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Long-term trends in mortality differences

Register-based studies in Finland, 1970–2020

Ulla Suulamo

DOCTORAL DISSERTATION

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Supervisors

Professor Pekka Martikainen, University of Helsinki

University Researcher Hanna Remes, University of Helsinki

University Researcher Lasse Tarkiainen, University of Helsinki

Pre-examiners

Professor Martin Bobak, University College London

Professor Neil Mehta, The University of Texas Medical Branch

Opponent

Professor Seppo Koskinen, THL

Custos

Professor Pekka Martikainen, University of Helsinki

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Abstract

Mortality has declined substantially over the last century, reflecting significant overall health improvements across populations. Yet despite the overall improvement, notable differences in mortality risks persist across population subgroups, with evidence suggesting that these differences have even widened in recent decades, at least when measured by socioeconomic position. However, mortality differences are not solely shaped by socioeconomic inequalities but also by other dimensions, such as where people live, with whom they live, and frailty to seasonal mortality risks. These aspects have received less attention, particularly from a long-term perspective.

This thesis examined long-term trends in mortality differences in Finland since the 1970s in three independent sub-studies, each focusing on distinct and less-studied dimensions of mortality variation: area of residence, living arrangements, and seasons of the year. The studies were based on comprehensive individual-level total population data of those aged 30 and above, drawn from administrative registers and covering the period from 1970 to 2020.

Over the past five decades, variation in mortality rates between municipalities increased markedly, largely explained by widening differences in population age structures. Once these age structure differences were accounted for, mortality differences remained unchanged amongst those age 70 and over. In contrast, disparities widened at younger ages, with the most consistent increase observed among working-age men (30–49), for whom area differences were the most pronounced. Men in this age group living in higher-mortality municipalities faced, on average, a 33% higher hazard of death compared to those in lower-mortality municipalities, up from 17% in the early 1970s. This increase in mortality variation was largely driven by external causes of death and linked to growing socioeconomic disparities between municipalities.

Living arrangements that involve co-residence with a partner have traditionally been linked to lower mortality. This advantage persisted between 1990 and 2020. Throughout this period, all-cause mortality was lowest among men and women living with a partner, while those living alone or with persons other than a partner or child faced up to a fivefold excess mortality risk compared to those living with a partner and children. Although mortality declined across all living arrangement groups and absolute differences in mortality rates narrowed, relative disparities widened partially due to the declining mortality level. The relative mortality disadvantage increased particularly in the growing group of individuals living alone. Adjusting for socioeconomic factors attenuated mortality differences between living arrangement categories only modestly but their contribution grew slightly towards the end of the study period.

Mortality typically follows a seasonal pattern, with higher mortality rates observed during winter months, particularly among the older population. Since 1970, excess winter mortality steadily declined in Finland. Yet despite this overall decline, winter mortality

rates consistently remained higher compared to non-winter rates, with approximately 12% higher mortality observed during winter months in the most recent two decades. While older individuals, and those with dementia or living in institutional settings, were identified as being more vulnerable to winter mortality, the increased risk of winter death extended beyond these groups in the population aged 60 years and over. No differences were observed between income groups.

Overall, these findings demonstrate that while mortality has continuously declined over the past decades, disparities between the dimensions studied in this thesis persist. However, some differences have widened, others have remained stable, and some have narrowed. The results further show that the factors driving mortality differences, and their changes vary across contexts, with socioeconomic factors playing different roles in explaining the trends over time. Taken together, insights from this study extend perspectives on the long-term developments of mortality disparities and emphasise the need for holistic, sustained, and coordinated efforts to address them.

Tiivistelmä

Viime vuosikymmeninä kuolleisuus on laskenut ja väestön terveydentila parantunut merkittävästi. Tästä huolimatta väestöryhmien väliset erot kuolleisuudessa ovat pysyneet huomattavina ja ajoittain jopa kasvaneet, etenkin sosioekonomisen aseman mukaan tarkasteltuna. Sosioekonomisten tekijöiden ohella kuolleisuus voi vaihdella myös asuinpaikan, asumisjärjestelyjen sekä vuodenajan mukaan. Tässä tutkimuksessa tarkasteltiin kuolleisuuserojen muutoksia Suomessa 1970-luvulta alkaen kolmen erillisen osatutkimuksen kautta, keskittyen näihin vähemmän tutkittuihin ulottuvuuksiin. Aineistona käytettiin koko Suomen aikuisväestön kattavia rekisteritietoja vuosilta 1970–2020.

Alueiden väliset erot kuolleisuudessa ovat Suomessa huomattavia. Kuntien väliset kuolleisuuserot kasvoivat viimeisten viiden vuosikymmenen aikana selvästi. Kehitystä selitti pitkälti kuntien ikärakenteiden eriytyminen. Kun erot ikärakenteissa huomioitiin, kuntien väliset kuolleisuuserot pysyivät ennallaan yli 70-vuotiailla, mutta kasvoivat nuoremmissa ikäryhmissä. Suurin ja johdonmukaisin kasvu havaittiin työikäisillä miehillä (30–49 v.). Tässä ikäryhmässä korkeamman kuolleisuuden kunnissa asuvilla miehillä oli keskimäärin 33 % suurempi kuolemanriski verrattuna matalamman kuolleisuuden kuntiin, kun vastaava ero oli 1970-luvun alussa 17 %. Erot kasvoivat erityisesti tapaturmaisissa ja väkivaltaisissa kuolinsyissä, ja kasvun taustalla oli kuntien välisten sosioekonomisten erojen voimistuminen.

Vuosina 1990–2020 kuolleisuus oli alhaisinta puolison kanssa asuvilla miehillä ja naisilla, kun taas yksin tai muiden kuin puolison tai lapsen kanssa asuvien kuolleisuus oli jopa viisinkertaista puolison ja lasten kanssa asuviin verrattuna. Vaikka kuolleisuus laski kaikissa asumismuodoissa kolmen vuosikymmenen aikana ja absoluuttiset erot ryhmien välillä kaventuivat, suhteelliset erot kasvoivat, osittain kuolleisuuden yleisen tason laskun seurauksena. Erityisesti yksinasuvien muista korkeampi kuolemanriski korostui entisestään. Sosioekonomisten tekijöiden huomioiminen ei merkittävästi kaventanut eroja, mutta niiden merkitys kasvoi hieman tutkimusjakson loppua kohden.

Kuolleisuus vaihtelee vuodenajoittain ollen etenkin ikääntyneillä korkeampaa talvikuukausina. Talven ylikuolleisuus on vähentynyt Suomessa tasaisesti 1970-luvulta alkaen, mutta pysynyt johdonmukaisesti muita vuodenaikoja korkeampana. Viimeisten kahden vuosikymmenen aikana 60 vuotta täyttäneillä ja tätä vanhemmilla talvikuolleisuus oli noin 12 % korkeampaa kuin muina vuodenaikoina. Riski kuolla talvella oli korkeinta vanhimmissa ikäryhmissä, laitoksissa asuvilla sekä muistisairailla. Tulotasoon perustuvia eroja ei havaittu.

Kuolleisuuden tasaisesti laskiessa kuolleisuuserot ovat kehittyneet erisuuntaisesti: osa on kasvanut, osa pysynyt ennallaan ja osa kaventunut. Näiden erojen ja niiden muutosten taustatekijät vaihtelevat kontekstista ja ajasta riippuen. Kokonaisuutena tutkimus tarjoaa

uusia näkökulmia kuolleisuuserojen pitkän aikavälin kehitykseen ja korostaa tarvetta kokonaisvaltaisille, pitkäjänteisille ja koordinoiduille toimille erojen kaventamiseksi.

List of abbreviations

ASMR	Age-standardised mortality rate
CI	Confidence interval
HR	Hazard ratio
ICD	International Classification of Diseases
ISCED	International Standard Classification of Education
Kela	Social Insurance Institution of Finland
MHR	Median hazard ratio
THL	Finnish Institute for Health and Welfare
RR	Rate ratio

Index

List of original publications

This thesis is based on the following publications:

I **Suulamo, U.**, Tarkiainen, L., Remes, H., & Martikainen, P. (2021). Changes in regional variation in mortality over five decades – The contribution of age and socioeconomic population composition. *SSM - Population Health*, 15, 100850.

II **Suulamo, U.**, Remes, H., Tarkiainen, L., & Martikainen, P. (2025) Long-term trends in mortality by living arrangements and the role of socioeconomic factors, Finland 1991–2020. *European Journal of Public Health*, ckaf068.

III **Suulamo, U.**, Remes, H., Tarkiainen, L., Murphy, M., & Martikainen, P. (2024). Excess winter mortality in Finland, 1971–2019: A register-based study on long-term trends and effect modification by sociodemographic characteristics and pre-existing health conditions. *BMJ Open*, 14(2), e079471.

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1 Introduction

Population health has improved significantly over the past centuries, as evidenced by decreasing mortality and increasing longevity across countries (Oeppen & Vaupel, 2002; Wilmoth, 2011). However, important differences in mortality risks within populations persist. Research consistently indicates that an individual's chances to live a long life vary according to a number of social or environmental factors, including socioeconomic circumstances, place of residence, and living arrangements, among others (Elo, 2009; Ø. Kravdal, 2006; Macintyre & Ellaway, 2003; Koskinen et al., 2007). Furthermore, empirical evidence suggests that mortality differences have even grown over the past decades, especially when measured across socioeconomic groups (Mackenbach et al., 2016). This implies that overall mortality reductions have benefited some segments of populations more than others.

In recent decades, the mortality decline has been most consistent in high-income regions, where life expectancy has continued experiencing steady gains (Leon, 2011). Across Western European countries, between 1970 and 2020, life expectancy at birth rose from around 71 years to nearly 82 years, reflecting an average increase of around 2 years per decade (United Nations, 2024). Non-infectious diseases now dominate the profile of causes of death, and most people die from cardiovascular diseases and cancer (Bergeron-Boucher et al., 2020). While before 1950, gains in longevity were due to improvements in infant and childhood survival, since the second half of the 20th century, the gains have been driven by progress at older ages (Christensen et al., 2009).

Public health interventions have played a central role in the long-term decline in mortality. Early efforts focused on controlling infectious diseases and improving sanitation, but in recent decades, the focus has shifted towards disease prevention and health promotion (Mackenbach, 2020). The role of medical care and treatment of chronic conditions has also become more important (Bunker, 2001). Beyond more direct health measures that have been, and remain, key to improving population health, much of the decline in mortality is linked to broader societal changes that lie outside the usual scope of health policy. Over the long term, economic growth and rising living standards paved the way for mortality declines from the 18th century onwards. Furthermore, the overall increase in educational attainment has importantly contributed to reducing mortality rates, for instance, by fostering the adoption of healthier behaviours and a better understanding of health risks (Mackenbach, 2020).

While mortality has declined substantially across all countries and population subgroups over the long term, the timing and magnitude of these declines have often varied. Declines in high-income countries have tended to outpace those in lower-income nations, whereas within individual countries, some groups have experienced faster and more sustained reductions than others (Mackenbach, 2020; Ruzicka et al., 1989). Mortality differences across population subgroups have been a long-standing focus of socio-epidemiological research (Kitagawa & Hauser, 1973) and socioeconomic position in particular is widely recognised as a key determinant of mortality. Studies consistently show that individuals in more advantaged positions tend to experience better health and longer lives, whereas those who are more disadvantaged face higher risks of illness and premature death. Despite overall declines in mortality, shifting health threats, societal expectations and policy efforts aimed at reducing health inequalities, socioeconomic disparities in mortality have remained remarkably persistent, and in some cases, have even widened, as more advantaged groups have experienced faster mortality improvements. This persistence supports the argument that socioeconomic position functions as a fundamental determinant of health and mortality (Bartley, 2017; Glymour et al., 2014; Lynch & Kaplan, 2000).

While much research has focused on mortality disparities by socioeconomic position, mortality also varies by other dimensions. Age is a fundamental determinant of mortality risk, and women generally outlive men. Differences are also evident across geographic regions, living arrangements, and environmental conditions such as seasons of the year. Although these factors are sometimes overlooked in favour of more commonly studied social indicators such as education and income, they are crucial for understanding how mortality risks are distributed within populations. The sub-studies in this thesis address these less frequently examined dimensions of mortality differences and their changes over time.

Mortality is rarely evenly distributed across regions within a country and can exhibit substantial variation. Evidence suggests that subnational regional mortality differences have widened in many high-income countries in recent decades (Leyland, 2004; Pearce & Dorling, 2006; Vierboom et al., 2019). While the underlying reasons remain poorly understood, broader societal changes, such as economic restructuring, urbanisation, and selective migration, may have contributed. In particular, the migration of young people from peripheral areas to urban centres has altered the demographic and socioeconomic composition of areas (Grunfelder et al., 2020). These changes may, in turn, have contributed to regional mortality trends, as discrepancies in population structure, particularly in areas affected by economic restructuring and high outmigration, can affect the availability of essential services, economic opportunities, and overall living conditions, potentially aggravating health and mortality disparities between regions.

Mortality differences by living arrangement reflect the broader role of social relationships and household environment for health. Research consistently shows that those living with a partner have the lowest mortality risk, while those living alone tend to have higher mortality (Hu & Goldman, 1990; Koskinen et al., 2007; Rendall et al., 2011). The protective effects of living with a partner are thought to stem from economic security, emotional and social support, and the regulation of health behaviours, while living alone may increase vulnerability to isolation and financial difficulties (Holt-Lunstad et al., 2010, 2015; Umberson, 1992). In recent decades, living alone has become increasingly common alongside population aging, rising rates of cohabitation and union dissolution, and postponement of marriage and childbearing (Jamieson et al., 2009; Yeung & Cheung, 2015; Esteve et al., 2020). At the same time, the likelihood of being in a partnership has decreased and has become increasingly concentrated among those with higher levels of education, stable employment, and higher incomes (Erola & Kilpi-Jakonen, 2022; Jalovaara, 2012; Van Bavel et al., 2018). These ongoing shifts in living arrangements could have implications for individuals' well-being, which may be reflected in mortality patterns and the evolution of mortality differences.

Seasonal and environmental factors have long been recognised as important determinants of mortality (Rau, 2007). One clear example is the seasonal pattern of mortality observed in temperate countries, where significantly more deaths occur during the colder winter months compared to the rest of the year. The primary drivers of this winter excess include low temperatures (Gasparrini et al., 2015) and seasonal peaks in respiratory infections such as influenza (Reichert et al., 2004), with the largest fluctuations occurring in circulatory and respiratory diseases (Rau et al., 2018). Despite being observed across diverse regions, its magnitude varies widely between countries, suggesting that beyond external seasonal determinants, non-seasonal risk factors play a crucial role in shaping individual vulnerability. Age is a well-established risk factor, with older adults being particularly affected (Rau, 2007). However, other individual-level characteristics influencing winter mortality risk remain poorly understood, partly due to the reliance of many studies on aggregate-level analyses. Although evidence suggests that excess winter mortality has declined over time, it remains a significant public health concern in many countries (Fowler et al., 2015) and may become even more pressing as populations age.

Through three sub-studies examining regional differences, living arrangement differences, and excess winter mortality in Finland over the past five decades, this thesis aims to broaden perspectives on the long-term evolution of mortality disparities. The research relies on high-quality, individual-level register data covering the entire Finnish population from 1970 to 2020, offering a unique opportunity to analyse mortality trends in exceptional detail. By considering individual-level determinants and their changes over time, the study provides insights often unavailable in international research based on aggregate data. Given the societal changes with far-reaching consequences for people's living conditions, potentially shaping the patterns of health and illness, and the relative scarcity of studies with a long-term perspective, expanding the evidence on the dynamics of persisting mortality differences in high-income societies remains an important area of research.

2 Theoretical framework and empirical evidence

This section presents the theoretical background and empirical evidence on the three dimensions of mortality variation examined in this thesis: geographic differences, living arrangement differences, and excess winter mortality. It summarises key conceptual frameworks and underlying mechanisms and reviews empirical findings relevant to each sub-study. The discussion of long-term trends focuses on evidence since the second half of the 20th century, highlighting gaps in the literature specific to each topic.

2.1 Regional mortality variation

Geographic differences in mortality have been extensively documented, providing evidence of significant variations across various spatial scales, from local neighbourhoods to broader regions, even within high-income countries. In the United States, for example, a gap of 20 years has been estimated between counties with the lowest and highest life expectancy in 2014 (Dwyer-Lindgren et al., 2017). Similarly, in England and Wales, life expectancy in 2012 varied by 8 years for men and 7 years for women between districts (Bennett et al., 2015).

The reasons for regional mortality differences are complex and stem from a combination of factors. The literature often distinguishes between two principal sources: compositional and contextual effects. Compositional effects arise from the characteristics of individuals within an area, meaning that regional mortality differences largely reflect the spatial distribution of people with different mortality risks based on factors such as age and socioeconomic position. Contextual effects, on the other hand, refer to characteristics of places, meaning that mortality disparities originate from differences in area-level conditions (Subramanian et al., 2003). Multi-level analyses have provided evidence that area-level factors, including socioeconomic conditions, area disadvantage, social cohesion, and public policies, have significant effects on all-cause and cause-specific mortality (Martikainen et al., 2004; Riva et al., 2007; Bentley et al., 2008; Kibele, 2014; Montez et al., 2016). The role of these factors can vary depending on the geographic scale of analysis. For instance, at broader regional levels, policy differences and economic conditions may play a crucial role, whereas at the local or neighbourhood level, factors such as social cohesion may be more influential. Moreover, their impact may vary across population subgroups, with some being more affected than others (Blomgren & Valkonen, 2007; Montez & Cheng, 2022; Riva et al., 2007). Although the context–composition division has been critiqued because the effects of composition and context are interrelated, the approach provides a useful framework to explore how both individual characteristics and contextual circumstances contribute to regional mortality differences (Macintyre et al., 2002; Subramanian et al., 2003).

Over the past decades, research has increasingly focused on identifying and understanding place effects to better assess how the environments where people live may shape health and mortality. As a result, contextual factors are now widely recognised as important determinants of population health and mortality. However, studies consistently show that much of the geographic variation in mortality stems from the demographic and socioeconomic composition of populations. Areas with higher mortality often have a greater concentration of individuals with higher mortality risks, including older populations, lower socioeconomic status groups, and individuals with higher exposure to behavioural risk factors. While disentangling the relative contributions of compositional and contextual effects remains a challenge, there is broad consensus that population structure plays a more significant role in shaping geographic mortality differences (Pickett & Pearl, 2001).

Migration is another potential factor contributing to regional mortality differences affecting both compositional and contextual factors by altering population structures and shaping exposure to place-based risks. While migration can refer to both international and internal movement, the focus here is on internal migration within countries, which plays a key role in redistributing populations across regions. Migration is selective in nature, meaning that those who move tend to differ from the general population in terms of age, socioeconomic characteristics, and health status (Brimblecombe et al., 1999). Typically, migrants are younger, healthier, and better off socioeconomically than those who remain in place (Boyle et al., 2014), which can reinforce existing regional disparities. Regions experiencing outmigration may see an increase in mortality rates as they are left with older populations and a higher concentration of individuals with lower socioeconomic position. Conversely, regions receiving healthier, more advantaged migrants may see their mortality rates decline. Moreover, migrants themselves are selective in their choice of destination (Norman et al., 2005). If individuals with lower mortality risk move into low-mortality regions while those with higher risk migrate into areas with high mortality, existing disparities are further reinforced.

2.1.1 Long-term trends

While geographical variations in mortality are well-documented, studies on long-term trends remain limited. Furthermore, the direction of these trends is somewhat ambiguous across countries and levels of aggregation, which may reflect expected differences due to country-specific factors and historical contexts. Nonetheless, several studies highlight widening mortality gaps in recent decades, raising concerns about growing inequalities.

