the earliest date. The derived outcome is an additive index of these 44 conditions measured annually at 1st January. For some descriptive analyses, we created a binary version of the index classified into 2+ conditions vs less. As a robustness check, we used an alternative multimorbidity score with fewer conditions (the Charlson index [26]) in sensitivity analyses. In addition, we corroborated our results by looking at trajectories of multimorbidity for individuals aged 40-59 in 2011, for which we had a longer record of the 44 conditions in the index before follow-up.

Covariates

Age was measured in years and calculated as the difference between birth year of respondent and their age in 2001. Birth cohort was classified into (approximate) 5-year groups: 1931-35, 1936-40, 1941-45, 1946-50, 1951-55, 1956-1960, 1961-65 and 1966-1971. We used sex classified into male/female as recorded in the census 2001. We included a range of socioeconomic indicators capturing different scales. Individual educational attainment was measured in 2001, classified into no qualifications, low (secondary school level), medium (further education e.g., advanced higher), high (any higher education). Household tenure was measured in 2001 (classified into private renting, social renting and owning property). Finally, we measure area-based social deprivation using the Scottish Index for Multiple Deprivation (SIMD) in 2014 [27], which measures deprivation in 6,976 small areas or data zones and based on seven broad domains:

income, employment, education, health, access to services, crime and housing, into five distinctive quintiles.

Statistical Analysis

Analyses included a total of 122,147 individuals with full records on SIMD, educational qualification and household tenure. We measured chronic disease score on an annual basis at 1 January. We transformed the data to a person-year file where each cohort member could contribute a maximum of 19 annual observations. We use an accelerated longitudinal design [28] and fit a series of linear mixed age-cohort models that predict the score of chronic conditions in 2001 and the subsequent change in chronic conditions between 2001 and 2019 (full model specifications and development are available in the supplementary material). Over the follow-up period, the age/period/cohort overlaps occur around middle age (50-70 years) providing an opportunity to compare birth cohorts at the same ages. The linear mixed effects models account for repeated observations over time for the same individuals, and the final models included age from the beginning of the follow-up period and cohort as fixed effects. We tested different age and cohort specifications (linear, quadratic and cubic), assessing their fit using AIC/BIC values, and present those including age and cohort linear and quadratic polynomial forms.

In nested models, we tested interactions between age, birth cohort, and gender. To assess variations in socioeconomic inequalities between cohorts, we also tested interactions between age, birth cohort and the three socioeconomic variables (SIMD, educational level and housing tenure). Final models presented in the results only included statistically significant interaction terms ($p<0.05$). Where there were significant differences between multimorbidity trajectories by cohort and age, we calculated predicted values of the multimorbidity score to draw curves for birth cohorts across age by SIMD quintiles, educational level and housing tenure. To measure and visualize socioeconomic inequalities by birth cohort and age, we used model predicted values and calculated crude and relative differences in these comparing, for instance, the most and least socioeconomically deprived categories. So, for example, we compared the model predicted multimorbidity scores for the most and least deprived SIMD quintile at age 40, in the birth cohort born in 1970-74.

Results

Sample description

At the start of the observation period in 2001, 52% of the sample were female (Table 1). Most of the sample had no qualifications or low education (60%), and over 20% had higher education. The majority of the sample (75%) owned their house, and nearly 20% lived in social housing. At baseline, the proportion of the sample with 2 or more diseases increased substantially with age and was higher among older people (55 years and over compared to those <55 years). Men were more likely to have multimorbidity than women. The proportion with 2 or more diseases increases with higher deprivation, and was more than twice as high in the most versus least deprived SIMD quintile (5 vs 2%). Likewise, there was an educational gradient, with those with no education having higher multimorbidity. Those who were living in social rented housing or not paying rent had higher multimorbidity than private renters or house owners.