Research from the United States provides consistent evidence of growing disparities across multiple geographical levels. County-level differences in life expectancy in the United States have widened notably since the 1980s (Dwyer-Lindgren et al., 2017; Wang et al., 2013; Ezzati et al., 2008). Similar trends of increasing mortality differences have been observed between states (Fenelon, 2013; Wilmoth et al., 2010) and across large spatial units (Vierboom et al., 2019). Evidence of widening disparities covering similar time periods has also emerged from other countries. In Canada, premature mortality increased in regions with the highest initial mortality rates between the 1980s and 1990s, leading to growing disparities (Mustard et al., 1999). Increasing differences during the last two decades of the 20th century have also been reported between districts in Great Britain (Leyland, 2004) and District Health Boards in New Zealand (Pearce & Dorling, 2006), as well as between French départements in 1995–2005 (Bonnet & d'Albis, 2020) and Polish regions from 1991–1993 to 2008–2010 (Muszyńska et al., 2014).

In contrast, other high-income countries, particularly in Europe, have experienced declines or stability in within-country mortality variation. Several studies from Germany have shown significant declines in regional differences following reunification, with mortality gaps narrowing between both states (van Raalte et al., 2020) and districts (Hrzic et al., 2023; Kibele et al., 2015), though recent trends indicate some reversal (Bonnet et al., 2024). Similarly, gaps between communities in Austria (1969–2004) (Gächter & Theurl, 2011) and counties in Norway (1980–2014) (Skaftun et al., 2018) have narrowed over time. In contrast, variation between Dutch regions (1988–2009) and Swedish and Finnish regions (1990–2014) has remained relatively stable (Janssen et al., 2016; Wilson et al., 2020).

Within-country variation in mortality is often greater among younger adults than older age groups and tends to be more pronounced in men than women. Evidence on trends by age and sex shows mixed results. For example, in the United States, rising area-level differences have been largely driven by increasing dispersion in mortality risk among older adults (Dwyer-Lindgren et al., 2017), with larger increases among women than men (Vierboom & Preston, 2020). In contrast, the promising regional trends observed in Germany have been more recently offset by growing regional disparities in mortality among working-age men (Bonnet et al., 2024).

While many previous studies have been primarily descriptive, some factors have been proposed to explain the observed trends. Cause-specific analyses suggest that geographic differences in health behaviours are strongly linked to regional mortality trends. Smoking, in particular, has been widely studied, with differences in past smoking behaviour identified as a key contributor to increasing geographical inequalities in all-cause mortality in the United States (Vierboom et al., 2019), Poland (Muszyńska et al., 2014) and Germany (Grigoriev et al., 2022). Regional variations in economic factors, such as unemployment rates and the tax base (Hrzic et al., 2023), as well as national healthcare reforms (Montero-Granados et al., 2007) have also been linked to growing disparities.

Empirical evidence on the extent to which migration contributes to changes in geographic mortality disparities is mixed. A study in England and Wales found that a dominant flow of healthy individuals leaving deprived areas accounted for much of the increasing inequality in mortality between 1971 and 1991 (Norman et al., 2005). Similarly, a Danish study showed that growing differences between areas was due to the selective in-migration of less healthy individuals into a specific area of the country (Holmager et al., 2022). In contrast, a study from the United States covering a shorter period (1993–1999) suggested that migration was unlikely to have contributed significantly to rising life expectancy differences across counties (Ezzati et al., 2008).

A limitation of previous studies is that they have not explored the contribution of individual-level compositional changes to trends in area-level mortality variation, despite most research agreeing that individual-level compositional characteristics play a larger role in shaping regional mortality patterns than contextual area effects. This shortcoming is particularly significant considering the societal changes of recent decades, marked by deindustrialisation and structural shifts, which have widened the economic disparity between urban centres and peripheral areas. Selective migration, especially of young people to cities, has reshaped local population structures, leaving peripheral areas with aging populations and diminished resources to address growing healthcare needs (Grunfelder et al., 2020; Margaras, 2019), possibly leading to increasing regional disparities in mortality.

Geographic differences in mortality in Finland are considered substantial and follow a well-documented spatial pattern. Mortality is higher in the eastern and northern parts of the country than in the western and southern regions (Parikka et al., 2020; Saarela & Finnäs, 2006; Wilson et al., 2020), a divide that extends to other health outcomes, including overall morbidity (Parikka et al., 2022). This pattern has been attributed, at least in part, to regional differences in lifestyles, socioeconomic conditions, and the accessibility and effectiveness of health services (Parikka et al., 2022). While previous evidence suggests that geographic mortality differences have remained relatively stable in recent decades, studies on long-term trends remain limited. One study found that life expectancy gaps between large Finnish regions persisted from 1990 to 2014, with differences of approximately 2 years for men and 4 years for women between the longest- and shortest-living regions (Wilson et al., 2020). However, broad regional classifications may be too coarse to capture variations effectively, potentially masking heterogeneity across smaller geographical units. No studies have examined trends in mortality variation at the municipal level, where differences might be more pronounced. Similarly, age-group-specific differences remain underexplored.

2.2 Living arrangement differences in mortality

A long tradition of research has documented significant mortality differences by marital status (Hu & Goldman, 1990; Martikainen et al., 2005; Manzoli et al., 2007; Rendall et al., 2011). More recently, studies have expanded the focus to living arrangements, recognising that beyond marital status, the household context and who one lives with also have important implications for mortality (Hughes & Waite, 2002). Evidence consistently shows that married individuals and those living with a partner have lower mortality than others (Koskinen et al., 2007; Robards et al., 2012; Frisch & Simonsen, 2013), with this advantage often being more pronounced among men (Staehelin et al., 2012), in younger age groups (Martikainen et al., 2005), and for deaths linked to health behaviours (Franke & Kulu, 2018). In contrast, living alone has been associated with an increased risk of mortality (Herttua et al., 2011; Abell & Steptoe, 2021; Elovainio et al., 2021; Olfson et al., 2022). Additionally, research suggests that living with other family or household members, such as children, or other adults besides a partner, may provide some health benefits, though not to the same extent as living with a partner (Joutsenniemi, 2007).

Differences in mortality by living arrangements have been suggested to arise from advantages and disadvantages associated with different living arrangements. A key factor in this regard is the role of social relationships. Numerous studies have shown that individuals with stronger social relationships have higher likelihoods of survival (Holt-Lunstad et al., 2010), with various forms of social support—emotional, instrumental, appraisal, and informational—contributing to this association (Berkman & Krishna, 2014). Living arrangements serve as a key social context in which such support may be provided. Those living with a partner are more likely to benefit, for example, from continued emotional support and care, which can mitigate stress and promote mental well-being, as well as from instrumental support, such as assistance with access to services and practical help during illness or recovery. In contrast, individuals living alone may have more limited access to these forms of support, increasing their vulnerability to social isolation and loneliness and their associated health risks (Holt-Lunstad et al., 2015). An additional way in which living arrangements may influence mortality is through health-related behaviours. Partners often exert social control over each other, potentially discouraging risky habits (Umberson, 1992). Economic factors also play a role. Financial resources are commonly shared among married couples and cohabiting partners, contributing to greater economic security. This, in turn, may benefit health by facilitating access to healthcare and other essential resources (Stimpson et al., 2012). The benefits of resource sharing and economies of scale arising from shared housing and utilities can also extend to individuals living with other adults besides a partner. In contrast, individuals living alone and single-parent households relying on a single income are likely to experience greater financial strain in meeting household needs.

Another explanation for living arrangement differences in mortality is selection, where individuals sort into living arrangements based on health (direct selection) or on health-related determinants such as socioeconomic characteristics and health behaviours (indirect selection) (Joung et al., 1998). In this view, married individuals and those living with a partner have lower mortality not necessarily because of the protective effects of cohabitation, but because healthier individuals, or individuals without characteristics potentially harmful to health, are more likely to enter and sustain stable relationships, while those in poorer health or engaged in harmful health behaviours are more likely to remain single or experience union dissolution. Evidence on direct health selection is inconsistent and may be limited to individuals with severe health issues, whereas indirect selection can be more influential (Joutsenniemi, 2007). Socioeconomic disadvantage, for example, has been linked to lower rates of union formation (Jalovaara, 2012), higher risks of relationship dissolution (de Graaf & Kalmijn, 2006), and a greater likelihood of childlessness (Jalovaara et al., 2019). Accordingly, those living alone or in non-partnered households more often occupy lower socioeconomic positions (Knop et al., 2023).

2.2.1 Long-term trends

Although studies examining trends are limited, the available evidence consistently indicates that the excess mortality of the non-married groups relative to the married has increased over time. Due to the scarcity of research on trends in mortality differences across living arrangements, most of the evidence referenced here derives from the traditional marriage-centric perspective.

Multi-country comparative studies using aggregate-level data have provided insights into broader trends in marital status differences in mortality during the second half of the 20th century. Hu and Goldman (1990) examined mortality differences among men and women aged 25–64 across 16 developed countries, revealing a consistent increase in relative mortality differences between married and non-married individuals from the 1950s to the early 1980s. This trend was observed across all unmarried groups: single, divorced, and widowed. Focusing on both the working-age population (45–54 years) and retirees (65–74 years), Valkonen (Valkonen, 2001; Valkonen et al., 2004) similarly identified a general trend of increasing excess mortality among non-married groups in Western European countries and Canada between 1970 and the mid-1990s. The mortality disadvantage of singles, in particular, became more pronounced over time in most countries studied. Moreover, the increase in excess mortality among all non-married groups was generally more systematic among women and in the older age group of 65–74 years. Likewise, Murphy and co-authors (2007) analysed mortality differentials among older individuals (up to age 84) in 7 European countries during the 1990s, confirming the persistence and widening of relative mortality differences by marital status, even at older ages. In general, the growing mortality advantage of married individuals has been attributed in these studies to faster declines in mortality among the married compared with slower declines, or even increases, among the non-married. Although increases in relative differences are most consistently reported, widening absolute differences have also been documented.

Building on the evidence of widening differentials, more recent national studies have confirmed these trends and offered some insights into potential mechanisms driving them. Cause-specific analyses have shown that the disparities, and their growth, have been most pronounced for deaths linked to behavioural factors. For instance, the widening disparities between marital status groups has been particularly marked for circulatory diseases in Norway (Kravdal & Syse, 2011) and cardiovascular diseases in Israel (Jaffe et al., 2007) and the US (Liu, 2009). In Finland, external causes such as accidents, violence, and alcohol-related conditions, particularly among working-age men, have been identified as major contributors to the increasing mortality differentials between the married and non-married (Martikainen et al., 2005). Additionally, rising mortality differentials have been observed for cancer-related deaths (Jaffe et al., 2007; Kravdal & Syse, 2011), which may suggest a growing advantage for those with a partner who can provide support in daily life, facilitate access to timely medical care, and assist in managing complex treatments. Authors of a Swedish study on older adults suggest that the slight increase in mortality risk associated with living alone may be linked to changes in care policies, such as stricter eligibility criteria for institutional care, which have led to a greater number of vulnerable older adults living alone (Shaw et al., 2020).

While existing studies have mostly suggested a growing protective effect of having a partner, other factors, such as compositional changes in marital categories, may also play a role. Socioeconomic factors can be particularly relevant in explaining these associations and trends due to their well-established relationship with mortality and the social patterning of marital status and living arrangements. These overlapping associations suggest that changes in the socioeconomic composition of living arrangements could partly explain the observed trends in mortality disparities. Indeed, evidence indicates that positive socioeconomic selection into living with a partner has intensified over time (Erola & Kilpi-Jakonen, 2022; Van Bavel et al., 2018; Jalovaara, 2012), implying an increased mortality advantage for those in a partnership, given the association between higher socioeconomic position and lower mortality.

Two previous studies (Kravdal et al., 2018; Martikainen et al., 2005) have investigated whether changes in the distribution of individual socioeconomic characteristics, namely education and occupation-based social class, have contributed to the widening mortality gap between married and non-married individuals. While these studies suggest that such changes have not significantly contributed to the increasing mortality advantage of the married, they were limited to marital status categories that do not necessarily reflect the household environment in which people live. No studies have examined whether changes in the socioeconomic composition of different living arrangement categories have influenced mortality differences between them.

2.3 Excess winter mortality

Mortality rates vary throughout the year, following a well-established seasonal pattern in temperate countries (Rau, 2007). Deaths tend to occur more frequently during winter months than at other times of the year, a phenomenon commonly referred to as excess winter mortality (Healy, 2003). While this seasonal pattern has been documented across different populations (Davie et al., 2007; Fowler et al., 2015; He et al., 2018; Parks et al., 2018), the magnitude of winter excess varies considerably by region and demographic group, particularly by age, mostly affecting the elderly (Rau, 2007). A winter peak in mortality is apparent for most major causes of death, but the largest seasonal fluctuations are seen for circulatory and respiratory diseases (Rau et al., 2018).

The increased risk of dying in winter is attributed to multiple factors, but two primary explanations have been proposed: influenza-like communicable illnesses and low temperatures (Reichert et al., 2004; Analitis et al., 2008; von Klot et al., 2012; Gasparrini et al., 2015). Cold temperatures can have direct physiological effects, increasing the risk of cardiovascular events and respiratory infections (Eurowinter Group, 1997; Fan et al., 2023). At the same time, seasonal peaks in influenza and other respiratory infections significantly contribute to winter excess deaths, particularly among vulnerable individuals with pre-existing conditions (Vestergaard et al., 2017). The simultaneous occurrence of cold weather and peak influenza activity makes it difficult to isolate their independent contributions, thus the relative importance of the two remain debated. However, some studies suggest that cold-related mortality has declined over time, with infectious diseases now playing a more dominant role (Kinney et al., 2015; Staddon et al., 2014).

The extent of excess winter mortality is commonly expressed as the percentage increase in mortality during winter months compared to the rest of the year. A multi-country comparative study in Europe (Fowler et al., 2015) reported increases ranging from 8% to 28% during the first decade of the 2000s, with some of the highest rates observed in countries with milder winters, such as Malta and Portugal. In contrast, Northern European countries, despite experiencing colder winters, tended to have lower excess winter mortality. This paradox suggests that absolute winter temperatures matter little, whereas factors affecting vulnerability may be more important.

Accordingly, several non-seasonal risk factors have been found to influence individual susceptibility to winter mortality. The evidence on age is clear, with risk increasing as individuals grow older (Rau, 2007). Additionally, socioeconomic factors such as low income, inadequate housing, and fuel poverty have been associated with higher winter mortality risks (Rudge & Gilchrist, 2005; Tanner et al., 2013). Although research remains limited, living arrangements may also play a role, with studies indicating a higher risk of excess winter mortality among those living alone or in institutional settings (Rau, 2007; Phu Pin et al., 2012; Rolden et al., 2015). Pre-existing illness is often assumed to heighten vulnerability to winter mortality, suggesting that those already in poor health and at increased risk of dying are most affected. However, empirical support for this assumption is limited. One study found an increased risk of winter death for individuals with respiratory illnesses, whereas other chronic conditions did not significantly elevate risk (Wilkinson et al., 2004). Further research is needed to clarify which groups are most vulnerable to seasonal changes in the risks of mortality.

2.3.1 Long-term trends

Only a handful of longitudinal studies of excess winter mortality exist. Overall, the available evidence on excess winter mortality indicates that the winter excess has been declining across high-income countries throughout the 20th century. For example, declines in Finland have been reported as early as the 1930s, while steady reductions have been observed in England and Wales, New Zealand, and the Netherlands from the 1950s onwards.

For trends in all-cause excess winter mortality, the most recent study, conducted in New Zealand (Telfar-Barnard et al., 2024), spanned an extensive period from 1876 to 2020. This study found that the relative winter excess rose during the late 19th and early 20th centuries, peaking in the 1920s, but began a sustained decline from the 1950s onwards. By the 2010s, the age- and sex-standardised excess winter mortality had decreased from over 30% in the mid-20th century to approximately

14%, considering deaths of all ages. Kunst et al. (1991) examined trends between the 1950s and 1980s in the Netherlands, documenting a significant reduction in the winter excess, from 23% in the early 1950s to 11% by the late 1980s. Similarly, Keatinge et al. (1989) observed substantial declines in England and Wales between 1960 and 1980. A multi-country study in Europe (Fowler et al., 2015) found that excess winter mortality declined between 1988–1997 and 2002–2011. By comparing estimates with an earlier study (Healy, 2003), the authors identified statistically significant reductions in several countries, including Greece, Ireland, and Spain, while no country showed a significant increase in winter excess mortality during this period. More recent evidence of a decline comes from Portugal, which saw a reduction from 32% to 28% between 2005 and 2016 (Almendra et al., 2019). In Finland, which ranks among the lowest in excess winter mortality, declines in the difference between winter and summer mortality were observed as early as the 1930s (Näyhä, 1972). A continued, though slow, downward trend was also reported between 1961 and 1995, with the percentage excess of all-cause mortality across all ages declining from 8% to 6% (Näyhä, 2000).

Although variations across countries in excess winter mortality suggest that local contexts significantly shape the levels, the uniform trend towards decreasing winter excess mortality points to the existence of possible common determinants. The observed declines have been hypothesised to be attributed to a range of factors, all linked to general socioeconomic progress, advancements in healthcare, and improvements in living conditions. However, pinpointing specific drivers has proven challenging, as no single measure stands out as dominant (Telfar-Barnard et al., 2024). Although housing quality is frequently cited as an important contributor to excess winter mortality (Aylin et al., 2001; Clinch & Healy, 2000; Tanner et al., 2013), empirical evidence on the effect of improved insulation and more effective heating on the long-term decline remains limited (Telfar-Barnard et al., 2008). However, findings from the United Kingdom, a country known for its thermally inefficient housing stock (Stacey & Pritchard, 2016), suggests that the introduction of a winter fuel payment benefit, aimed at helping households with heating costs, has indeed played a decisive role in reducing excess winter mortality since 1999/2000 (Iparraguirre, 2015). The declining winter excess mortality has been in parallel with reductions in mortality from cardiovascular and respiratory diseases, the leading contributors to the winter excess (Kunst et al., 1991), which likely reflects broader improvements in healthcare, including the management of chronic conditions and acute winter illnesses, as well as better access to care. The introduction of influenza vaccines has also been proposed as a contributing factor, though its impact on long-term trends remains debated (Simonsen et al., 2005). While vaccinations are thought to be effective at reducing both influenza-related and all-cause mortality (Vu et al., 2002), evidence from New Zealand suggests that the impact of the addition of the influenza vaccine to the national immunisation schedule has not had a substantial enough influence on winter mortality trends to mark a clear turning point (Telfar-Barnard et al., 2024).

While the factors that have contributed to mitigating excess winter mortality over time remain poorly understood, there is also little consensus about how excess winter mortality varies across individual-level social and health characteristics. This gap in understanding is partly due to the reliance of most previous studies on aggregate-level risk factors, which limits insights into individual-level vulnerabilities. Apart from advanced age, a well-established risk factor for winter mortality, there is limited evidence on which groups are most affected. It is generally assumed that individuals with pre-existing health conditions are particularly vulnerable, since these conditions may exacerbate the adverse effects of winter. However, studies that incorporate information about individuals' prior health status remain scarce.

Although Finland fares well in international comparisons regarding excess winter mortality, no studies have examined the role of pre-existing health conditions and social factors in this context. Given its individual-level longitudinal register data and pronounced seasonal variation, the country offers an important setting to investigate how individual characteristics shape vulnerability to winter-related mortality risks.

3 Finnish context

Between 1970 and 2020, the time frame of this study, Finland evolved from a country still marked by strong agricultural and industrial sectors to a high-income nation with a knowledge-based economy and high standards of living. Over this period, Finland experienced rapid population aging, with the share of those aged 65 and over rising from 9% in 1970 to 23% in 2020. At the same time, life expectancy rose by more than 11 years, reaching approximately 82 years by 2020, exceeding the Western European average (United Nations, 2024). These developments mirror global trends of rising living standards, public health advancements, and educational expansion, with Finland's welfare state model, characterised by universal healthcare, free education, and comprehensive social services, playing a supportive role (Chung & Muntaner, 2007; Lundberg et al., 2008). However, while Finland remains relatively affluent and egalitarian, with low levels of poverty and inequality and a fairly well-performing universal healthcare system (Fullman et al., 2018), large socioeconomic disparities in health and mortality persist and have even widened in recent decades (Lumme et al., 2018; Mackenbach et al., 2016; Tarkiainen et al., 2012). In 2018–2020, the life expectancy gap at age 30 between men and women in the highest income quintile and those in the lowest income quintile was approximately 11 and 6 years, respectively (Tarkiainen et al., 2024).

The leading causes of death in Finland reflect patterns commonly observed in high-income countries, with non-communicable diseases dominating. Circulatory diseases account for the largest share of deaths, followed by cancers and neurodegenerative diseases such as Alzheimer's and other dementias (OECD & European Observatory on Health Systems and Policies, 2023). In younger and middle-aged adults, external causes, such as accidents, suicides, and alcohol-related conditions, contribute substantially to premature mortality (Official Statistics of Finland (OSF), n.d.-a).

Finland's regional landscape is often characterised as polarised, with large contrasts in population and economic dynamics across areas (Vasanen, 2024; Aro, 2020). Much of the relatively large country is sparsely populated, with the majority of its 5.6 million inhabitants concentrated in the southern and central regions, where most larger urban centres are located. All in all, Finnish municipalities (309 in 2024) are notably small, with 93% having fewer than 50,000 inhabitants and only 9 exceeding 100,000 (Official Statistics of Finland (OSF), n.d.-b). Economic transformations over recent decades have further widened regional disparities and intensified urban concentration. While larger cities have expanded through growth in service and knowledge-intensive sectors, rural regions and smaller towns have struggled with the decline of traditional industries and sustained outmigration of younger and working-age populations (Kupiszewski et al., 2005). Although urbanisation in Finland began relatively late compared to other Nordic countries, it has progressed rapidly, with the urban population share rising from 64% in 1970 to approximately 85% by 2020 (United Nations, 2018) and continues to grow.

Finnish municipalities hold broad self-government and have traditionally been responsible for delivering and funding public services, including social services and healthcare (though a 2023 reform centralised these responsibilities to well-being services counties) (Tynkkynen et al., 2023). This decentralised welfare service system has been under increasing pressure, particularly in remote and rural municipalities, which face the dual challenge of rising healthcare needs due to an aging population and a shrinking working-age population to provide and finance such care (Stjernberg, 2020; Valkama & Oulasvirta, 2021). While the public healthcare system ensures comprehensive coverage and is generally considered high-quality and accessible (OECD & European Observatory on Health Systems and Policies, 2021), disparities between municipalities have been identified, particularly in primary care availability, due in part to shortages of qualified health workers and financial constraints (Tynkkynen et al., 2023).

The increasing concentration of the population in cities has occurred alongside changes in living arrangements. Over the past decades, the number of households in Finland has increased, from approximately 2.04 million in 1990 to 2.77 million in 2020, meaning a considerable decline in average household size—from 2.42 persons in 1990 to 1.96 in 2020 (Official Statistics of Finland (OSF), n.d.-c). An important reason for this trend is the stark increase in the number of individuals living alone. Finland, like other Nordic countries, stands out in the European context for its high prevalence of single-person households. Since 1990, their number has doubled, and by 2020, single-person households accounted for 45% of all households, up from 32% in 1990 (Official Statistics of Finland (OSF), n.d.-c). While the rise in solo living is not unique to Finland and reflects broader demographic trends of population aging and changes in family formation, certain Finnish-specific factors further support this trend, including generous welfare state housing subsidies, societal norms emphasising early independence, informal partnerships, and high divorce rates. In addition to the growth in single-person households, there has also been an increase, although more modest, in two-person households, rising from 29% in 1990 to 33% in 2020. Parallel to the increase in smaller households, and closely linked to declining fertility rates, the share of households with children has declined. In 2020, only 20% of households in Finland included children, marking an 11-percentage point decrease from 1990 (31%) (Official Statistics of Finland (OSF), n.d.-c).

Given Finland's northern location and long, cold winters, buildings have been traditionally designed to ensure thermal efficiency and indoor comfort. Winter typically lasts about 100 days in southwestern Finland and up to 200 days in Lapland. It begins in mid-October in the north and gradually moves southwards, covering most of Finland by November–December. Mean temperatures remain below 0°C for much of the season, with occasional warmer periods as well as extreme cold spells, where temperatures can drop as low as -45°C in the north and east (Finnish Meteorological Institute, n.d.). Strict building regulations have long ensured high housing standards. Since the 1970s, efforts have particularly focused on improving airtightness and insulation to reduce heat loss and maintain stable indoor temperatures. While these measures have occasionally raised concerns about indoor air quality, Finnish residential buildings across different housing types and tenure categories generally perform well during winter (Pekkonen et al., 2015; Elsayed et al., 2024).

4 Aims of the study

The overall aim of this thesis was to extend perspectives on the long-term developments in mortality differences over the past five decades. This was achieved by examining long-term trends in three relatively less explored dimensions of mortality variation: (i) geographic differences, (ii) living arrangement differences, and (iii) excess winter mortality.

The specific aims of the three sub-studies were:

1. To investigate how mortality variation across Finnish municipalities has evolved over the period 1972–2018 and assess the role of changes in the population composition of areas in explaining the trends. (Sub-study I)
2. To analyse how mortality differences by living arrangements have changed between 1990 and 2020 and examine the extent to which these changes are explained by changes in the socioeconomic composition of living arrangement groups? (Sub-study II)
3. To assess trends in excess winter mortality over five decades (1971–2019) and analyse how sociodemographic characteristics and pre-existing health conditions modify the risk of a winter death. (Sub-study III)

5 Data and methods

5.1 Data sources and study populations

The sub-studies of this thesis were conducted using Finnish longitudinal administrative register data. This individual-level data was gathered from various registers maintained by different authorities, including Statistics Finland, the Finnish Institute for Health and Welfare (THL), and the Social Insurance Institution (Kela). The data were compiled at Statistics Finland using unified personal identification codes as identifiers to link the data from different registers. The data used offers full coverage of the total resident population of Finland over the study period, starting from 1970.

Data from Statistics Finland provided individual-level sociodemographic information, such as gender, age, place of residence, living arrangements, education, income and occupation, as well as data on mortality and causes of death harmonised over time. For the years 1970–1985, the information corresponds to that obtained from censuses conducted every five years (1970, 1975, 1980, and 1985). Since 1987, most data have been updated annually from end-of-year population registers. Information on dates and causes of death, available since 1971, has been extracted from death certificates.

In Sub-study III, the data maintained by Statistics Finland were complemented with data for the years 1999–2017 from two external sources. The THL care register for health provided data on inpatient and specialised outpatient care episodes, including dates of admission and discharge, as well as primary and additional diagnoses. Data on the right to special reimbursement for medicine expenses due to diagnosed chronic medical conditions were obtained from Kela's medication reimbursement register. This register contains information on the dates when a right to reimbursement is granted and ended, as well as the related medical conditions.

The study populations for each sub-study were defined based on the research aims and data availability. Sub-study I, examining changes in municipal-level mortality variation, included individuals aged 30 and older at the end of 10 baseline years: 1971, 1975, 1980, 1985, 1990, 1995, 2000, 2005, 2010 and 2015. These individuals were followed for mortality in the periods 1972–75, 1976–80, ..., 2011–2015, and 2016–2018. Altogether, 2,236,420 deaths were identified between 1972 and 2018. Sub-study II, on trends in living arrangement differentials in mortality, included individuals aged 30 and over residing in Finland at the end of the baseline years 1990, 1995, 2000, 2005, 2010 and 2015. Mortality follow-up covered five years after each of the six baselines. In total, 1,479,576 deaths were recorded between 1991 and 2020. Finally, Sub-study III, on trends in excess winter mortality, covered the period from August 1971 to July 2019 and included individuals aged 60 and over at the end of July each year from 1971 to 2018. Mortality was measured in 12-month intervals, from August of one year to July of the following year. During the period, 1,902,824 deaths were recorded, with slightly over a third occurring in the winter months (December–March). Table 1 summarises the main characteristics of the sub-studies.

Table 1 Summary of sub-study characteristics

	Sub-study I (municipalities)	Sub-study II (living arrangements)	Sub-study III (winter excess)
Data sources	Statistics Finland, THL, Kela	Statistics Finland	Statistics Finland
Study period	1972–2018	1991–2020	1971–2019
Age range	30 and over	30 and over	60 and over
Outcome	All-cause mortality and internal and external mortality	All-cause mortality and external and alcohol-related mortality	All-cause mortality, diseases of the circulatory system, diseases of the respiratory system, dementia
Mortality follow-up	Ten periods: 1972–75, 1976–80, …, 2011–2015, and 2016–2018	Six five-year periods: 1991–1995, …, 2016–2020	One year (from Aug to July) between 1971–2019
Total of deaths	2,236,420	1,479,576	1,902,824
Exposure	Municipality of residence	Living arrangement	Winter (December to March)
Covariates	Gender (stratified), age (stratified and controlled), education, occupation-based social position, income	Gender (stratified), age (stratified and controlled), education, occupation-based social position	Gender (stratified), age (stratified and controlled), living arrangement, income, region of residence, health conditions
Methods	Multi-level survival modelling	Age-adjusted mortality rates, Poisson regression	Age-adjusted mortality rates, breakpoint analysis, Poisson regression

Finland's long history of producing extensive individual-level administrative data, facilitated by the unified personal identification code system introduced in the 1960s, is a key asset for this study. The population-based data is of high quality and spans nearly half a century, including detailed information on sociodemographic and health measures. This provides a unique opportunity to analyse long-term processes between individual and contextual characteristics and mortality, free from issues caused by small sample sizes, recall and selection biases, and measurement errors.

5.2 Variables

The outcome of interest in all three sub-studies was mortality and the main exposure variables were municipality of residence, type of living arrangement and winter. The operationalisation of these variables, as well as all other covariates, is described below.

5.2.1 Outcome: mortality

All three sub-studies assessed all-cause as well as cause-specific mortality. The cause-of-death groups were constructed from Statistics Finland's 54-category cause of death classification, which is harmonised across different revisions of the International Classification of Diseases (ICD) and enables consistent analysis over time. Different groupings of causes were used based on the aims of each study.

Sub-studies I and II examined external and alcohol-related mortality since behaviour-related causes have been shown to be associated with living arrangements and contribute to variations in all-cause mortality across areas. Deaths were classified as external if the underlying cause was alcohol-attributable disease or poisoning, injury- or violence-related, or suicide (ICD-10: F10, G312, G4051, G621, G721, I426, K292, K70, K852, K860, O354, P043, Q860, V01–Y89). In addition to the external and alcohol-related causes, Sub-study I also considered internal causes, classifying all other deaths as internal.

In Sub-study III, the cause-specific analysis considered causes that have been shown to contribute significantly to excess winter mortality. Four groups were formed: deaths due to diseases of the circulatory system (I00–I425, I427–I99), diseases of the respiratory system (J00–J64, J66–J99), dementia (F01, F03, G30, R54), and other internal and external causes (V01–X44, X46–Y89).

5.2.2 Exposures

In Sub-study I, the exposure of interest was municipality of residence. For the years 1971, 1975, 1980, and 1985, this refers to the municipality in which a person was registered in the population register as of January 1. From 1990 onwards, it corresponds to the municipality where the person resided on the last day of the year. Given the significant changes in the number and boundaries of Finnish municipalities since the 1970s, the 2019 classification was used, with a total of 311 municipalities, to ensure consistency over time.

Sub-study II determined living arrangements based on information about household size, composition, and marital status, measured at the end of the 6 baseline years between 1990 and 2015. Six living arrangement categories were used: living with a partner and child(ren), with a partner, with child(ren), with someone other than partner or child(ren), living alone, and living in an institution or with unknown living arrangement. The 'with a partner' categories included both married and cohabiting couples. Unmarried individuals living together were considered cohabiters if they were of different genders, not siblings, and had an age difference of less than 16 years. Same-sex couples were only identified as living with a partner if they had registered their partnership (from 2002) or were married (from 2017). Parents living with their child were classified as such, regardless of the child's age.

In Sub-study III, winter was defined as the four-month period from December to March. This definition aligns with previous studies on excess winter mortality in the northern hemisphere. Additionally, during these months in central and southern Finland, where most of the population resides, the average daily temperature remains below 0°C, marking the period of cold weather. Non-winter months were defined as the four months preceding and following this winter period (August–November, April–July). Following this definition, the study period, which began in August 1971 and continued until July 2019, encompassed a total of 48 winters.

5.2.3 Covariates

Most covariates were treated as time-invariant variables, measured at the end of the calendar year preceding the mortality follow-up.

All sub-studies incorporated information on individuals' socioeconomic position using three indicators—educational attainment, occupation-based socioeconomic position, and income—in different combinations. Educational attainment (Sub-studies I and II) was categorised into three levels: basic/no qualifications (International Standard Classification of Education ISCED 2011 codes 0–2), secondary (ISCED 3–4), and tertiary (ISCED 5–8), based on the highest completed degree. Occupation-based socioeconomic position (Sub-studies I and II) was classified into five categories based on an individual's current or previous occupation (if currently unemployed or inactive): upper-level employees, lower-level employees, manual workers, self-employed and farmers, and others or unknown occupation. Income, based either on the taxable (Sub-study I) or disposable (Sub-study III) income of an individual's household, was adjusted for household composition (OECD, 2013) and categorised into quintiles or quartiles within the corresponding sample population. In Sub-studies I and III, indicators of socioeconomic position were used as control variables, while in Sub-study III, income served as an effect modifier.

Gender and age were included in all sub-studies. The majority of analyses were conducted separately for men and women. Age was used both to adjust mortality for baseline age in 5-year groups, and to stratify analyses into broad age categories: 30–49, 50–69, and 70 and over in Sub-studies I and II; and 60–69, 70–79, 80–89, and 90 and over in Sub-study III. In Sub-study III, age and gender were used as both stratifiers and modifiers.

Sub-study III incorporated additional socio-demographic and health characteristics, with potential effects on excess winter mortality. Living arrangements were categorised as living alone, living in households with at least one other person, or living in institutions. Region of residence was aggregated into four broader regions (coastal, southern, central, and northern) based on average winter temperatures. Pre-existing health conditions were assessed using information on individuals' hospitalisation history. Conditions were indicated by a dichotomous yes/no variable based on hospitalisation during the preceding calendar year and were classified into 11 categories: dementia, mental disorders, cancer, diseases of the nervous system, diabetes, diseases of the circulatory system, diseases of the respiratory system, alcohol-related causes, injuries due to accidents and violence, other health conditions, and an overall measure of hospitalisation due to any health condition.

5.3 Methods

Sub-study I applied multi-level survival models, with individuals nested within municipalities, to examine mortality differences across areas. The median hazard ratio (MHR) (Austin et al., 2017) served as the primary summary measure, quantifying the extent to which municipalities influence individual mortality risk, referred to as the general contextual effect. The MHR represents the median ratio of the mortality hazard for a randomly selected individual in a municipality with higher mortality compared to an individual in a municipality with lower mortality. A high MHR indicates a strong general contextual effect of municipalities on individual mortality risk, whereas an MHR close to one suggests a weak or negligible effect. To analyse how mortality differences between municipalities evolved over time, the models were estimated for 10 periods spanning from 1972–1975 to 2016–2018. Three models were specified. Model 0 was unadjusted, Model 1 adjusted for age, and in Model 2 all socioeconomic covariates were added. To examine trends by age, MHRs were estimated separately for age groups 30–49, 50–

69, and 70 and over. Within these groups, age was adjusted for in five-year groups. The models were repeated for all-cause, internal and external causes of death. Additionally, for all-cause mortality, municipality-specific effects were predicted for the first and last study periods and presented as hazard ratios (HR) in caterpillar plots, using the average hazard across all municipalities as the reference.

In Sub-study II, age-, gender-, and living arrangement-specific mortality trends were described using directly age-standardised mortality rates with 95% confidence intervals (CIs) calculated for six 5-year periods between 1990 and 2020. Separate standard populations for each age group (30–49, 50–69, 70 and over) were created by aggregating person-years by single age across all study periods for men and women combined. Absolute differences in mortality rates between individuals living with a partner and children (reference group) and other living arrangements were calculated based on these rates. Poisson regression was used to examine relative mortality differences between living arrangement groups, assess changes over time, and evaluate the effect of socioeconomic factors using data from the first (1991–1995) and last (2016–2020) study periods. The models included an interaction term between living arrangement and period to obtain period-specific rate ratios (RR) with 95% CIs for each living arrangement category. To ensure comparability and maintain a consistent modelling structure, the models were estimated twice, alternating the reference period (1991–1995 and 2016–2020). Model 1 adjusted for age in 5-year categories, while Model 2 further incorporated education and occupation-based socioeconomic position.

In Sub-study III, trends in winter and non-winter mortality were assessed using age-adjusted annual mortality rates with 95% CIs for the period 1971–2019, standardised to the combined age structure of men and women aged 60 and older across the entire study period. Absolute and relative differences between winter and non-winter rates were calculated, and segmented linear regression analysis was used to identify breakpoints in the time series. To examine the moderating effects of individual characteristics on excess winter mortality, data from August 2000 to July 2019 were analysed using Poisson regression models with interactions between the winter indicator and covariates. These interaction effects, interpreted as relative risks, indicate how the impact of winter varies multiplicatively across categories of modifying factors compared to the reference group. Each potential modifier was analysed independently, with models adjusted for all other covariates.

5.4 Ethical considerations

In Finland, the research use of register data is governed by legal frameworks to protect individual privacy and data confidentiality. The primary regulatory frameworks include statistical legal acts of the European Union and national regulations such as the Finnish Statistics Act (280/2004), the Finnish Data

Protection Act (1050/2018), and the health sector–specific Act on the Secondary Use of Health and Social Data (552/2019) (Finlex, 2004, 2018, 2019). These legal regulations provide comprehensive guidelines for the ethical use of personal data.

To access the data used in this thesis, a personal request for a user license was sent to relevant data holders. The applications included a research plan justifying the data need and ensuring that adequate privacy protections for secure data access were in place. Before data is made available to researchers, Statistics Finland replaces personal identity codes with pseudo-identifiers so that personal data cannot be directly linked back to any individual. These pseudo-identifiers allow for flexible and highly reliable linkages between datasets, while ensuring that individual privacy in not compromised.

Strict practical measures guiding data use and reporting were followed. Data was accessed exclusively through a closed remote access system, and research was conducted in environments that ensured data confidentiality. Additionally, research results were screened before being transferred outside the remote system to verify adherence to established privacy standards. Informed consent from individuals was not required for this study, as per the regulations governing the use of register data for research purposes.

6 Results

6.1 Changes in regional mortality variation (Sub-study I)

Sub-study I analysed long-term trends in municipal-level mortality variation and assessed the contribution of age and socioeconomic composition of the population to these trends. Mortality was examined in 10 periods between the years 1972 and 2018, and MHR was used as the main summary measure of between-municipality differences.