Table 2 shows the 10 most common diseases to be diagnosed over the observation period 2001-2019, from the 44 conditions in our index, stratified by age group of the individual at baseline. Cancer was the most common disease in every age group. After cancer, hypertension was most common in almost all age groups. Alcohol/drug misuse as a more frequently occurring condition in younger adults (i.e. those aged <55 years at baseline) than among older adults. Depression and asthma were relatively more commonly diagnosed in the younger age groups, than the older. On the other hand, among adults aged over 49, hypertension, osteoarthritis, coronary heart disease (CHD), diabetes and arrhythmia were among the top 5 diseases to be newly recorded.

Table 1: Sample description at baseline (2001); individuals aged 30-69

MEASURED AT BASELINE		**N**	**Percent**	**MM score Mean**	**2+ diseases (%)**
SEX	**Males**	58,420	47.8	0.18	3.8
	Females	63,727	52.2	0.14	2.7
AGE GROUP	**30-35**	14,709	12.0	0.05	ND
	35-39	16,730	13.7	0.06	ND
	40-44	18,778	15.4	0.09	1.4
	45-49	16,934	13.9	0.11	2.0
	50-54	17,261	14.1	0.16	3.1
	55-59	14,307	11.7	0.22	4.8
	60-64	12,562	10.3	0.31	6.8
	65-69	10,866	8.9	0.41	9.3
SIMD	**(1) Most deprived**	21,207	17.4	0.24	5.2
	(2)	23,159	19.0	0.19	4.1
	(3)	24,509	20.1	0.15	3.0
	(4)	25,817	21.1	0.12	2.3
	(5) Least deprived	27,455	22.5	0.11	2.0
EDUCATION	**No qualifications**	45,710	37.4	0.25	5.4
	Low	27,621	22.6	0.12	2.2
	Medium	22,701	18.6	0.10	1.8
	High	26,115	21.4	0.10	1.7
HH TENURE	**Owned**	91,189	74.7	0.51	2.5
	Private rented	4,328	3.5	0.51	2.7
	Social rented	24,322	19.9	0.82	5.9
	No rent	2,308	1.9	0.76	5.5
TOTAL		122,147	100.0	*0.16*	*3,915*

Source: Scottish Longitudinal Study
Note: household tenure missing cases 2,465 (1.98%) ND= Not disclosed due to cell size count.

Table 2: Most commonly occurring diseases newly diagnosed during the 18-year follow-up by age at baseline.

Number of individuals diagnosed, ranked	Age in years in 2001					
	30-34	**35-39**	**40-44**	**45-49**	**50-54**	**55-59**
	(n=13,882)	(n=15, 677)	(n=16,457)	(n=14,439)	(n=13,982)	(n=10,562)
1	Cancer	Cancer	Cancer	Cancer	Cancer	Cancer
2	Asthma	Hypertension	Hypertension	Hypertension	Hypertension	Hypertension
3	Drug/alcohol misuse	Asthma	Osteoarthritis	Osteoarthritis	Osteoarthritis	Osteoarthritis
4	Hypertension	Osteoarthritis	CHD	CHD	CHD	CHD
5	Osteoarthritis	Drug/alcohol misuse	Asthma	Diabetes	Arrythmia	Arrythmia
6	Depression	CHD	Drug/alcohol misuse	Asthma	Diabetes	Diabetes
7	Endometriosis	Depression	Diabetes	Drug/alcohol misuse	Asthma	COPD
8	Diabetes	Diabetes	Arrythmia	Arrythmia	COPD	Asthma
9	Arrythmia	Arrythmia	Depression	Thyroid	Drug/alcohol misuse	Stroke
10	CHD	Endometriosis	Thyroid	COPD	Thyroid	Drug/alcohol misuse

Source: Scottish Longitudinal Study

Notes: CHD = coronary heart disease COPD = chronic obstructive pulmonary disorder. Red-shaded cells show diseases that are more likely to onset in younger ages/ later born cohorts; blue shaded are more likely to onset at older ages/ in earlier born cohorts; unshaded show no clear age pattern.

Chronic disease accumulation patterns by age and cohort

We show nested multilevel models in Table 3 which model the outcome of chronic disease score. Before running these more complex models, we tested the fit of a simple model containing age, gender and cohort, and compared this with one containing an age*cohort interaction. This suggested that a model with age*cohort interactions was a better fit.