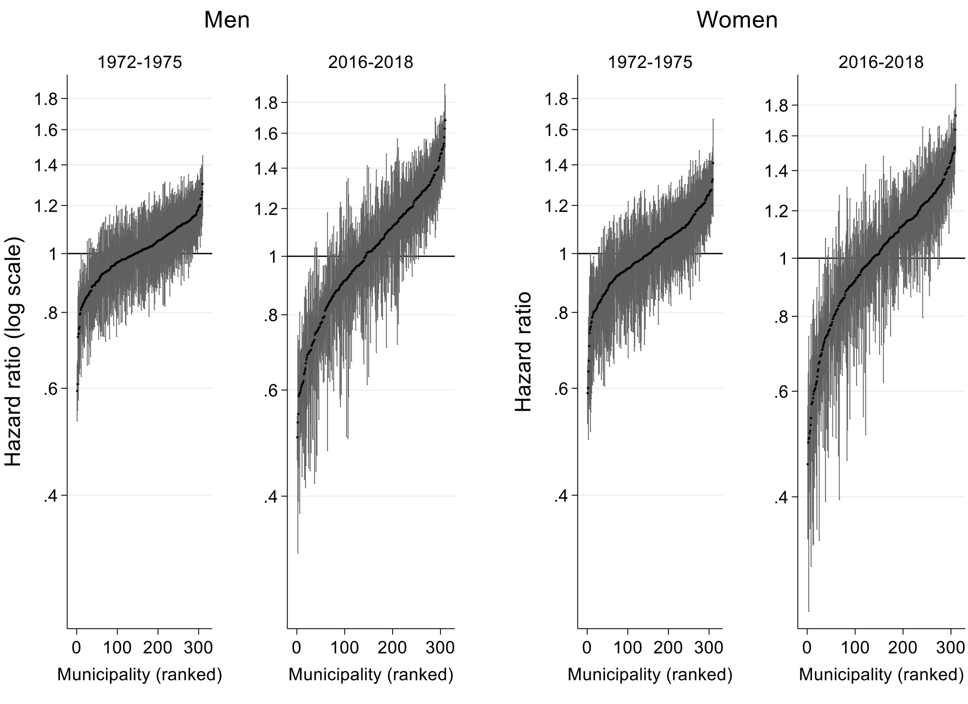

Figure 1 Differentials in mortality across Finnish municipalities in 1972–1975 and 2016–2018 among men and women aged 30 and over, represented by unadjusted municipality-specific hazard ratios (HRs) and 95% confidence intervals, with the reference being the average hazard of all municipalities (horizontal line at 1). Note: This figure was originally published in *SSM - Population Health*, Vol 15, Suulamo, U., Tarkiainen, L., Remes, H., & Martikainen, P. (2021). Changes in regional variation in mortality over five decades – The contribution of age and socioeconomic population composition, p. 100850, Copyright Elsevier (2021).

Unadjusted municipality specific HRs for individuals 30 and older during the first (1972–1975) and last (2016–2018) study periods showed a strong increase in mortality variation across municipalities over 5 decades, with larger differences observed in the most recent period. Specifically, in 1972–1975, the 10th and 90th percentile values of HRs ranged from 0.86 to 1.13 for men and 0.83 to 1.19 for women, while in 2016–2018 these values had widened to 0.71 to 1.33 for men and 0.70 to 1.32 for women (Figure 1).

This increase in variation was found to be almost entirely due to changes in age distribution between municipalities. Unadjusted MHRs increased for men from 1.14 (95% CI 1.12–1.15) in the early 1970s to 1.28 (95% CI 1.26–1.30) in the late 2010s, with the most marked increase occurring after 2000. For women, the MHRs rose from 1.17 (95% CI 1.15–1.18) to 1.30 (95% CI 1.27–1.32) over the same period. These figures indicate that in the early 1970s, men and women in higher-mortality municipalities faced, on average, a 14% and 17% higher hazard of death compared to those in lower-mortality municipalities: by the late 2010s, this gap had grown to 28% for men and 30% for women. However, after adjusting for age, this strong upward trend was no longer observed, and differences between municipalities remained more or less stable from 1970 onwards (Figure 2).

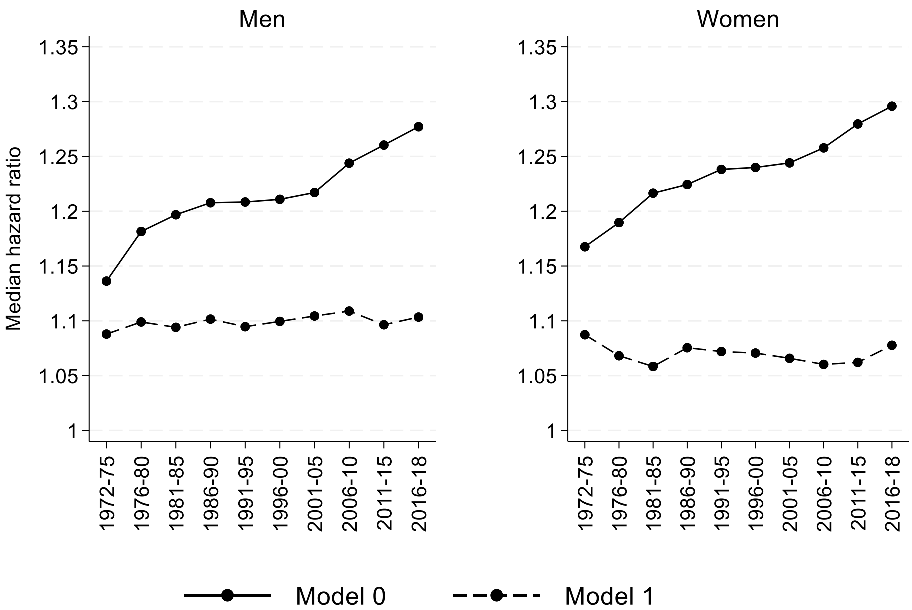

Figure 2 Median hazard ratio (MHR) for 10 periods between 1972–1975 and 2016–2018 from unadjusted (Model 0) and age-adjusted (Model 1) models, by gender, population aged 30 and over.

Age-specific analysis, however, revealed that all-cause mortality differences did increase substantially among younger men, particularly those aged 30–49 (MHR 1972–75: 1.17, 95% CI 1.14–1.19; MHR 2016–18: 1.33, 95% CI 1.22–1.44) for whom disparities were the most pronounced of all subgroups studied. Patterns across age groups were less clear among women, and no changes in mortality differences were observed in the oldest age group, 70 years and over. Municipality-level differences were generally larger for external causes of death than for internal causes. Additionally, while mortality differences for internal causes remained relatively stable over time, disparities for external causes generally increased, particularly among younger men (Table 2).

Table 2 Municipal-level mortality variation between 1972–1975 and 2016–2018 indicated by median hazard ratios (MHR) adjusted for age (Model 1), by age group, gender, and cause of death.

	Period									
	1972–1975	1976–1980	1981–1985	1986–1990	1991–1995	1996–2000	2001–2005	2006–2010	2011–2015	2016–2018
Men										
30–49										
All-cause	1.17	1.20	1.22	1.25	1.22	1.23	1.23	1.26	1.26	1.33
Internal	1.16	1.17	1.17	1.18	1.16	1.16	1.11	1.15	1.22	1.20
External	1.23	1.21	1.23	1.28	1.28	1.31	1.31	1.33	1.30	1.29
50–69										
All-cause	1.10	1.11	1.11	1.12	1.12	1.14	1.15	1.17	1.15	1.14
Internal	1.10	1.11	1.10	1.12	1.12	1.12	1.13	1.15	1.14	1.11
External	1.13	1.16	1.20	1.18	1.20	1.22	1.26	1.25	1.21	1.23
70+										
All-cause	1.06	1.06	1.04	1.05	1.05	1.05	1.05	1.06	1.05	1.06
Internal	1.06	1.06	1.04	1.04	1.05	1.05	1.05	1.06	1.05	1.06
External	1.26	1.12	1.10	1.14	1.14	1.16	1.14	1.13	1.15	1.09
Women										
30–49										
All-cause	1.06	1.13	1.09	1.10	1.13	1.13	1.12	1.16	1.14	1.03
Internal	1.01	1.10	1.07	1.07	1.11	1.08	1.12	1.11	1.09	1.12
External	1.22	1.50	1.23	1.24	1.26	1.31	1.22	1.29	1.30	1.17
50–69										
All-cause	1.07	1.05	1.06	1.06	1.06	1.06	1.08	1.10	1.09	1.11
Internal	1.07	1.06	1.05	1.06	1.07	1.06	1.07	1.08	1.08	1.11
External	1.13	1.17	1.18	1.24	1.21	1.20	1.21	1.26	1.16	1.17
70+										
All-cause	1.10	1.08	1.06	1.08	1.07	1.07	1.07	1.06	1.06	1.07
Internal	1.10	1.08	1.06	1.07	1.08	1.07	1.07	1.06	1.06	1.07
External	1.08	1.27	1.13	1.20	1.22	1.30	1.19	1.16	1.19	1.12

The impact of individual-level socioeconomic characteristics of the population to municipality-level variation in mortality was mixed. Among men, differences were substantially attenuated for all-cause mortality and for both cause-of-death groups, but in particular for external causes since the 2000s. Among women, socioeconomic adjustment did not attenuate the estimates as in the case of men, except in the last periods studied, where moderate attenuation was also observed (Table 3).

Overall, the findings indicate that the importance of individual-level compositional factors, such as age and socioeconomic characteristics, in explaining regional differences in mortality increased throughout the study period.

Table 3 Municipal-level mortality variation between 1972–1975 and 2016–2018 indicated by median hazard ratios (MHR) adjusted for age and socioeconomic characteristics (Model 2), by age group, gender, and cause of death.

	Period									
	1972–1975	1976–1980	1981–1985	1986–1990	1991–1995	1996–2000	2001–2005	2006–2010	2011–2015	2016–2018
Men										
30–49										
All-cause	1.10	1.14	1.11	1.17	1.17	1.13	1.10	1.08	1.06	1.14
Internal	1.09	1.08	1.07	1.13	1.12	1.10	1.06	1.06	1.06	1.10
External	1.21	1.20	1.16	1.21	1.25	1.18	1.15	1.12	1.11	1.13
50–69										
All-cause	1.07	1.08	1.08	1.10	1.09	1.10	1.10	1.11	1.09	1.07
Internal	1.07	1.07	1.06	1.08	1.09	1.09	1.09	1.09	1.07	1.06
External	1.15	1.18	1.22	1.20	1.21	1.20	1.19	1.19	1.17	1.12
70+										
All-cause	1.06	1.06	1.05	1.05	1.04	1.05	1.07	1.06	1.06	1.06
Internal	1.06	1.06	1.04	1.05	1.04	1.05	1.06	1.06	1.06	1.05
External	1.26	1.14	1.13	1.15	1.15	1.18	1.17	1.15	1.18	*
Women										
30–49										
All-cause	1.10	1.15	1.12	1.14	1.13	1.13	1.09	1.12	1.04	1.00
Internal	1.09	1.11	1.09	1.12	1.11	1.08	1.09	1.08	1.00	1.12
External	1.22	1.52	1.29	1.27	1.29	1.29	1.19	1.20	1.15	1.07
50–69										
All-cause	1.06	1.07	1.07	1.07	1.08	1.08	1.10	1.10	1.09	1.07
Internal	1.06	1.06	1.06	1.07	1.08	1.08	1.09	1.09	1.08	1.08
External	1.15	1.20	1.25	1.29	1.26	1.24	1.24	1.27	1.19	1.12
70+										
All-cause	1.10	1.07	1.06	1.07	1.07	1.07	1.07	1.05	1.05	1.06
Internal	1.10	1.08	1.06	1.07	1.07	1.06	1.07	1.05	1.06	1.07
External	1.07	1.27	1.14	1.19	1.22	1.30	1.19	*	*	*

* Models failed to converge given low number of deaths

6.2 Changes in living arrangement differences in mortality (Sub-study II)

Sub-study II examined changes in mortality differences across living arrangements, focusing particularly on how the evolving socioeconomic composition of these groups influenced the change in differences. Mortality was analysed in six 5-year periods between 1990 and 2020, with differences assessed by comparing the mortality of individuals living with a partner and children to the mortality of those in 5 other living arrangements. Over the period, the share of two-parent families with children declined, while living alone, especially among men, and living only with a partner, particularly among older adults, became more common (Table 4).

Table 4 Distribution of living arrangements and total deaths by age group and gender, in 1990 and 2015.

	Men		Women	
	1990	2015	1990	2015
30–49				
Partner and children	61	50	65	55
Partner	13	16	13	15
Children	2	2	10	12
Others	11	8	3	3
Alone	12	22	9	13
Institution/unknown	2	3	1	1
N	794,273	701,778	760,854	669,155
Deaths (% external)	15,317 (51)	6,736 (48)	5,778 (33)	2,999 (28)
50–69				
Partner and children	30	20	20	15
Partner	46	48	42	49
Children	2	2	7	5
Others	6	5	5	2
Alone	14	24	25	27
Institution/unknown	1	2	1	1
N	468,797	735,197	536,122	760,262
Deaths (% external)	44,231 (13)	41,240 (18)	23,445 (7)	21,901 (11)
70 and over				
Partner and children	9	4	2	2
Partner	57	63	20	35
Children	2	1	7	4
Others	6	2	12	3
Alone	22	25	50	50
Institution/unknown	22	25	8	7
N	147,440	303,373	302,887	438,389
Deaths (% external)	57,021 (4)	85,157 (5)	93,880 (3)	109,311 (3)

Throughout the 30-year time period, mortality was consistently the lowest among individuals living with a partner (and children), while the highest rates were observed among those living alone or those living with someone other than a partner or child. Mortality declined across all living arrangements, though the extent of the decline varied by age and arrangement group. Among younger adults, the largest absolute reductions in mortality were seen in high-mortality groups, such as individuals living alone. For older adults, those living with a partner experienced the most significant absolute declines. Although absolute mortality differences between individuals living with a partner and children and those in other arrangements generally decreased over time, they widened for certain groups, such as women aged 50–69 and men aged 70 and over (Figure 3).

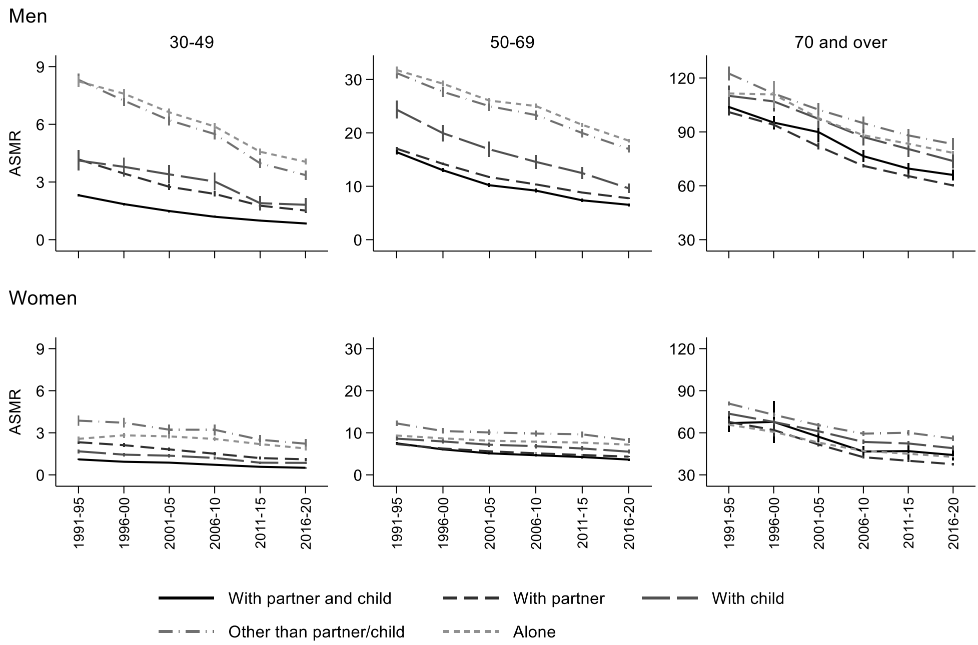

Figure 3 Directly age-standardised mortality rates (ASMRs) (per 1,000 person-years) with 95% confidence intervals by living arrangements, gender, age group and period; age adjustment using person-years among men and women in the broad age group across all periods as the standard; men and women aged 30 and over.

Relative differences in all-cause mortality between living arrangement categories were already substantial, but even greater disparities were observed for external and alcohol-related causes. These differences grew wider between the early 1990s and the late 2010s. This trend of increasing relative disadvantage was most notable among individuals aged 50 and older and among those living alone, who by the late 2010s faced up to a sixfold higher external and alcohol-related mortality rate than those living with a partner and children (results shown in the research article of Sub-study II).

Table 5 Percentages of tertiary-educated and upper-level employees by living arrangement category, age group and gender in 1990 and 2015.

	Men		Women	
	1990	2015	1990	2015
Tertiary-educated				
30–49				
Partner and children	30	41	29	57
Partner	26	36	24	50
Children	20	30	22	40
Others	11	20	23	40
Alone	24	27	37	50
Institution/unknown	11	13	22	29
50–69				
Partner and children	20	40	15	51
Partner	16	32	9	36
Children	16	31	10	43
Others	5	17	9	28
Alone	10	23	12	34
Institution/unknown	4	13	4	18
70 and over				
Partner and children	8	20	3	15
Partner	13	28	6	22
Children	5	15	2	9
Others	4	12	4	14
Alone	9	19	7	16
Institution/unknown	4	14	4	10
Upper-level employees				
30–49				
Partner and children	20	26	14	25
Partner	17	22	13	21
Children	12	17	11	15
Others	5	8	10	13
Alone	14	14	20	19
Institution/unknown	7	4	9	7
50–69				
Partner and children	12	21	8	21
Partner	7	10	4	10
Children	8	14	5	17
Others	2	4	3	7
Alone	4	7	4	9
Institution/unknown	2	2	2	2

Socioeconomic characteristics, measured by educational attainment and occupational status, varied significantly across living arrangements. Individuals living alone were generally less educated and less likely to hold upper-level employment positions than those living with a partner. These socioeconomic disparities persisted or even widened over time, at least partly due to a larger increase in the proportion of tertiary-educated individuals and upper-level employees among those living with a partner (and children) (Table 5). Adjusting for socioeconomic characteristics somewhat reduced both all-cause and external and alcohol-related mortality differences across living arrangements, though the attenuation was less significant in older age groups. Reductions were most pronounced among younger individuals, especially men, with differences decreasing by up to a quarter. By the late 2010s, attenuation increased but only modestly compared to the early 1990s (Figure 4; results for those 50 and over shown in the research article of Sub-study II).

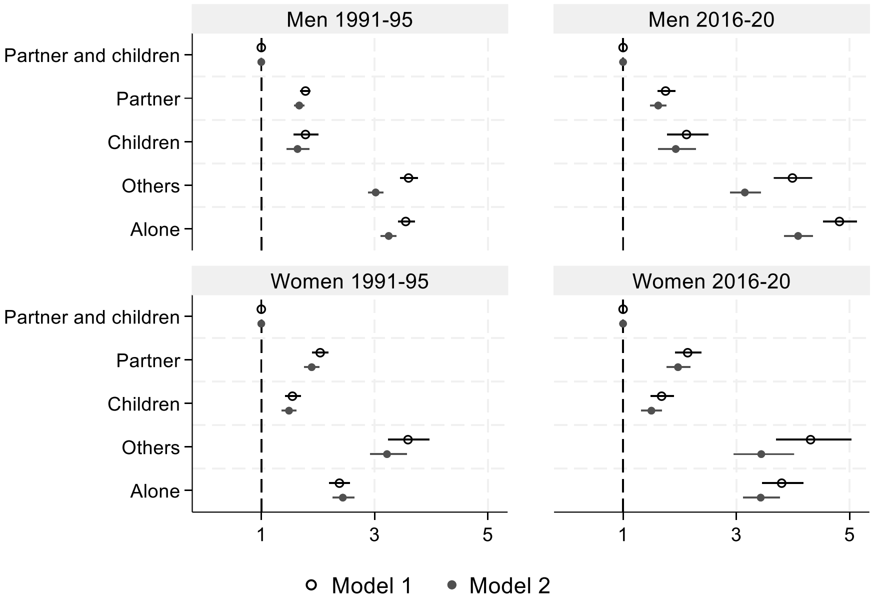

Figure 4 Relative all-cause mortality differences by living arrangement in 1991–1995 and 2016–2020 among men and women aged 30–49 years. Rate ratios and 95% confidence intervals from models adjusted for age (Model 1) and for age and socioeconomic characteristics (Model 2). Institution/unknown category not shown in the figure.

This study shows that while mortality rates have declined across all living arrangement groups over the past three decades, relative differences between groups remain substantial and have increased. However, this increase in differences appears to be mainly due to factors beyond growing socioeconomic differentiation between living arrangements.

6.3 Changes in excess winter mortality (Sub-study III)

Sub-study III analysed long-term trends in excess winter mortality between 1971 and 2019. In addition, the study examined how individual-level characteristics influenced the risk of winter mortality, specifically during the period 2000–2019. Winter was defined as the months of December to March, with non-winter months covering the four months on each side of this period. Mortality was measured in 12-

month intervals, starting from August of one year to the end of July of the next. Over the full study period, slightly over a third (36%) of deaths occurred during winter.

Age-adjusted winter mortality rates declined substantially over 5 decades, with rates for men falling from 95 to 37 deaths per 1,000 person-years and for women from 66 to 23. Mortality rates during non-winter months remained consistently lower but showed a similar downward trend (Figure 5).

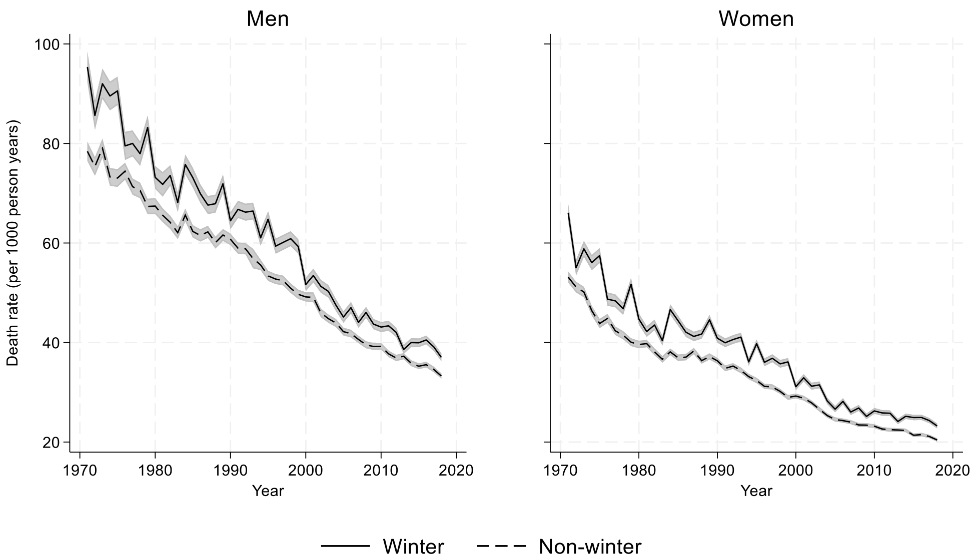

Figure 5 All-cause winter and non-winter mortality rates and 95% confidence intervals, Finland 1971–2019, men and women aged 60 and over.

The gap between winter and non-winter mortality narrowed over time, both in absolute and relative terms for both men and women. As overall mortality levels declined, absolute differences also fell, from an average of 15 deaths per 1,000 person-years to below 5 deaths per 1,000 over the 5 decades. Relative differences decreased from a winter excess of over 30% in earlier years to below 5% in more recent years. In addition to this overall decreasing trend, a break in the trend occurred around the year 2000, after which yearly values of both absolute and relative differences fluctuated at much lower levels. Compared to earlier decades, the mean rate difference between winter and non-winter mortality dropped by 50% for both men and women, while the RRs decreased by approximately 10% for men and 20% for women (Figure 6).

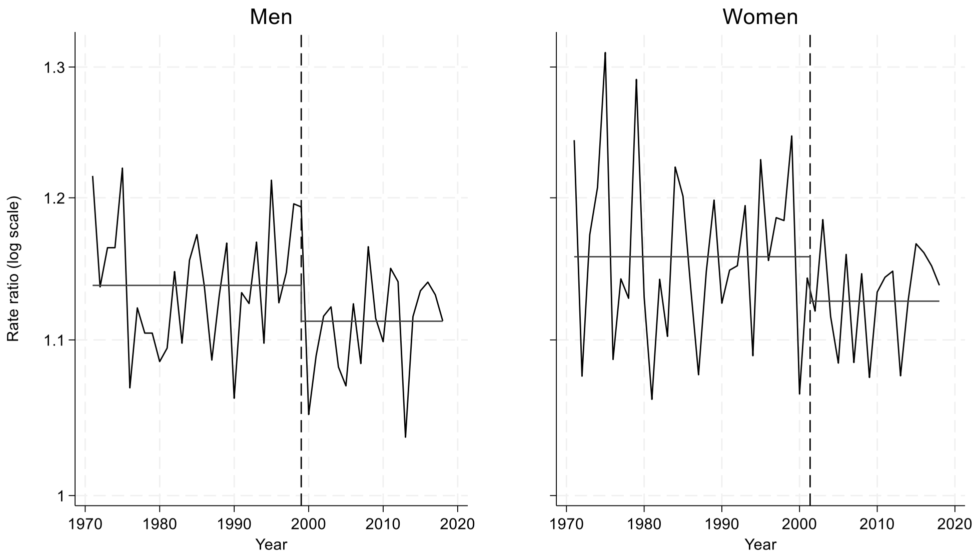

Figure 6 Rate ratios of winter and non-winter mortality rates with detected breakpoints (vertical dashed lines) and mean rate ratios before and after the breakpoint (horizontal lines). Finland 1971–2019, men and women aged 60 and over.

In 2000–2019, all-cause mortality in winter exceeded non-winter rates by 11% and 14%, for men and women, respectively. The winter excess was observed in nearly all disease categories studied, except external causes among men. The excess was most pronounced in respiratory diseases, where winter deaths exceeded non-winter rates by 26% for men and 40% for women. Dementia-related mortality also showed a notable winter excess (21% for men, 22% for women), exceeding the seasonal excess observed in circulatory disease deaths.

Analysis of potential sociodemographic effect modifiers indicated that the risk of dying in winter increased with age and was slightly higher among women than men. Living in institutions was associated with a higher winter mortality risk compared to living with others. There was no evidence that excess winter mortality risk varied by socioeconomic position as measured by income, and only weak evidence of differences between different regions of the country (Table 6).

Table 6 Mortality rates in winter and non-winter periods, and relative differences in excess winter mortality by sociodemographic characteristics. Finland 2000–2019, men and women aged 60 and over.

	Age-adjusted rate per 1,000 person-years		Full adjusted relative risk with 95% CI[a,b]
	Winter (n=295,236)	Non-winter (n=529,688)	
Gender			
Men	49.5	44.8	1.00
Women	31.4	27.6	**1.03 (1.02, 1.04)**
Age category			
60–69	11.9	11.2	1.00
70–79	30.7	27.9	**1.04 (1.02, 1.05)**
80–89	94.6	83.2	**1.07 (1.06, 1.09)**
90 and over	269.8	228.0	**1.12 (1.10, 1.13)**
Income quartile			
1 (lowest)	41.5	37.2	1.00
2	38.5	34.3	1.00 (0.99, 1.02)
3	37.9	33.7	1.01 (0.99, 1.02)
4 (highest)	32.9	29.2	1.01 (0.99, 1.02)
Living arrangement			
Household of >1	31.0	28.0	1.00
Alone	34.3	30.6	**1.01 (1.00, 1.02)**
Institution	110.1	93.6	**1.07 (1.05, 1.08)**
Region			
Coast	36.8	33.1	1.00
South	37.5	33.2	**1.02 (1.00, 1.03)**
Centre	38.9	34.8	1.01 (0.99, 1.02)
North	39.3	34.7	**1.02 (1.01, 1.03)**

Bold values indicate estimates with 95% confidence intervals (CIs) that do not contain 1.

[a] Models are adjusted for gender, age, income, living arrangement, region and year.

[b] Relative risks in the last column are the interaction terms of the winter indicator and the effect modifier. These show the relative differences in the effect of winter on mortality between effect-modifier categories.

Although individuals with each of the pre-existing health conditions faced clearly higher mortality risks during both winter and non-winter periods compared to those without such conditions, most conditions included in the study did not predict winter death. Somewhat an exception were individuals with dementia, whose relative risk of winter death was elevated compared to those without dementia (1.06, 95% CI 1.04–1.07). This excess was not attributable to the more frequent residency of individuals with pre-existing dementia in institutional care, as the effect modification of winter mortality among those with dementia living in institutions was modest or negligible (results shown in the published research article). Respiratory diseases and mental disorders were also associated with slightly increased winter mortality risk (Table 7).

Table 7 Death rates in winter and non-winter periods, and relative differences in excess winter mortality by pre-existing health conditions. Finland 2000–2019, men and women aged 60 and over.

	Age-adjusted rate per 1,000 person-years		Full adjusted relative risk with 95% CI[a,b]
	Winter (n=295,236)	Non-winter (n=529,688)	
Dementia			
No	34.0	30.6	1.00
Yes	78.9	67.2	**1.06 (1.04, 1.07)**
Mental health disorders			
No	36.5	32.6	1.00
Yes	69.6	60.9	**1.02 (1.00, 1.04)**
Cancer			
No	34.9	30.7	1.00
Yes	74.1	70.4	**0.93 (0.92, 0.94)**
Diseases of the nervous system			
No	36.1	32.2	1.00
Yes	65.6	58.7	0.99 (0.98, 1.01)
Diabetes			
No	35.2	31.4	1.00
Yes	57.0	50.5	1.01 (1.00, 1.02)
Circulatory			
No	29.9	26.8	1.00
Yes	45.5	40.4	1.01 (1.00, 1.02)
Respiratory			
No	34.7	31.0	1.00
Yes	61.2	53.6	**1.02 (1.01, 1.03)**
Alcohol-related			
No	37.5	33.4	1.00
Yes	169.7	161.8	**0.93 (0.89, 0.98)**
Accidents and violence			
No	36.4	32.5	1.00
Yes	56.0	49.7	1.00 (0.99, 1.02)
Other than specified above			
No	34.1	30.1	1.00
Yes	44.2	39.9	**0.98 (0.97, 0.99)**
Any health condition			
No	19.2	17.2	1.00
Yes	43.7	38.9	1.00 (0.99, 1.02)

Bold values indicate estimates with 95% confidence intervals (CIs) that do not contain 1.

[a] Models are adjusted for gender, age, income, living arrangement, region and year.

[b] Relative risks in the last column are the interaction terms of the winter indicator and the effect modifier. These show the relative differences in the effect of winter on mortality between effect-modifier categories.

In conclusion, this study demonstrates that winter mortality has steadily declined since 1971, and especially after 2000, but has consistently remained higher than non-winter mortality. The findings provide strong evidence that advanced age, institutional living, and dementia are associated with particularly high winter mortality risk.

7 Discussion

This thesis aimed to explore long-term trends in mortality differences in Finland over five decades. By examining three distinct and less studied dimensions of mortality variation—area of residence, living arrangements, and seasons—the study provides new perspectives on dynamics that sustain and shape mortality disparities over time. Furthermore, the use of detailed register data spanning five decades and covering the total population enabled analysing the role of individual-level sociodemographic determinants in long-term processes. The findings highlight diverse ways mortality differences have changed, without a clear overall trend of increasing or decreasing disparities. The main results of each sub-study will be discussed below, along with methodological considerations and some directions for future research.

7.1 Persistent municipal mortality differences over five decades with diverging trends by age group

Sub-study I, which examined long-term trends in municipal-level mortality variation, found that overall differences between municipalities have remained relatively stable in Finland over a period of five decades, aligning with earlier findings on larger areas of the country (Wilson et al., 2020). However, the results of this study revealed that this apparent stability masks significant age-specific differences. While mortality variation among the elderly remained largely unchanged, possibly reflecting the effectiveness of universal welfare policies in reducing regional disparities in this age group, mortality differences among younger working-age individuals, particularly men, significantly increased, driven largely by external causes of death.

To better understand these trends, the study specifically focused on examining the role of changes in the population composition of areas. Area differences in mortality are often attributed to two main factors: compositional effects, which reflect the uneven spatial distribution of individuals with varying mortality risks, and contextual effects, which arise from characteristics specific to the area itself (Macintyre et al., 2002; Subramanian et al., 2003). While existing research recognises that compositional factors frequently outweigh contextual characteristics in explaining the differences (Pickett & Pearl, 2001), their contribution to changes over time has received little attention. To address this gap, the study distinguished itself from previous research by also considering unadjusted trends, highlighting the challenges faced by local healthcare systems. This approach also draws attention to important mechanisms behind regional mortality differences and their trends that might otherwise remain unacknowledged.

The findings indicated that the contribution of individual-level compositional factors, particularly age, but also socioeconomic characteristics, to area-level mortality variation has grown over time. Stark increases in unadjusted overall mortality differences since the 1970s point to substantial changes in the spatial distribution of populations by age over 5 decades. Furthermore, the increasing importance of the socioeconomic composition of municipality populations in explaining within-country area variation in mortality, particularly at younger ages from the mid-1990s onwards, suggest that differences between municipalities in terms of the socioeconomic composition of their inhabitants have increased.

While the study design did not allow for direct conclusions about the mechanisms behind the growing influence of individual-level factors on area-level mortality differences, this trend likely reflects broader demographic and economic processes of recent decades. In Finland, regional differentiation has increased alongside processes of urbanisation, population aging, internal migration, and industrial restructuring (Grunfelder et al., 2020). Migration, in particular, may play a critical role here, as it is inherently selective: movers tend to differ from the rest of the population in terms of age, socioeconomic characteristics and health (Vaalavuo & Sihvola, 2021). This kind of selectivity significantly impacts regional health profiles, with positive effects for destination areas and negative effects for the regions the movers leave behind (Westphal, 2016). Urban centres with better educational and labour market opportunities often attract younger, healthier individuals with higher socioeconomic position, while rural areas are left with aging populations with increasing healthcare needs. Over time, this selective migration amplifies compositional disparities between regions, contributing to widening overall mortality gaps.

The interconnectedness of composition and local context further emphasises the importance of examining the role of compositional changes in mortality differences between areas. Local context shapes the opportunities available to residents, influencing individual characteristics such as income, occupational social class, and educational attainment through the constraints and opportunities of local labour markets and educational facilities (Macintyre et al., 2002). Economic restructuring and out-migration, particularly in peripheral localities, may exacerbate local disadvantage by reducing access to adequate services, limiting job markets, and weakening social capital. These effects may disproportionately impact certain population groups, leading to the adoption of risky behaviours. Consistent with such dynamics, the study found increased mortality variation among 30–49-year-old men, driven largely by external causes of death. Future research should focus on identifying area characteristics that may have contributed to these growing disparities. Additionally, since reducing regional inequalities requires prioritising resources for areas with the greatest needs, it is important to assess the spatial patterns of these disparities to develop targeted investments in both the places and the people who inhabit them.

7.2 Increasing relative differences in mortality by living arrangement despite favourable mortality trends

Sub-study II investigated long-term trends in mortality differences by living arrangement, highlighting persistent and increasing disparities over three decades despite generally favourable mortality trends across all living arrangement groups studied. The results showed that individuals living alone or in arrangements other than with a partner consistently experienced higher mortality, with relative disparities widening over time. The study results align with earlier research on marital status and mortality but provide novel insights on the role of changes in the socioeconomic composition of living arrangements.

The study found that while absolute mortality differences between living arrangements narrowed for most groups, relative disparities increased. This reflects a slower relative decline in mortality among high-risk groups, particularly among those living alone. Men aged 30–49 living alone exhibited a four- to fivefold excess in mortality compared to those living with a partner and children, with even more pronounced excess observed for external and alcohol-related causes of death. These findings highlight the associations between living arrangements, health behaviours, and mortality, particularly among men, for whom these associations have been shown to be especially pronounced in previous research (Staehelin et al., 2012).

At older ages, living arrangements appear to have become increasingly relevant for mortality outcomes. Among those aged 70 and above, even absolute mortality differences widened for individuals living alone or with children compared to those living with a partner. This may reflect changing thresholds for institutional care, as policies in Finland have increasingly emphasised supporting independent living for as long as possible (Korhonen et al., 2024). A similar trend has been observed in Sweden, where stricter eligibility criteria for institutional care have been linked to a greater number of vulnerable older adults living alone (Shaw et al., 2020). As a result, the older population living alone today may include individuals in worse health compared to previous decades. Additionally, navigating fragmented health services may have become more challenging over time for those without the support of a partner.

The study confirmed that socioeconomic disadvantage is a significant factor in mortality differences by living arrangement. Adjusting for education and occupation-based social position attenuated these differences, indicating that part of the mortality gap between living arrangement groups can be attributed to socioeconomic disparities. Over the study period, the already uneven socioeconomic composition across living arrangement groups persisted and became more pronounced, with a greater increase in higher education and upper-level occupations among those living with a partner and children. Similar findings in previous research suggest that partnerships have become increasingly concentrated among individuals with higher education, stable employment, and higher incomes (Erola & Kilpi-Jakonen, 2022). These observations suggest an increasing mortality advantage for those in a partnership, given the association between higher socioeconomic position and lower mortality. However, the compositional shifts were only modestly reflected in the results. While the socioeconomic attenuation of mortality differences grew somewhat over time, indicating that increased socioeconomic differentiation between living arrangements played a role, its overall role in the widening relative mortality disparities appears to have been limited. Similar trends have been observed in research on marital status differences in mortality (Martikainen et al., 2005; Kravdal et al., 2018). This study extends those findings by demonstrating that the same pattern applies to living arrangements, which may better capture the everyday household environment in which people live. Since socioeconomic factors accounted for only a minor share of the growing disparities, other mechanisms are likely at play.

The increasing relative mortality disparity of those living alone can be considered particularly concerning given the high and still rising prevalence of one-person households, which now constitute nearly half of all Finnish households. Living alone has been associated with increased mortality risk and other health adversities, and this risk appears to be rising even more sharply relative to those living with a partner than for other living arrangement categories. While individuals living alone represent a socioeconomically diverse group, the findings underscore the need to consider vulnerabilities that may intersect with this living arrangement, such as loneliness, mental health challenges, or limited resources, when considering future research, health policies, and social interventions.

7.3 Declining excess winter mortality over time

Sub-study III analysed long-term trends in excess winter mortality from 1971 to 2019 among individuals aged 60 and older. The findings showed a steady decline in both winter and non-winter mortality over the study period, yet winter rates exceeded non-winter rates throughout. However, both absolute and relative differences between winter and non-winter rates showed a clear downward trend, aligning with a prior Finnish study up to the mid-1990s (Näyhä, 2000). By extending the analysis into the 21st century, this study identified a marked reduction in the year-to-year variation of these differences during the last 2 decades, along with a noticeable downturn in both absolute and relative measures around the year 2000.