Model 1 included main effects for cohort, age and gender, and interactions between cohort and gender, and cohort and age. Multimorbidity scores increased with time and birth cohort. We used predicted scores derived from model 1 to visualise average cohort trajectories (Figure 2). Each curve represents a disease accumulation trajectory for a given cohort,

starting in 2001 and tracking the average disease scores over the next 18 years. This demonstrates rapid increases with age, and a somewhat curvilinear pattern at younger ages. Later born birth cohorts also have higher average multimorbidity scores, suggesting that at similar ages, more recently born cohorts suffer higher levels of multimorbidity. For example, at age 50, those born between 1956-60 have higher multimorbidity scores than the 1951-55 or 1946-50 cohorts at the same age. There is also a significant age-cohort interaction, suggesting steeper age gradients in earlier born cohorts (and at older ages).

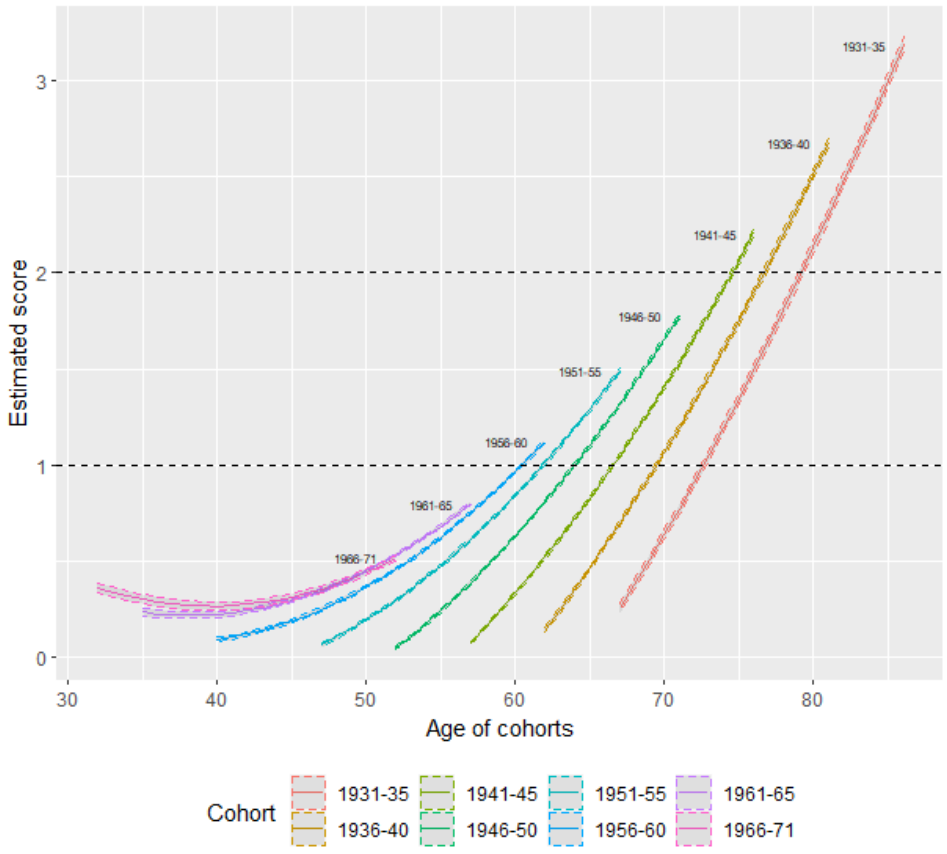
Table 3: Estimated multimorbidity scores from linear multilevel models, adults aged 30-69, Scotland 2001-2019

Disease scores	**Model 1** **β (95% CI)**	**Model 2** **β (95% CI)**	**Model 3** **β (95% CI)**
Age	0.069*** [0.069,0.070]	0.091*** [0.089,0.092]	0.091*** [0.089,0.092]
Age quadratic	0.002*** [0.002,0.002]	0.002*** [0.002,0.002]	0.002*** [0.002,0.002]
Birth cohort	0.198*** [0.194,0.203]	0.263*** [0.255,0.271]	0.276*** [0.267,0.284]
Birth cohort quadratic	-0.044*** [-0.046,-0.043]	-0.045*** [-0.046,-0.043]	-0.045*** [-0.046,-0.043]
Females (ref. males)	0.003 [-0.010,0.016]	-0.061*** [-0.091, -0.031]	-0.073*** [-0.132,-0.0415]
Females*Cohort	-0.006 [-0.012,0.000]	-0.008** [-0.014,-0.002]	-0.007* [-0.013,-0.001]
Age*Cohort	-0.005*** [-0.005,-0.004]	-0.005*** [-0.005,-0.004]	-0.005*** [-0.005,-0.004]
SIMD (most deprived)			
SIMD 2		-0.146***[-0.176,-0.115]	-0.148*** [-0.186,-0.110]
SIMD 3		-0.214*** [-0.244,-0.184]	-0.236*** [-0.275,-0.197]
SIMD 4		-0.299*** [-0.329,-0.270]	-0.332*** [-0.372,-0.291]
SIMD – least deprived		-0.336*** [-0.365,-0.306]	-0.376*** [-0.420,-0.332]
SIMD (most deprived)*Linear age			
*SIMD 2*Linear age*		-0.012*** [-0.013,-0.010]	-0.012*** [-0.013,-0.010]
*SIMD 3*Linear age*		-0.021*** [-0.023,-0.019]	-0.021*** [-0.023,-0.019]
*SIMD 4*Linear age*		-0.030*** [-0.032,-0.028]	-0.030*** [-0.032,-0.028]
*SIMD – least deprived*Linear age*		-0.038***[-0.040,-0.036]	-0.038*** [-0.040,-0.036]
SIMD (most deprived)*Cohort (1931-35)			
*SIMD 2*Cohort*		-0.036*** [-0.046,-0.026]	-0.038*** [-0.048,-0.027]
*SIMD 3*Cohort*		-0.062*** [-0.072,-0.052]	-0.068*** [-0.078,-0.058]
*SIMD 4*Cohort*		-0.088*** [-0.098,-0.079]	-0.097*** [-0.108,-0.087]
*SIMD least deprived*Cohort*		-0.117*** [-0.126,-0.107]	-0.128*** [-0.138,-0.118]
SIMD (most deprived)*Male (ref)			
*SIMD 2*Females*		0.059** [0.017,0.101]	0.064** [0.022,0.106]
*SIMD 3*Females*		0.054* [0.013,0.096]	0.063** [0.022,0.104]
*SIMD 4*Females*		0.095*** [0.055,0.136]	0.104*** [0.063,0.145]
*SIMD Least deprived*Females*		0.071*** [0.031,0.112]	0.079*** [0.038,0.119]
Education qualification (ref. none)			
Low			-0.144*** [-0.183,-0.105]
Medium			-0.199*** [-0.248,-0.149]
High			-0.235*** [-0.297,-0.173]
SIMD (ref. most deprived)*Education (ref. none)			
*SIMD 2*Low*			0.037 [-0.017,0.092]

*SIMD 2*Medium*			0.043 [-0.023,0.109]
*SIMD 2*High*			0.068 [-0.011,0.146]
*SIMD 3*Low*			0.078*** [0.023,0.133]
*SIMD 3*Medium*			0.097** [0.033,0.162]
*SIMD 3*High*			0.137*** [0.063,0.212]
*SIMD 4*Low*			0.118*** [0.0617,0.173]
*SIMD 4*Medium*			0.135*** [0.071,0.199]
*SIMD 4*High*			0.143*** [0.070,0.216]
*SIMD Least deprived*Low*			0.137*** [0.085,0.202]
*SIMD Least deprived*Medium*			0.172*** [0.106,0.237]
*SIMD Least deprived*High*			0.160*** [0.087,0.234]
Individual	1.223 [1.213, 1.234]	1.207 [1.196, 1.217]	1.203 [1.193, 1.213]
Var (age slope)	0.015 [0.014, 0.016]	0.014 [0.013, 0.015]	0.014 [0.013, 0.015]
Residual	0.148 [0.148, 0.148]	0.148 [0.148, 0.148]	0.148 [0.148, 0.148]
AIC	2982066.8	2978892.7	2978643.4
N	2,120,400	2,120,400	2,120,400