The long-term decline in excess winter mortality, observed in this study and in previous research from Finland and beyond, is likely attributable to a combination of factors that have also contributed to the overall mortality decline, including general socioeconomic progress, improved housing, advancements in healthcare and better disease management (Kunst et al., 1991; Telfar-Barnard et al., 2024). Previous research has suggested that these developments have especially weakened the contribution of low temperatures to winter mortality (Linares et al., 2016), possibly both directly through better-insulated housing and effective heating systems and indirectly through advancements in public health that have reduced vulnerability to cold-related health risks such as hypertension.

Besides low temperatures, influenza-like illnesses are considered another key contributor to excess winter mortality. These illnesses may have played a role in shaping the patterns observed in the last 2 decades of this study, especially in contributing to the reduced fluctuations in winter mortality since around 2000, with at least 2 factors standing out. Firstly, seasonal influenza activity and its associated mortality were notably lower in the early 21st century compared to preceding decades (Jones, 2020). Secondly, the extension of influenza vaccinations in Finland's national vaccination programme in 2002 to include all individuals aged 65 and older (Finnish Institute for Health and Welfare (THL), n.d.) may have contributed to reducing winter mortality peaks. Vaccination is widely regarded as an effective measure for preventing influenza-related deaths, with studies reporting substantial mortality reductions (Fireman et al., 2009; Voordouw et al., 2003). However, questions remain regarding the extent of the benefits of the vaccination, particularly for the oldest age groups (Simonsen et al., 2007). Additionally, vaccine coverage in Finland has remained below recommended levels, raising uncertainty about its overall impact (Jansson, 2008). While further research is needed, this study suggests that both lower influenza activity and the expanded vaccination coverage may have played a role in reducing excess winter mortality peaks over recent decades.

Beyond examining trends, the study also addressed sociodemographic and health-related modifiers of excess winter mortality in 2000–2019. While advanced age emerged as the strongest predictor of winter mortality, other modifiers such as institutional living and dementia also significantly influenced the risk of winter death, highlighting the importance of frailty to environmental stressors in shaping mortality outcomes during the winter months.

While there is a well-known link between socioeconomic position and overall mortality, this study found no evidence of an income gradient in vulnerability to excess winter mortality. This contrasts with findings from other countries, such as New Zealand and the United Kingdom, where socioeconomic disparities in excess winter mortality have been attributed to poor housing conditions and fuel poverty (Hales et al., 2012; Tanner et al., 2013). In Finland, the absence of socioeconomic differences in vulnerability to winter mortality likely reflects the country's high-quality housing standards, which ensure adequate thermal insulation and heating across all income levels.

Similarly, most pre-existing health conditions showed minimal effect on winter mortality in this study. Not even individuals with respiratory or circulatory conditions—traditionally considered high-risk groups—faced significantly elevated risks during winter. This finding challenges the widely held belief, though not strongly supported by evidence, that those with pre-existing health conditions are particularly vulnerable. It may suggest that individuals with diagnosed conditions benefit more from targeted preventive measures, such as influenza vaccinations and regular healthcare monitoring. However, further research is needed to better understand these patterns, particularly to assess the effectiveness of preventive interventions, the potential role of undiagnosed conditions, and how healthcare access and utilisation might mitigate winter mortality risks.

The study's finding that individuals with dementia experienced higher excess winter mortality, even after accounting for institutional living, warrants further attention. While a tendency to attribute deaths to the underlying chronic condition rather than, for example, a respiratory infection could explain some of the observed excesses, dementia-related vulnerabilities, including difficulties in communicating health changes and reduced perception of cold, may contribute to this heightened risk. Additionally, evidence from similar contexts, such as Canada, suggests that extended periods of darkness during winter, which are known to impact general well-being even among healthy individuals, may especially exacerbate restlessness, anxiety, and behavioural challenges in those with dementia (Joseph et al., 2013). In countries like Finland, where winters are similarly long and dark, these factors may be significant, highlighting the importance of further research.

7.4 Parallels between sub-studies

This thesis integrated three sub-studies to examine long-term trends in mortality disparities across distinct dimensions. Given the varied scope of the studies, drawing overarching conclusions is challenging. However, some general parallels can be identified alongside important contrasts that highlight the complex dynamics of mortality differences.

One takeaway from the studies is that while overall population health has improved and mortality has continued its decline over the long term, mortality differences have not followed a similar, uniform trajectory. Instead, disparities have evolved in varied ways across different contexts and population subgroups, with both narrowing and widening, as well as stable, differences. For instance, overall mortality differences between municipalities remained relatively stable over five decades, but trends varied significantly by age group, with working-age men experiencing widening gaps driven by external causes of death. In contrast, for living arrangements, the widening of relative disparities between those living with a partner (and children) and those in other living arrangements was not confined to a specific subgroup but was a more consistent finding, observed across both men and women, all studied age groups, and for both all-cause and external-cause mortality. The study on excess winter mortality introduced yet another perspective to mortality differences, combining a seasonal fluctuation affecting everyone with individual differences in susceptibility. The long-term decline in winter mortality relative to other times of the year illustrates how public health and socioeconomic advancements can mitigate risks. However, winter remains a period of elevated mortality for the subgroup of older adults, with frailty as a critical risk factor.

Sub-studies I and II examined how changes in the socioeconomic composition of living arrangement groups and municipalities contributed to changes in mortality gaps. While socioeconomic factors were associated with both dimensions studied, their contribution to long-term trends differed. In municipalities, changes in mortality differences were strongly driven by population composition, and in particular, the growing disparity among the working-aged appeared to be linked to widening socioeconomic differences between municipalities. In contrast, for living arrangements, rising relative disparities seemed to result largely from factors other than growing socioeconomic differences between groups. These findings highlight that while socioeconomic characteristics are persistently relevant, their role in explaining mortality disparity across other dimensions varies depending on how individuals are distributed across different contexts, whether by place of residence or living arrangement, and the extent to which social disadvantage influences these processes.

7.5 Methodological considerations

The studies in this thesis relied on high-quality, individual-level register data covering all persons in Finland between 1970 and 2020, providing a unique opportunity to examine mortality differences and their change. Drawn from the national population register, the data offers comprehensive coverage, minimal attrition, and eliminates biases associated with self-reported information, such as recall bias or selective non-response. The cause of death information was obtained from the Finnish Cause of Death Register, using Statistics Finland's harmonised classification allowing for comparability over time despite changes in ICD versions throughout the study period. A further advantage of the data was the ability to link individuals to their household members, area of residence, and a wide range of sociodemographic and health variables. These data characteristics enabled a detailed analysis of mortality determinants and their evolution over time, providing insights often unavailable in international research on mortality trends, which primarily relies on aggregate data. While the advantages of full-population individual-level register data were clear across all sub-studies, some more specific methodological considerations are discussed in the following.

For the study of area-level differences in mortality, the characteristics of the individual-level data allowed for the adoption of a multi-level design. The MHR was used as a summary measure of the general contextual effect of municipalities on individual mortality. A key advantage of the MHR is its ability to concisely capture variability in HRs within a single value, facilitating the observation of trends over time across 300+ municipalities. A potential disadvantage is that, as an average measure, the MHR may be disproportionately affected by single municipalities with high excess mortality. In this study, however, this concern was addressed, and the possibility that significant or increasing numbers of outliers drove changes in the overall estimate was ruled out. Additionally, while the MHR is expressed in the familiar metric of HRs, the MHR remains relatively new and lacks established threshold values or comparative studies to define what constitutes a large effect. Since the focus of the study was on changes over time, this limitation is, however, less problematic. Another issue concerns the definition of the area level. In area research, it is well known that results are likely to vary depending on the area unit of analysis, highlighting the importance of selecting an appropriate unit to ensure meaningful findings. In the case of Finland, municipalities serve as a well-justified choice for examining area-level differences in mortality. As the primary administrative entities responsible for organising and delivering social and health services, they represent a policy-relevant context for studying health outcomes.

The study on living arrangement differences in mortality covered a shorter time period (1990–2020). While Finnish register data on living arrangements is generally highly reliable, classification changes before and after 1990 limit comparability over longer periods (Official Statistics of Finland (OSF), n.d.-d). Before 1990, cohabiting couples were not systematically identified, whereas since 1990, they have been inferred based on shared residence. This change improved consistency but some misclassifications are likely. For example, among cohabiting couples, especially those without children, individuals meeting the classification criteria (different gender, unmarried, not siblings, over 18, with an age difference of less than 16 years) may not necessarily be in a couple relationship. Despite this, the inferred number of cohabiting couples has been found to closely match survey estimates, although slightly underestimated. The study, however, did not treat cohabiting couples as a separate group. Instead, to provide a more streamlined perspective on trends, a combined category of married and cohabiting couples was used. Although prior research suggests slightly higher mortality among cohabiters, this approach was considered appropriate given their likely similar household and social characteristics. However, this simplification should be kept in mind when interpreting results. Another potential source of misclassification concerns single parents since Finnish registers assign children in joint custody to only one parent's household, typically the mother's. As a result, some fathers classified as not living with children may, in practice, reside with them part-time. Additionally, non-registered same-sex partnerships were not captured in the data.

The study on excess winter mortality used a straightforward measure, comparing mortality during winter months to the rest of the year. This widely used approach is valued for its ease of calculation, straightforward interpretation, and applicability across different populations. However, it has also faced criticism (Hajat, 2017), much of which appears to come from research that prioritises temperature as the main driver of winter mortality. A common concern is that the measure captures overall seasonal mortality, not just cold-related deaths, making it unsuitable as a direct indicator of cold effects. While this is a valid critique, the excess winter mortality measure highlights the overall seasonal mortality burden, which is relevant from a public health perspective: whatever the explanation, winter places increased pressure on healthcare systems. Given that the study did not aim to disentangle specific causes of winter mortality, the chosen measure provides a suitable approach for assessing seasonal variations over time and examining individual-level determinants of vulnerability.

On a more general note, an important methodological consideration when studying mortality differences and their trends is whether to assess them in relative or absolute terms. While absolute differences between groups are naturally smaller when overall mortality levels are low, a well-documented phenomenon in epidemiology is that relative differences tend to be higher when overall mortality rates are lower (Mackenbach, 2015). This suggests that as mortality declines, relative differences are likely to widen. In practice, this often occurs because reductions in mortality are rarely uniform across all population groups; instead, mortality tends to improve relatively faster among those who are better off. As a result, absolute differences may narrow, but relative differences between groups increase. This dynamic raises a question about policy priorities: given that reducing relative differences would require greater mortality improvements in high-mortality groups, it has been argued that reducing absolute differences should be prioritised, as it brings measurable advantages and is more realistic to achieve (Mackenbach, 2019).

For research on time trends, the choice between absolute or relative measures can significantly influence conclusions about whether disparities are widening or narrowing. Therefore, reporting both measures alongside information on baseline risks has been encouraged (in practice, this still seems to be uncommon, as research tends to focus primarily on relative differences) (King et al., 2012). In this thesis, this issue is most clearly evidenced in the study on living arrangement differences in mortality.

8 Conclusions

This study used total population register data spanning nearly 50 years to examine long-term trends in mortality differences in Finland. Three independent sub-studies focused on less commonly studied dimensions of mortality variation: area of residence, living arrangements, and seasons. The findings show some reassuring developments, but also point to other more concerning trends in mortality differences.

Despite growing age structure differences between municipalities, and consequently rising gaps in healthcare needs and expenditures, mortality differences among the older population remained stable, suggesting that Finland's welfare system has worked relatively well in mitigating the potential widening of mortality gaps between areas. Likewise, mortality declined across all living arrangement groups, and absolute differences in mortality rates of those living with a partner and children and other groups mostly narrowed. Excess winter mortality also steadily declined.

On the other hand, other more concerning trends emerged. Relative mortality differences by living arrangement widened, with this disadvantage increasing particularly in the growing group of individuals living alone. Socioeconomic factors only modestly contributed to this increase, suggesting that other mechanisms, such as social isolation, health behaviours, and difficulties in accessing health services, may play a role. Additionally, while municipal-level mortality differences remained stable among the elderly, disparities widened at younger ages, particularly among working-age men. Furthermore, despite its overall decline, excess winter mortality continues to significantly affect older adults, individuals with dementia, and those living in institutions.

The period covered in this thesis provides a relevant historical framework for examining mortality differences and their evolution, capturing societal developments that remain relevant today. Regional polarisation between growing and shrinking areas is expected to continue, raising concerns about whether municipal mortality differences will widen further. At the same time, ongoing shifts in family and household structures, such as the rise in single-person households and declining family sizes, may limit informal support networks, a concern further exacerbated by cuts to public services that place additional strain on disadvantaged individuals. Population aging and the increasing share of older adults who are more vulnerable not only to winter mortality but possibly also to other environmental health risks means that addressing these risks is likely a critical public health concern in the years ahead.

Mortality differences are often examined from the perspective of socioeconomic disparities, but as the topics covered in this thesis highlight, health disparities are also shaped by other fundamental aspects of life, including where people live, how they structure their households, and how seasonal and environmental factors interact with these and other conditions. Because mortality disparities are both persistent and evolving, efforts to reduce them must be long-term and account for their multidimensional nature.

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Changes in regional variation in mortality over five decades – The contribution of age and socioeconomic population composition

Ulla Suulamo *, Lasse Tarkiainen, Hanna Remes, Pekka Martikainen

Population Research Unit, Faculty of Social Sciences, University of Helsinki, Unioninkatu 35 (P.O. Box 18), FIN-00014, Helsinki, Finland

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ABSTRACT

Existing evidence suggests that within-country area variation in mortality has increased in several high-income countries. Little is known about the role of changes in the population composition of areas in these trends. In this study, we look at mortality variation across Finnish municipalities over five decades. We examine trends by sex, age categories and two broad cause of death groups and assess the role of individual-level compositional factors. Analyses rely on individual-level register data on the total Finnish population aged 30 years and over. We estimated two-level Weibull survival-models with individuals nested in areas for 10 periods between 1972 and 2018 to assess municipal-level variation in mortality. Median hazard ratio (MHR) was used as our summary measure and analyses were adjusted for age and socioeconomic characteristics. The results show a clear overall growth in area variation in mortality with MHR increasing from 1.14 (95% CI 1.12–1.15) to 1.28 (CI 1.26–1.30) among men and 1.17 (CI 1.15–1.18) to 1.30 (CI 1.27–1.32) among women. This growth, however, was fully attenuated by adjustment for age. Area differentials were largest and increased most among men at ages 30–49, and particularly for external causes. This increase was largely due to increasing differentiation in the socio-economic composition of municipalities. In conclusion, our study shows increases in mortality differentials across municipalities that are mostly attributable to increasing differentiation between municipalities in terms of individual compositional factors.

1. Introduction

National-level measures of mortality often hide important within-country differentials. Recent studies provide evidence that while in some countries these differentials have narrowed over time, in others they have persisted and even grown even as overall mortality levels have steadily declined (Vierboom et al., 2019; Pearce & Dorling, 2006; Leyland, 2004; Wilson et al., 2020). Reasons for the developments are, however, unclear. Deindustrialisation constitutes a key feature of social change over the past decades, which has affected areas unevenly leading to growing regional differentiation and changes in the spatial population distribution (Bontje & Musterd, 2012; Martinez-Fernandez & Noya, 2012; Oswalt et al., 2006). We propose that these processes may be associated with the reported trends in within-country mortality variation.

Area differentials in mortality have been documented at different levels ranging from the immediate local area to broader regions, but relatively little evidence exists on long-term trends. In the United States, variation measured at county (Ezzati et al., 2008), state (Wilmoth, Boe, & Barbieri, 2010) and wider geographical (Vierboom et al., 2019) levels has increased from the 1980s. For example, the gap between counties with the lowest and highest life expectancy increased from approximately 10 years–15 years between 1985 and 2010 (Wang et al., 2013). A widening gap between low and high mortality areas in 1980–2000 has also been observed between health districts in New Zealand (Pearce & Dorling, 2006) and regional health authorities in Canada (Mustard et al., 1999). For European countries, the existing evidence points in opposite directions. In Germany (van Raalte et al., 2020), Austria (Gächter & Theurl, 2011) and Norway (Skaftun et al., 2018), differentials have narrowed, whereas widening differentials have been found, for example, in Britain (Leyland, 2004), Spain (Montero-Granados et al., 2007) and Poland (Muszynska et al., 2014). In some countries, variation between areas appears stable, including the Netherlands in 1988–2009 (Janssen et al., 2016) and Sweden and Finland in 1990–2014 (Wilson et al., 2020). Evidence on whether the observed trends differ by age and sex is limited and inconclusive. While larger increases in differentials have

* Corresponding author.
E-mail addresses: ulla.suulamo@helsinki.fi (U. Suulamo), lasse.tarkiainen@helsinki.fi (L. Tarkiainen), hanna.remes@helsinki.fi (H. Remes), pekka.martikainen@helsinki.fi (P. Martikainen).

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been reported among younger men in Germany (van Raalte et al., 2020) and Britain (Smith et al., 2002), important increases among older adults have been reported in France (Bonnet & d'Albis, 2020), Russia (Timonin et al., 2017) and the US (Vierboom & Preston, 2020).

Much of the discussion in the literature interprets area variation in mortality as arising from two principal sources. Compositional effects suggest that differences between areas relate to the uneven spatial distribution of people with different mortality risk due to individual-level characteristics such as age or socioeconomic position, while contextual effects originate from characteristics and processes occurring at the area level (Subramanian et al., 2003). Even though the extent to which these two effects can be separated is arguable (Macintyre et al., 2002), they offer a useful analytical framework for examining how both individual characteristics and contextual circumstances manifest in mortality differences between areas.

Previous studies have rarely attempted to identify reasons for the reported long-term trends in area-level mortality differentials, but some potential explanations and associated factors have been identified; these include changes in the importance of area-level socioeconomic conditions (Kibele et al., 2015) or changing social policies (Gächter & Theurl, 2011; Montero-Granados et al., 2007; Pearce & Dorling, 2006). Furthermore, results from cause-specific analysis suggest that the trends are closely related to changes in the prevalence of health behaviour between areas (Myrskylä & Scholz, 2013; Muszyńska et al., 2014; Timonin et al., 2017; Vierboom et al., 2019).

What we believe is noteworthy is that most prior research has not discussed the contribution of changes in individual-level age- and socioeconomic characteristics of the population, although empirical findings suggest their contribution on mortality variation is often more significant compared to area characteristics (Pickett & Pearl, 2001). In the context of increasing regional differentiation of the past decades in terms of spatial population distribution – most importantly through selective migration of young people from peripheral areas towards urban centres – the role of changes in compositional factors is however particularly relevant. Local population structures directly affect the need and provision of services at local levels. Especially areas with high out-migration face a challenging combination of increasing health care needs of an aging population and a decreasing proportion of younger people to both provide and finance such services as taxpayers. Such discrepancies may affect the availability of adequate services and eventually lead to increasing regional disparities in health and mortality. Therefore, besides from shedding light into the role of changing population composition of areas behind trends in regional mortality variation, research on this topic provides important information for policymakers.

This paper analyses trends in within-country mortality variation in Finland at ages 30 and above in the period 1972–2018. While trends in area level mortality variation have mostly been studied in an ecological setting and with aggregate data, we add to the literature by using individual level register data and a multilevel methodology that integrates the ecological approach with individual risk factor epidemiology (Pickett & Pearl, 2001). Using total population data spanning almost 50 years, we explore long-term trends in municipal-level variation in all-cause mortality among men and women, assess variation in these trends across age categories and internal and external causes of death, and examine the contribution of age and socioeconomic characteristics of the population to the trends.