Source: SLS Longitudinal study
95% confidence intervals in brackets
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figure 2: Predicted multimorbidity scores by cohort and age (based on model 1 estimates in Table 3)



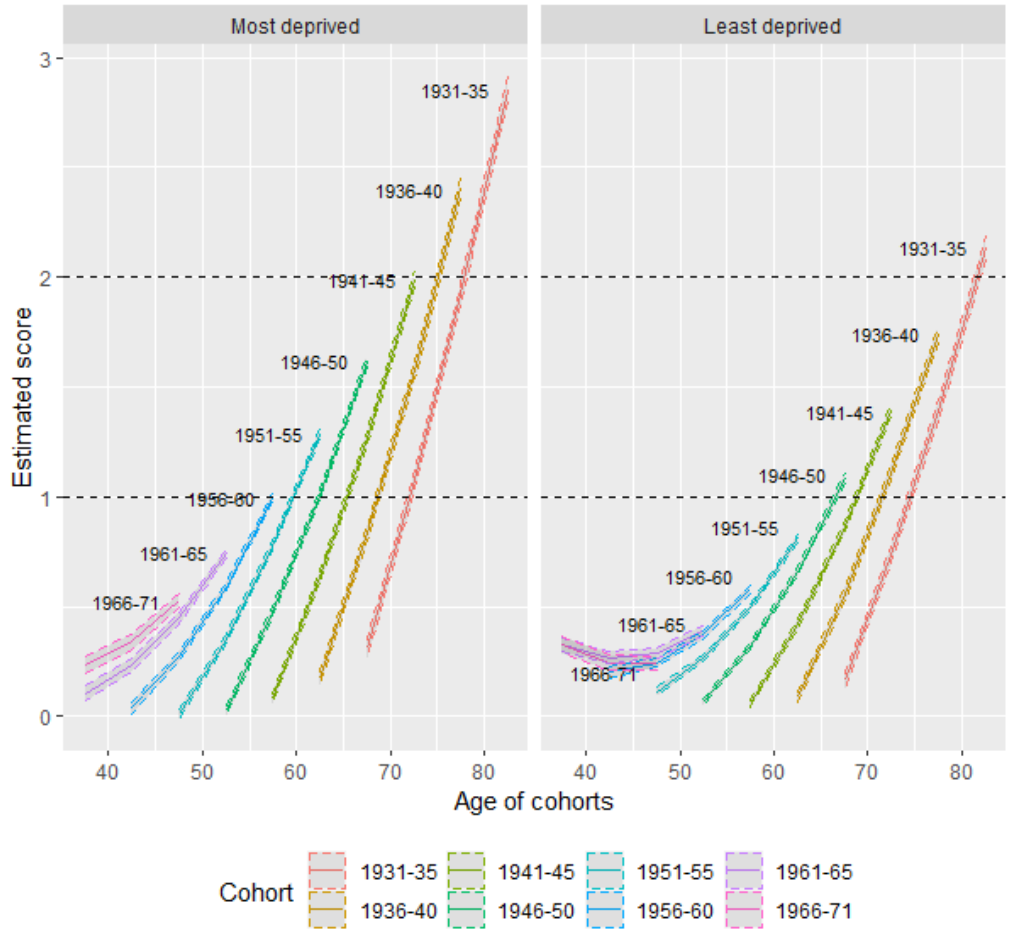
Source: Scottish Longitudinal Study

Disparities by socioeconomic factors

Area-level deprivation

To explore socioeconomic differentials by age and cohort, models 2 and 3 in Table 1 included SIMD quintiles, education and interactions between these variables, age and cohort. Living in more deprived SIMD quintiles is associated with higher average disease scores (model 2). Age significantly interacts with SIMD quintiles, suggesting that those living in more deprived areas have faster disease accumulation. We show predicted disease scores over age and cohort for the most and least deprived quintiles in Figure 3. The left panel (most deprived group) is marked by higher average scores at every age and in every cohort, and steeper age trajectories within each birth cohort. The average disease trajectory of an individual in the most deprived SIMD quintile is comparable with that for an individual 5 years older in the least deprived SIMD quintile. This pattern persists after further adjustment for individual education (model 3). At age 40, those in the most deprived quintile are already starting to see sharp accumulation of conditions with age, whereas for those in the least deprived quintile at the same age there are flat trajectories.

Figure 3: Predicted multimorbidity scores by age, cohort and SIMD quintile

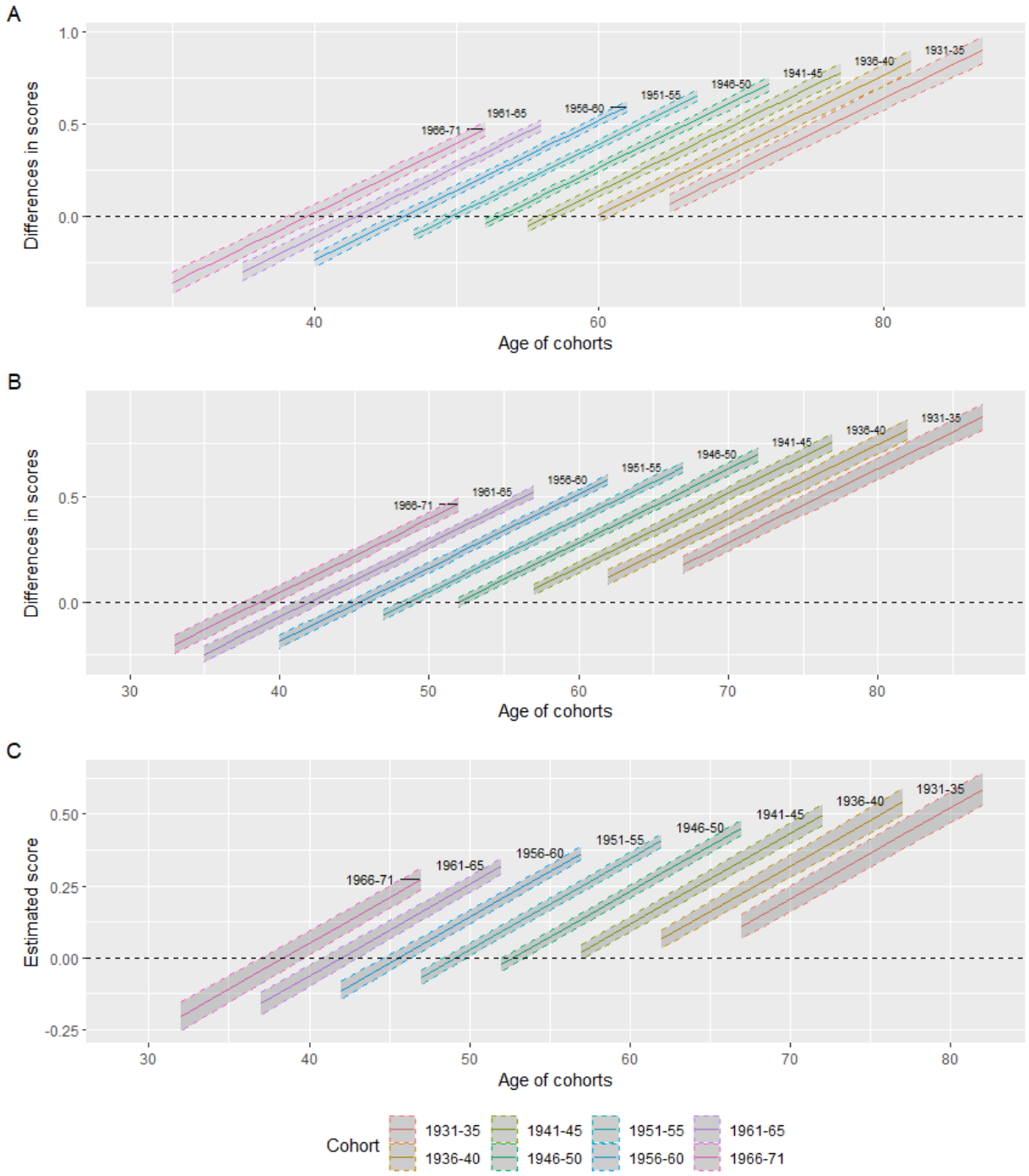


Source: Scottish Longitudinal Study

The significant SIMD by cohort interaction term in models 2 and 3 suggests that SIMD inequalities differ by cohort. To visualise these disparities, we calculated absolute differences in predicted scores between the least deprived quintile by scores from the most deprived, and plotted these by age and birth cohort (Figure 4A). Scores below zero indicate that individuals in the least deprived cohort have higher disease scores in that cohort for a given age; above zero indicates the most deprived quintile have higher scores. Higher values on the y axis indicate larger absolute disparities in scores between least and most deprived quintiles.

At most ages, those living in the most deprived quintile had higher disease scores. The exception to this is at younger ages (<45 years), where in more recently born cohorts, the least deprived quintile had higher average disease scores. In every cohort, as age increases, so do the score differentials between the least and most deprived quintiles, suggesting SIMD inequalities widen with age. Finally, considering overlapping ages for different birth cohorts, the average differences between least and most deprived quintile are progressively larger for every subsequently born birth cohort. For example, considering age 50, SIMD differentials are higher in the birth cohorts 56-60, and 61-65, than in the 51-55 cohort, suggesting widening socioeconomic inequality with each successive birth cohort.

Figure 4: Differences in estimated multimorbidity scores of multimorbidity (A: Least vs Most deprived SIMD quintiles; B: Social vs Owned housing tenure; C: No education vs High) by cohort and age



Source: Scottish Longitudinal Study

Disparities by education and household tenure