2. Methods

2.1. Data

We used individual-level data for the total Finnish population from 1972 to 2018. Socioeconomic and demographic data from censuses and administrative registers were linked by Statistics Finland to death records using personal identification numbers. We included individuals who were 30 years or older at the end of the baseline years 1971, 1975, 1980, 1985, 1990, 1995, 2000, 2005, 2010 and 2015 and followed them for mortality in the periods 1972–75, 1976–80, …, 2011–2015, and 2016–2018. Individuals were followed until death or end of follow-up. Altogether, the final dataset comprised 138,026,531 person-years and 2,236,420 deaths between 1972 and 2018.

We used municipality as the area unit since municipalities are the regional units responsible for the implementation of health services. The number and boundaries of the municipalities have changed from the 1970s. For consistency over time, we used the classification as of 2019 with a total of 311 units. In 1971, the total population of the municipalities varied from 173 to 509,256, with a median of 14,766. In 2015, the corresponding numbers were 99–628,168, and 17,643.

We studied all-cause mortality as well as internal and external mortality based on Statistics Finland's time series cause of death classification which harmonises across different revisions of the International Classification of Diseases (ICD). Death was defined as external if the underlying cause was alcohol-, injury- or violence-related (ICD-10: F10, G312, G4051, G621, G721, I426, K292, K70, K852, K860, O354, P043, Q860, V01–Y89). All other causes were defined as internal.

We adjusted the analyses for the following individual-level variables: age (in five-year groups), education level, occupational social class, and income, all measured at baseline. Education was classified as basic or lower (International Standard Classification of Education ISCED 2011 codes 0–2), secondary (ISCED 3–4) and higher (ISCED 5–8). Occupational class was divided into upper non-manual employees, lower non-manual employees, manual workers, employers/self-employed, and others. Household taxable income was used as our income measure and categorised into quintiles separately for men and women aged 30 and over. To adjust for household size, we divided the household income by the square root of the number of household members (OECD, 2013).

2.2. Statistical analysis

We estimated two-level Weibull survival-models, with municipal-level random intercepts and individuals nested within municipalities to assess the contribution of the municipality to the within-country variation. To examine how the variation has evolved over time, we studied mortality in 10 periods between 1972–1975 and 2016–2018. As our main summary measure of municipal-level mortality variation, we used the median hazard ratio (MHR). MHR allows one to quantify the magnitude of the general contextual effects (Austin et al., 2017). The general contextual effect is the correlation between individuals' survival within the same context, in our case municipality (Merlo et al., 2018). This is often measured using the intraclass correlation for continuous outcomes, but MHR is suitable for survival studies (see Austin et al., 2017). MHR indicates the median ratio when comparing the hazard of a randomly chosen individual from an area with higher mortality to the hazard of a randomly chosen individual from an area with lower mortality (Austin et al., 2017; Bengtsson & Dribe, 2010). The Stata 'mestreg' command was used for the estimation. We estimated 95% confidence intervals with a non-parametric bootstrap procedure accounting for clustering at municipality level with 250 iterations for all estimates mentioned in the text. We do not provide confidence intervals for all estimates as bootstrap iterations are computationally demanding with the large nested data sets we use. As our analysis is based on total population data, we trust our main results and conclusions to be robust. All analyses were carried out separately for men and women.

First, we calculated municipal-level mortality rates and descriptive statistics for age and socioeconomic characteristics for the first and last period of the follow-up. We then estimated empty models (model 0) for the first and the last period, and obtained predictions of municipality-specific effects (empirical Bayes means of random effects). These estimates are presented in caterpillar plots as hazard ratios (HR) with the average hazard over municipalities as a reference to visually examine the overall change in mortality variation between municipalities before adjusting for any individual-level variables. Second, we present MHRs for empty (model 0), and age-adjusted (model 1) models, and a model further adjusted for socioeconomic characteristics (model 2) for each of the ten periods to investigate the extent to which changes in area variation were explained by changes in municipality age and socioeconomic structures. Thereafter, to examine whether trends varied by age, we estimated MHRs separately for mortality at ages 30–49, 50–69 and 70 and over. Age was adjusted in five-year groups within these categories. We repeated these models for internal and external causes, and finally included both age and all individual socioeconomic characteristics simultaneously (model 2). In the cause specific analysis persons dying of another cause were censored at their time of death. We present MHRs by cause of death adjusted for age (model 1) and for all individual-level variables (model 2) for those aged 30–49 and 50–69 years since, as we show below, variation is highest among these categories. MHRs by cause of death from models 1 and 2 for the age category 70 and over are presented in the Appendix (Table A1).

3. Results

Descriptive statistics (Table 1) show considerable variation in the demographic and socioeconomic structure of Finnish municipalities. There are also significant changes in these underlying determinants of mortality over time. While the entire country is aging, since 1972–1975 the mean age of municipality populations has increased by more than 6 years for both men and women; the dispersion of mean ages across municipalities has also increased. Figure A1 in the Appendix shows that the aging of the population structure has been particularly pronounced in municipalities in the eastern and northern parts of the country. In contrast, the proportion of population with only basic education as well as the share of manual workers have substantially declined over time. For education, there is evidence of increased variation between municipalities, but not for the proportion of manual workers, and those with low income. Over the study period, crude mortality has decreased within each age category, whereas the proportion of deaths attributable to external causes has increased.

Fig. 1 shows predicted municipality-specific hazard ratios (HR) derived from empty models for 1972–1975 and 2016–2018. The HRs are plotted in ascending order along with 95% confidence intervals and they represent percentage deviations of each municipality relative to the predicted average hazard represented by the horizontal line at one. The overall variation in mortality across municipalities increased over time. For example, the 10th and 90th percentile values of municipality HRs (the point estimates of municipality ranks 32 and 280) in 1972–1975 were 0.86 and 1.13 among men and 0.83 and 1.19 among women, whereas in 2016–2018 the corresponding values were 0.71 and 1.33 for men and 0.70 and 1.32 for women.

While the hazard ratios of Fig. 1 show how the hazard in each municipality varied from the average hazard, in Fig. 2 the median hazard ratios (MHR) capture this variability and summarize it into one statistic, thereby permitting the observation of changes in variability over time. The MHRs estimated separately for each of the 10 periods between 1972–1975 and 2016–2018 show that the increase in mortality differentials between municipalities was in large part due to increasing differences in municipality age structures. Before adjusting for age (model 0), the MHR increased from 1.14 (95% CI 1.12–1.15) in 1972–1975 to 1.28 (CI 1.26–1.30) in 2016–2018 among men and from 1.17 (CI 1.15–1.18) to 1.30 (CI 1.27–1.32) among women, the increase being particularly pronounced from around 2000 onwards. For men, this increase implies that when comparing two random individuals from different municipalities, the one living in the municipality with higher mortality had, on average, a 14% higher hazard of dying in the early 1970s, whereas in the late 2010s this hazard had doubled to 28%. However, adjustment for age (model 1) made the upward trend disappear and MHRs fluctuated moderately at lower levels, between the extremes of 1.09 (CI 1.08–1.10) in 1972–75 and 1.11 (CI 1.10–1.12) in 2006–10 for men, and 1.06 (CI 1.05–1.07) in 1981–85 and 1.09 (CI 1.07–1.10) in 1972–75 for women. After adjusting for individual socioeconomic characteristics (model 2) the MHR values were further decreased in a similar manner throughout the entire period, but the change was relatively small, particularly among women.

Table 1
Deaths, person-years, death rates and mean rates by age category across municipalities and municipality means and standard deviations of age and socioeconomic characteristics in 1972–1975 and 2016–2018, men and women aged 30 years and over at baseline.

	1972–1975		2016–2018	
	Men	Women	Men	Women
Mortality at ages 30 years and over				
Deaths (% external)	86,263 (9.9%)	75,814 (4.1%)	79,420 (11.8%)	80,411 (5.1%)
Person-years	3,879,123	4,746,334	5,102,822	5,483,753
Death rate (per 1000)	22.2	16.0	15.6	14.7
Municipality mean (sd)	24.0 (4.1)	17.0 (3.8)	19.2 (5.2)	17.9 (5.1)
Mortality at 30–49 years				
Deaths (% external)	13,061 (32.7%)	4727 (17.9%)	3758 (50.7%)	1655 (27.6%)
Person-years	2,204,655	2,283,972	2,100,369	2,005,598
Death rate (per 1000)	5.9	2.1	1.8	0.8
Municipality mean (sd)	6.1 (2.1)	2.1 (1.1)	2.2 (2.4)	0.9 (1.3)
Mortality at 50–69 years				
Deaths (% external)	44,511 (7.5%)	26,960 (4.3%)	23,492 (19.6%)	12,176 (12.7%)
Person-years	1,422,565	1,954,507	2,171,630	2,263,803
Death rate (per 1000)	31.3	13.8	10.8	5.4
Municipality mean (sd)	31.0 (6.1)	13.6 (3.0)	11.3 (3.4)	5.5 (1.9)
Mortality at 70 years and over				
Deaths (% external)	28,691 (3.2%)	44,127 (2.5%)	52,170 (5.5%)	66,580 (3.1%)
Person-years	251,903	507,855	830,823	1,214,352
Death rate (per 1000)	113.9	86.9	62.8	54.8
Municipality mean (sd)	115.2 (19.1)	89.4 (16.5)	66.2 (12.0)	58.4 (10.4)
Age and socioeconomic characteristics, municipality mean (sd)				
Age	50.3 (1.8)	52.7 (2.1)	57.0 (2.5)	59.2 (2.8)
Proportion with basic education or less	84.5 (6.9)	85.7 (4.3)	33.7 (7.1)	31.0 (6.1)
Proportion of manual workers	30.5 (10.7)	18.9 (8.6)	19.7 (3.8)	9.0 (1.9)
Proportion in lowest income quintile	26.8 (8.9)	24.8 (5.8)	23.7 (7.1)	22.6 (5.7)

Although nearly no changes in age-adjusted mortality differentials between municipalities were observed for men and women aged 30 and over, models fitted separately for age categories (Fig. 3) showed that differentials were largest and increased most among younger men ages 30–49: MHR rose from 1.17 (CI 1.14–1.19) in 1972–75 to 1.33 (CI 1.22–1.44) in 2016–18. For men at ages 50–69, MHR also increased until the second half of the 2000s, from 1.10 (CI 1.09–1.12) in 1972–75 to 1.17 (CI 1.15–1.19) in 2006–10, but among men aged 70 years or more there were little to no changes in MHR during the study period and, overall, municipality variation was low among older men compared to younger age categories. The increase observed in younger age categories was not reflected in the overall trend shown in Fig. 2 as the high levels of mortality at older ages dominate the results for all ages. For women, patterns by age category and their trends were less clear, although there

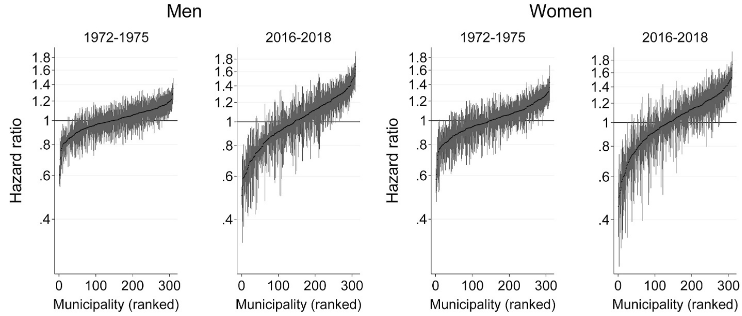

Fig. 1. Differentials in mortality across Finnish municipalities in 1972–1975 and 2016–2018 among men and women aged 30 and over, represented by municipality-specific HR and 95% confidence intervals with the reference being the average hazard of all municipalities. Notes: HRs are predicted from empty models (model 0) and y-axis is on log scale. Width of confidence intervals is inversely related to municipality size.

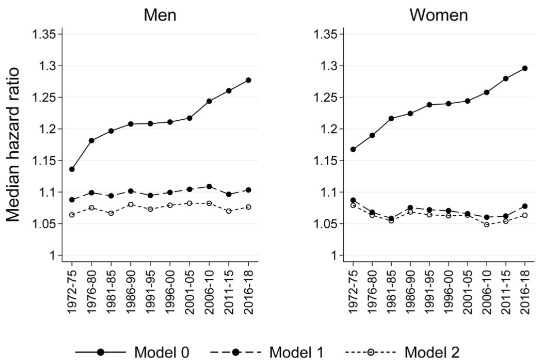

Fig. 2. Median hazard ratio (MHR) for 10 periods between 1972-1975 and 2016–2018 from empty (model 0) and age-adjusted (model 1) models, and a model adjusted for age and socioeconomic characteristics (model 2), by sex, population aged 30+.

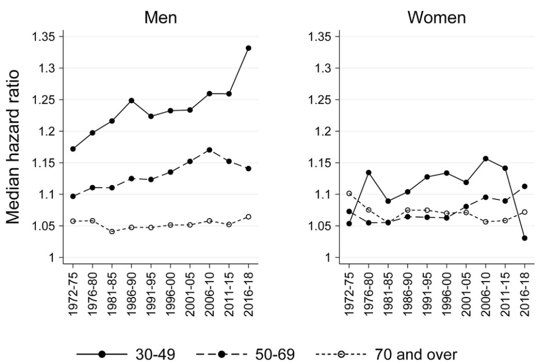

Fig. 3. Median hazard ratio (MHR) from age-adjusted models (model 1) for ten periods between 1972-1975 and 2016–2018, by age category and sex.

Table 2
Median hazard ratios (MHR) for 10 periods between 1972–1975 and 2016–2018 for all-cause, internal and external mortality, men and women aged 30–49 and 50–69 at baseline.

	Model 1			Model 2		
	All-cause	Internal	External	All-cause	Internal	External
Men						
30-49 years						
1972–1975	1.17	1.16	1.23	1.10	1.09	1.21
1976–1980	1.20	1.17	1.21	1.14	1.08	1.20
1981–1985	1.22	1.17	1.23	1.11	1.07	1.16
1986–1990	1.25	1.18	1.28	1.17	1.13	1.21
1991–1995	1.22	1.16	1.28	1.17	1.12	1.25
1996–2000	1.23	1.16	1.31	1.13	1.10	1.18
2001–2005	1.23	1.11	1.31	1.10	1.06	1.15
2006–2010	1.26	1.15	1.33	1.08	1.06	1.12
2011–2015	1.26	1.22	1.30	1.06	1.06	1.11
2016–2018	1.33	1.20	1.29	1.14	1.10	1.13
50-69 years						
1972–1975	1.10	1.10	1.13	1.07	1.07	1.15
1976–1980	1.11	1.11	1.16	1.08	1.07	1.18
1981–1985	1.11	1.10	1.20	1.08	1.06	1.22
1986–1990	1.12	1.12	1.18	1.10	1.08	1.20
1991–1995	1.12	1.12	1.20	1.09	1.09	1.21
1996–2000	1.14	1.12	1.22	1.10	1.09	1.20
2001–2005	1.15	1.13	1.26	1.10	1.09	1.19
2006–2010	1.17	1.15	1.25	1.11	1.09	1.19
2011–2015	1.15	1.14	1.21	1.09	1.07	1.17
2016–2018	1.14	1.11	1.23	1.07	1.06	1.12
Women						
30-49 years						
1972–1975	1.06	1.01	1.22	1.10	1.09	1.22
1976–1980	1.13	1.10	1.50	1.15	1.11	1.52
1981–1985	1.09	1.07	1.23	1.12	1.09	1.29
1986–1990	1.10	1.07	1.24	1.14	1.12	1.27
1991–1995	1.13	1.11	1.26	1.13	1.11	1.29
1996–2000	1.13	1.08	1.31	1.13	1.08	1.29
2001–2005	1.12	1.12	1.22	1.09	1.09	1.19
2006–2010	1.16	1.11	1.29	1.12	1.08	1.20
2011–2015	1.14	1.09	1.30	1.04	1.00	1.15
2016–2018	1.03	1.12	1.17	1.00	1.12	1.07
50-69 years						
1972–1975	1.07	1.07	1.13	1.06	1.06	1.15
1976–1980	1.05	1.06	1.17	1.07	1.06	1.20
1981–1985	1.06	1.05	1.18	1.07	1.06	1.25
1986–1990	1.06	1.06	1.24	1.07	1.07	1.29
1991–1995	1.06	1.07	1.21	1.08	1.08	1.26
1996–2000	1.06	1.06	1.20	1.08	1.08	1.24
2001–2005	1.08	1.07	1.21	1.10	1.09	1.24
2006–2010	1.10	1.08	1.26	1.10	1.09	1.27
2011–2015	1.09	1.08	1.16	1.09	1.08	1.19
2016–2018	1.11	1.11	1.17	1.07	1.08	1.12

Model 1: age. Model 2: age, education, occupational social class, and income.

was some indication of an increase since 1995 for those aged 50–69 (from 1.06 (CI 1.04–1.09) in 1996–2000 to 1.11 (CI 1.07–1.15) in 2016–18).

Table 2 shows the results from models adjusted for age and socioeconomic characteristics for ages 30–49 and 50–69 for all-cause, internal and external mortality (results for ages 70 and over shown in the Appendix Table A1). For internal causes, differentials between municipalities remained relatively stable over time for both age categories and sexes. For external causes, variation was larger than for internal causes, and increased over time, particularly among men at ages 30–49, from 1.23 (CI 1.16–1.29) in 1972–75 to 1.30 (CI 1.21–1.39) in 2011–15 and 1.29 (CI 1.09–1.50) in 2016–18.

After adjusting for individual socioeconomic characteristics, the municipal-level differences were substantially attenuated among men, for all-cause mortality and for both cause of death groups but especially for external causes in the 2000s. Among women, this adjustment did not attenuate the estimates as in the case of men, but in the last periods studied MHR also slightly decreased when socioeconomic characteristics were considered.

4. Discussion

Using individual-level data on the total Finnish population spanning nearly 50 years, we explored long-term trends in municipal-level mortality variation and the contribution of individual compositional factors. The results show a substantial increase in variation in all-cause mortality over time. However, adjustment for age revealed that virtually all the increase was accounted for by increasing differentiation in municipal age structures and, in effect, municipal-level variation in age-adjusted mortality has remained relatively stable since the 1970s. Similar results of persisting differentials between larger areas of the country have been documented in an earlier study (Wilson et al., 2020).

Despite the overall stability, age-specific results showed that at younger ages the differentials have grown wider. The greatest increases were found for men aged 30–49. At ages 70 years and older, variation remained stable throughout the period for both men and women. Adjustment for socioeconomic characteristics further reduced the mortality differentials between municipalities in all periods studied, but more so for men than for women. The attenuation was especially pronounced among men aged 30–49 from around mid-1990s onwards, suggesting that the importance of the socioeconomic population composition of municipalities in explaining within-country area variation also increased during the study period, and particularly for men.

Overall, our findings draw attention to the increased contribution of compositional factors – especially in terms of age, but also socioeconomic characteristics – in area-level mortality variation. We interpret these trends in light of the underlying macro-level developments of past decades. In Finland, recessionary periods, industrial restructuring and increasing unemployment have hit some areas harder than others and led to increasing regional differentiation with important implications for population structures at subnational levels (Grunfelder et al., 2020). Remote rural municipalities and smaller towns in particular have been losing young and working-age people moving to urban centres with better education and employment prospects. The Finnish population is among the most mobile in Europe in terms of internal migration (Grunfelder et al., 2020). Finland is also one of the fastest ageing countries (United Nations, Department of Economic and Social Affairs, Population Division, 2019), and the effects of an ageing population structure are felt especially severely in municipalities with high out-migration (Grunfelder et al., 2020; Stjernberg and Penje, 2019), developments also observed in other countries. These demographic processes are echoed in our findings – overall mortality variation between areas has increased as some municipalities are ageing faster than others due to youth out-migration – and provide support for the interpretation that the effects of restructuring have increased the importance of individual compositional factors in explaining area-level mortality variation.