We observed similar patterns of disparities in disease scores by education, when adjusting for area-level deprivation (see Table 2 (Model 3) and Table S2), as we did for SIMD. The main effect of education in model 3 in Table 2 shows an inverse relationship between education levels and disease scores, such that people with higher levels of education had lower levels of chronic disease. Table S2 additionally interacts education with age, cohort and gender, and suggests a significant age and education interaction, meaning that those with high education have slower disease accumulation with age. The significant education by cohort interaction term in model 2 suggests widening educational differentials with each subsequently born cohort (visualised in Figure 4C). Finally, we investigated disparities by household tenure (Table S3) by running similar models including household tenure, SIMD quintiles, education and interactions between age and cohort. Living in a housing tenure other than privately owned is associated with higher average disease scores, and faster accumulation by age (Table S3, and Figure S2). These disparities are larger for younger born cohorts. The models in Table S3 also show significant household tenure by cohort interactions, suggesting differing levels of household tenure inequalities across cohorts and ages. We plot the disease score differentials between those living in social rented houses compared to homeowners in Figure 4B, which shows that larger inequalities at the same age with each successive cohort.

Robustness Checks

We repeat the modelling with an alternative index of multimorbidity, the Charlson index (Tables S4-S6), this shows approximately the same patterns of associations but with lower score estimates, due to the more limited list of conditions. We also fitted the same models, restricting to observation period 2011-2019, to allow for more complete historical disease coverage. Figures S3 and S4 show predicted scores for cohorts over age, and then comparing these by highest and lowest SIMD quintile. The patterns hold in this restricted sample, suggesting that reduced disease coverage at baseline does not substantially bias our main results.

Discussion

This study analyses longitudinal administrative secondary care data that is linked to census data, providing a representative life course perspective on middle and older age health in Scotland. This enables us to explore how chronic diseases accumulate differently throughout the life course by gender, birth cohort, area deprivation, education and housing tenure. There are persistent social inequalities in the accumulation of chronic disease among working-age adults in Scotland, which widen with age and with every subsequent birth cohort. Our findings corroborate cross-sectional studies which suggest faster accumulation with age, gaps by area-level deprivation and gender [11]. Our evidence is based on census-linked administrative data, providing a more robust picture than cohort data using self-reported measures [19]. We also show that social disparities persist across many dimensions and scales, area-level deprivation (SIMD), housing tenure and individual level human capital (education).Taken together with other evidence, it appears that in Scotland, the rest of the UK the United States, and Canada, more recently born cohorts are suffering from complex morbidity at an earlier age compared to later born cohorts [6,8,9].

Our results suggest that in Scotland the time spent in good health in the life course is shortening, a trend noted in other high-income countries [29]. Drivers of this morbidity expansion have been discussed, for example the role of obesity and metabolic risk factors [9,19], and in the UK, austerity and rising socioeconomic inequalities[14]. A simple description of the most commonly diagnosed diseases by different ages/cohorts suggests Scottish patterns of disease accumulation are impacted by specific conditions. For example, drug and alcohol use was one of the most common conditions to onset at younger ages. This is not surprising given Scotland's relatively high rates of drug-related deaths[17]. Cancer and hypertension are leading diseases at all ages, underlining the need to address systematic risk factors for cardiovascular disease and cancer, such as obesity. On the other hand, the cohort pattern could be explained by improvements in health care seeking, screening and diagnosis, which could mean that diseases are diagnosed at an earlier age. Given that we are using data largely drawn from hospitalization records, rather than primary care, that is unlikely to be the main explanation. Further, our cohort and age-related patterns are similar to those that have applied methods taking account of age-period-cohort relations [9].

Younger cohorts also experience wider health disparities, which are expected to widen further with age. Uniquely, this study shows large inequalities by housing tenure, showing that living in social housing versus owning your own house, is associated with increasingly deleterious health effects. Importantly, this effect persists after adjustment for SIMD and education, indicating that disadvantage is embedded not only in individual and area-level material deprivation, but patterned by household-level level environments, which have so far not been extensively studied. Understanding how chronic disease risk is shaped by household and housing environments is key to reducing inequalities,

especially given how younger generations are experiencing much lower levels of housing ownership, and will likely experience greater housing precarity in later life than did previous generations [30]. Further, the results also suggest attention to subgroups that might be experiencing intersectional disadvantage. For example, men tended to have faster accumulation with age, but this disadvantage is amplified for men living in social housing.

The strengths of this study include the longitudinal data linkage between health administrative data and the census, which enable us to study detailed mental and physical trajectories in a large representative sample of the Scottish population, and to investigate social disparities from a number of dimensions. We also employ multilevel growth curve modelling to tease out age- cohort effects. However, we should mention a few limitations. First, we likely underestimate disease prevalence and incidence because we dd not have access to primary care data would might provide more coverage of less severe conditions. However, our study was not designed to comprehensively estimate prevalence /incidence, but to compare cohorts and socioeconomic groups, and these are likely to be comparable. However, our disease data does not cover the whole life course of our respondents, meaning that diseases suffered earlier in the life course are not counted, which disproportionately affects older individuals (or earlier born cohorts). It is therefore reassuring that cohort patterns we observe match those from studies using prospective disease data from cohort studies [8,19], and that our results hold when we estimate follow-up from 2011, which allows better coverage of diseases diagnosed prior to baseline.

Multimorbidity is a complex public health threat for which our health and social care systems are insufficiently prepared. This study highlights worsening trends in Scottish population health which will aggravate the situation. The study finds, using nationally representative administrative and census data, that younger generations typically develop disease at earlier ages than earlier cohorts, and that health inequalities, which are already pronounced in the Scottish population, develop earlier in the life course and continue to widen. Worsening cohort trends underscore the urgent need for public health policies that tackle the root causes of chronic disease, present in environments are multiple scales, which develop early in the life course.

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Author's contributions

ER: Conceptualisation, data curation, formal analysis, visualisation, writing-original draft GC: Data curation, writing-review and editing AM: Methodology, writing-review and editing KK: Conceptualization, data curation, funding acquisition, project administration, resources, supervision, writing- original draft

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