Highlighting the contribution of compositional changes is important not least because composition and context operate together (Macintyre & Ellaway, 2003). Local context determines the opportunity structure available to residents (Macintyre et al., 2002), and the impact of economic restructuring may increase local disadvantage in municipalities with high out-migration (Strohmeier & Silvia, 2004). Furthermore, the consequences may be felt most acutely among certain population groups (Franklin, 2021). Younger residents in particular are exposed to limited job markets, inadequate educational opportunities and weakened social capital structure. Such effects may be reflected in adoption of risky behaviour, as our results of increased variation in external mortality suggest. Further research to identify specific area characteristics that may have contributed to these trends on the one hand, and assessment of the spatial patterning of the variation on the other, are needed to help clarify the processes at play.

The impact of migration on within-country mortality differentials has been acknowledged in many previous studies. Evidence on the direction of the impact is, however, mixed. Studies from Britain support the idea that migration accounts for a significant part of the increase in mortality differentials between areas (Brimblecombe et al., 1999; Norman et al., 2005), whereas evidence from the US in contrast suggests that differentials have been attenuated by migration (Ezzati et al., 2008). The impact of migration on shaping area mortality differentials is based on its selectivity. This selectivity has been argued to operate mainly through sociodemographic selection (Jongeneel-Grimen, Droomers, Stronks, & Kunst, 2011; Vaalavuo & Sihvola, 2021) – as the propensity to move is higher among those who are younger – but also directly through health as according to many studies those who move are healthier than those who stay (Luy & Gazelli, 2007). Previous research on regional mortality variation in Finland has consistently shown that mortality in the northern and eastern parts of the country is higher compared to regions located in southern and western Finland (Wilson et al., 2020). Our results are in line with these findings as is shown in the maps of Figure A2 in the Appendix. These maps show the spatial patterning of the municipality specific hazard ratios displayed in Fig. 1 classified into five intervals of equal length across periods and sexes. All in all, municipalities with highest hazard ratio values are mostly located in the eastern and – to a lesser extent – northern parts of the country. The maps displaying unadjusted figures clearly show the increase in the number of municipalities at the extremes of the distribution. In these maps also the main urban centres and their surrounding areas appear more clearly as areas of low mortality in the latter period, which is explained by the migration of young people to these areas.

While many previous studies provide evidence of increasing area differentials in mortality (Fenelon, 2013; Leyland, 2004; Montero-Granados et al., 2007; Mustard et al., 1999; Pearce & Dorling, 2006; Wang et al., 2013), studies reporting stagnation or declines in differentials also exist (Gächter & Theurl, 2011; Janssen et al., 2016; Skaftun et al., 2018). It is likely that the diversity arises from differences in population structures and social contexts but probably also from heterogeneity in methodological choices. Our approach draws attention to the role of changes in population composition of areas, an aspect not addressed in previous studies. We present unadjusted figures as they describe the actual challenges health care systems are facing locally and also because if we only analysed age-standardized measures important mechanisms behind regional mortality disparities and their trends would remain unacknowledged and the regional policy impact of ageing populations unrecognized. This impact is likely to be particularly challenging for the aging municipalities in terms of financing and organisation of hospital and elderly long-term care (Murphy & Martikainen, 2013).

Although in this respect our approach differs from most previous studies and making direct comparisons with existing research is therefore difficult, some interesting parallels to previous findings can be identified, in particular with regards to younger age categories. A study looking at state-level differentials in mortality in Germany between 1991 and 2015 (van Raalte et al., 2020) also found increasing variation among working-age men. Although this study did not consider causes of death, the role of health behaviour as a key driver of changes in within-country mortality variation has been observed in previous studies (Vierboom et al., 2019; Muszyńska et al., 2014). These studies have pointed out that differences and changes in smoking behaviour over time may largely explain mortality differentials between areas and their trends.

We found higher area differentials for external causes of death, and although for internal causes variation remained relatively stable over time, for external causes it grew wider. The growth was particularly evident, again, for men aged 30–49, and this was largely responsible for the increase in variation observed for all-cause male mortality in this age category. Since among women deaths due to external causes were much rarer, the modestly increasing variation in external mortality did not affect all-cause female variation, which explains the lack of similarity with the trends and age patterns observed among men. Based on previous evidence from Finland, alcohol-related mortality is known to significantly contribute to differences in all-cause mortality between different areas of the country (Mäkelä et al., 2001). Although alcohol-related deaths have a determinant role in the mortality of the working-age, particularly male, population and the adverse health effects of alcohol consumption, including mortality, have been reported to be increasing (Mäkelä, 2003) we are not aware of studies examining changes in regional variation in alcohol-related mortality over time. Our results suggest that this variation may have increased.

Key strengths of this study include the total individual-level population data, detailed municipal-level data, and the long study period covering nearly five decades. The data is based on high-quality registers that have minimal attrition and are not subject to underreporting or recall bias. These data characteristics permitted us to adopt a multilevel design and to adjust for individual-level covariates and assess their role in long-term change. We used the median hazard ratio (MHR) as our summary measure to examine changes in the magnitude of municipal level mortality variation. The advantage of using this relatively new measure is that it provides a concise measure to assess whether mortality variation across municipalities has changed over time while accounting for individual-level characteristics. A possible disadvantage is that an increasing number of outliers (e.g. single municipalities with high excess mortality) may drive changes in the overall estimate. Caterpillar plots of municipality hazard ratios predicted from models 1 and 2 however rule out this possibility as no major outliers appear between periods (see Figure A3 in the Appendix).

The choice of area unit is an issue that deserves some thought. We studied variation at the municipality level as we believe it is a valid unit of analysis when it comes to mortality since it holds administrative authority in the health sector. Additionally, it is the smallest unit available in our data, and it has been suggested that area effects vary inversely according to the size of the area – smaller areas are less heterogeneous, which increases variation between areas (Tarkiainen et al., 2010). As a sensitivity analysis, we tested whether the exclusion of the largest municipalities (pop>100,000) significantly changed the results. However, findings were similar, and we thus show results incorporating all municipalities. Furthermore, since previous results on mortality differentials in the Finnish capital region suggest that the choice of area unit does not significantly affect the estimation of area effects (Tarkiainen et al., 2010), we believe our main results are robust to the area level chosen. Nevertheless, further longitudinal studies using different area definitions are needed.

In conclusion, our results suggest that, conditional on age, overall municipal-level variation in all-cause mortality has remained relatively stable in Finland over a period of five decades. A possible explanation relates to the Finnish welfare system aiming at securing equal health and social care regardless of place of residence and policies to mitigate the consequences of economic restructuring. While these policies seem to have been successful among the elderly as increased age structure differences between municipalities and diverging health care needs and expenditures have not coincided with increased area variation in mortality in the oldest age group, the findings regarding younger men is a source of concern. Similarly, our results provided no evidence of decreasing variation, which would be ideal from an equity perspective. Moreover, there is not much reason to expect mortality differentials between areas to decrease since spatial differentiation is likely to continue as the population continues concentrating in a few growth centres. This will have important implications for future planning since policy measures and interventions need to consider how to meet the ever more divergent service needs of municipalities.

Author statement

Ulla Suulamo: Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing - Original Draft, Writing - Review & Editing, Visualization **Lasse Tarkiainen:** Conceptualization, Methodology, Software, Writing - Review & Editing **Hanna Remes:** Conceptualization, Methodology, Writing - Review & Editing **Pekka Martikainen:** Conceptualization, Methodology, Writing - Review & Editing.

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Ethical statement

The study has been approved by Statistics Finland Board of Statistical Ethics. As the data were collected for routine administrative registration purposes informed consent from participants was not required.

The manuscript is based on original research of the authors. The manuscript is not currently being considered for publication elsewhere. We confirm that the order of authors listed in the manuscript has been approved by all of us and that all authors have read and approved the final version of the manuscript.

There is no financial or other conflict of interest that might have biased our work.

Declarations of competing interest

None.

Appendix

Table A1
Median hazard ratios (MHR) for 10 periods between 1972–1975 and 2016–2018 for all-cause, internal and external mortality, men and women aged 70 and over at baseline.

	Model 1			Model 2		
	All-cause	Internal	External	All-cause	Internal	External
Men						
70 years and over						
1972–1975	1.06	1.06	1.26	1.06	1.06	1.26
1976–1980	1.06	1.06	1.12	1.06	1.06	1.14
1981–1985	1.04	1.04	1.10	1.05	1.04	1.13
1986–1990	1.05	1.04	1.14	1.05	1.05	1.15
1991–1995	1.05	1.05	1.14	1.04	1.04	1.15
1996–2000	1.05	1.05	1.16	1.05	1.05	1.18
2001–2005	1.05	1.05	1.14	1.07	1.06	1.17
2006–2010	1.06	1.06	1.13	1.06	1.06	1.15
2011–2015	1.05	1.05	1.15	1.06	1.06	1.18
2016–2018	1.06	1.06	1.09	1.06	1.05	*
Women						
70 years and over						
1972–1975	1.10	1.10	1.08	1.10	1.10	1.07
1976–1980	1.08	1.08	1.27	1.07	1.08	1.27
1981–1985	1.06	1.06	1.13	1.06	1.06	1.14
1986–1990	1.08	1.07	1.20	1.07	1.07	1.19
1991–1995	1.07	1.08	1.22	1.07	1.07	1.22
1996–2000	1.07	1.07	1.30	1.07	1.06	1.30
2001–2005	1.07	1.07	1.19	1.07	1.07	1.19
2006–2010	1.06	1.06	1.16	1.05	1.05	*
2011–2015	1.06	1.06	1.19	1.05	1.06	*
2016–2018	1.07	1.07	1.12	1.06	1.07	*

Model 1: age. Model 2: age, education, occupational social class, and income.
[*] Models failed to converge given low number of deaths.

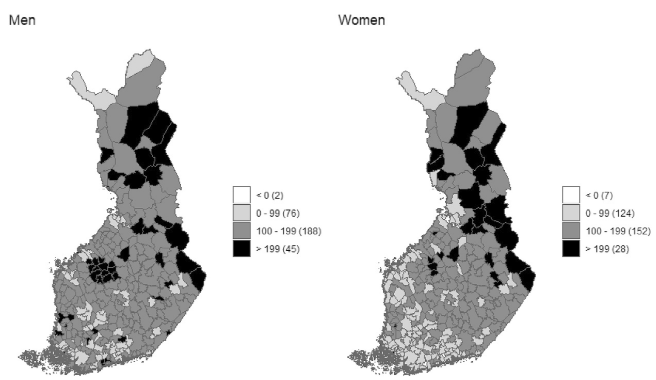

Fig. A1. Percentage change between 1972-1975 and 2016–2018 in the share of population 70 years and over, by municipality and sex.

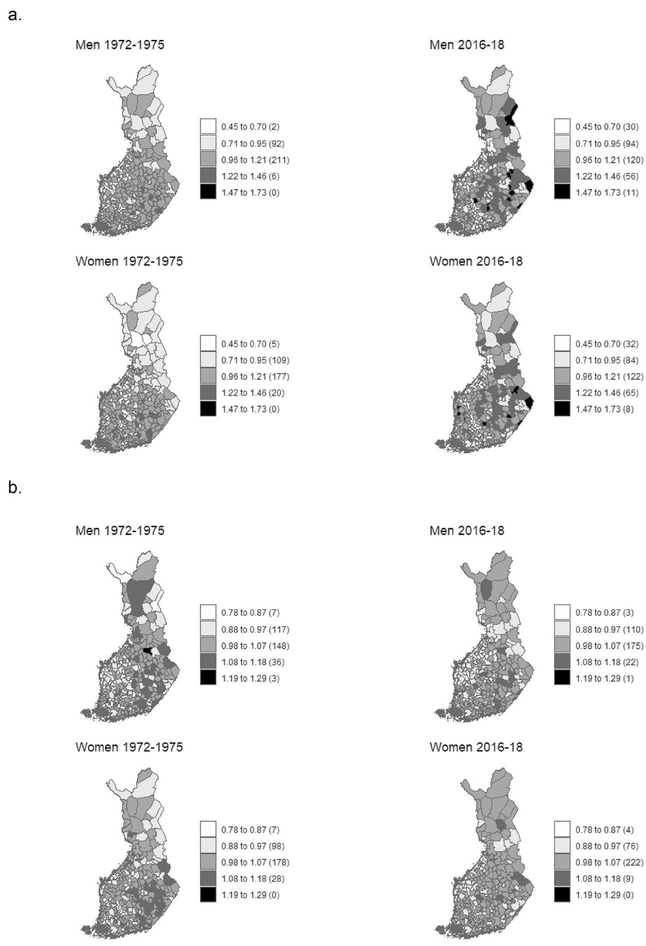

Fig. A2. Municipality specific hazard-ratios in 1972–1975 and 2016–2018 among men and women aged 30 and over. Maps in the upper panel (a) display hazard ratios predicted from unadjusted models (model 0) and maps in the lower panel (b) are from models adjusted for age and socioeconomic characteristics (model 2).

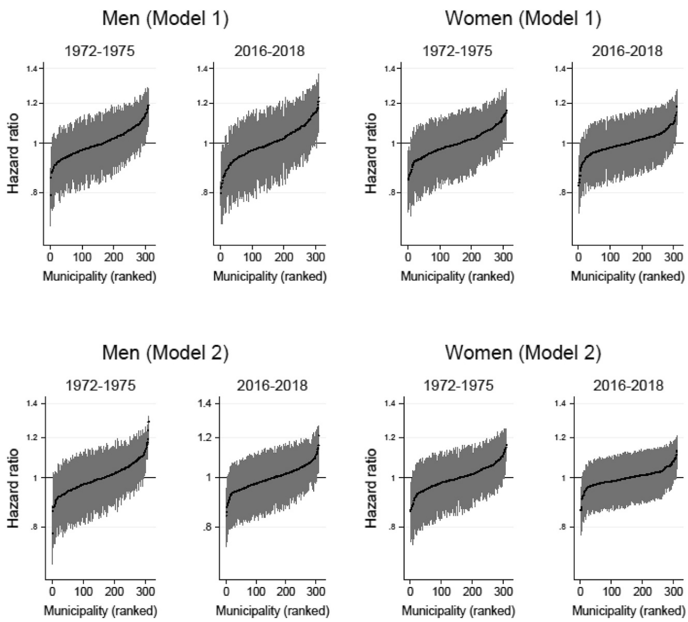

Fig. A3. Differentials in mortality across Finnish municipalities in 1972–1975 and 2016–2018 among men and women aged 30 and over, represented by municipality-specific HR and 95% confidence intervals predicted from models adjusted for age (model 1) and for age and socioeconomic characteristics (model 2).

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Long-term trends in mortality by living arrangements and the role of socioeconomic factors, Finland 1991–2020

Ulla K. Suulamo[1,2,3,*], Hanna M. Remes[1,2], Lasse H. Tarkiainen[1,2], Pekka T. Martikainen[1,2,4]

[1]Helsinki Institute for Demography and Population Health, Faculty of Social Sciences, University of Helsinki, Helsinki, Finland
[2]Max Planck—University of Helsinki Center for Social Inequalities in Population Health, Helsinki, Finland
[3]International Max Planck Research School for Population, Health and Data Science, Rostock, Germany
[4]Max Planck Institute for Demographic Research, Rostock, Germany

*Corresponding author: Helsinki Institute for Demography and Population Health, Faculty of Social Sciences, University of Helsinki, PO Box 42 (Unioninkatu 33), FIN-00014 Helsinki, Finland. E-mail: ulla.suulamo@helsinki.fi.

Abstract
Recent decades have witnessed major changes in living arrangements, potentially impacting their well-established associations with mortality. However, research considering long-term trends in these differentials is scarce. We used individual-level register data on the total Finnish population aged 30 years and over from 1991 to 2020 to examine trends in the association between living arrangements and all-cause, as well as external and alcohol-related mortality. We calculated age-standardized mortality rates, quantified group differentials in absolute and relative terms, and assessed the contribution of socioeconomic factors with Poisson-models. Analyses were conducted separately for men and women in age groups 30–49, 50–69, and 70+. All-cause mortality was consistently lowest among men and women living with a partner. Highest rates were observed in the growing group of individuals living alone or with persons other than a partner or child, who experienced up to a five-fold excess mortality compared to those living with a partner and children. Mortality declined across all living arrangement groups over time. While absolute rate differences mostly narrowed, relative differences widened across all ages. Adjustments for socioeconomic factors somewhat attenuated mortality differentials, with their contribution increasing modestly by the end of the study period. In conclusion, over the past 30 years, relative mortality differences by living arrangement have increased at all ages for both men and women. These widening differentials pose a growing public health burden, particularly for the growing group of individuals living alone. Our results suggest that factors beyond socioeconomic differentiation are contributing to these trends.

Introduction

Living arrangements are known determinants of mortality in high-income countries, with research consistently indicating those living with a partner as the most advantaged group [1–3]. However, major changes in living arrangements have unfolded over recent decades, resulting in declines in the proportion of two-parent families with children, and in more people living alone, in single-parent households, or in other less traditional settings [4–6]. This growing diversity may be reflected upon mortality disparities across different living arrangements. Yet, there has been little research considering changes in these disparities and the possible sociodemographic drivers behind them.

A long tradition of research has documented lower mortality among married individuals and those living with a partner [7–9], with associations typically more pronounced among men [1, 10, 11], in younger age groups [12], and for deaths related to behaviours, such as accidental, violent, and alcohol-related deaths [13]. It is thought that living with a partner confers health benefits through multiple protective mechanisms, including economic advantages, emotional and social support, and control of harmful behaviours [14, 15]. While these benefits are largely attributed to partnership, other social relationships within households, particularly the presence of children, may also have mortality-protective effects in the working-age population [8]. The association between living arrangements and mortality may, however, also reflect pre-existing differences among individuals selecting into specific living arrangements [16]. For instance, socioeconomic disadvantage may influence union formation [17], dissolution [18], and parenthood [19] with those living alone or with someone other than a partner more often occupying lower socioeconomic positions [20].

Recent changes in living arrangements have raised concerns about their potential health impacts, particularly due to the increasing prevalence of arrangements—such as living alone—that are associated with higher mortality and high-risk health behaviours [8, 21, 22]. While living alone is more common in high-income countries, its prevalence is rising even in regions where it remains low. In Northern America and north-western Europe, one-person households have more than doubled since the 1950s, now making up a third or more of all households [23, 24]. Whether recent changes in living arrangements have implications for how mortality differentials between them are unfolding depends on changes in the health advantages or disadvantages associated with different arrangements or on changes in how people select into them. Evidence suggests that as living arrangements have become more diverse, socioeconomic selection into living with a partner may indeed have intensified [17, 25].

Research on long-term trends in living arrangements and mortality is scarce, but there is some indication of increasing differentials between marital status groups up to the early 2000s [10, 12, 26, 27]. One possible explanation for the increase relates to compositional changes, so that living with a partner is increasingly concentrated among those with higher socioeconomic position or other personal characteristics potentially beneficial to health. While two previous studies [12, 28] have examined whether changes in socioeconomic composition explain the widening mortality gap, they have found limited support for this compositional explanation. However, these studies focused solely on differences between married and non-married individuals.

Using total population register data, we analysed mortality differentials by living arrangements among men and women aged 30 and above from 1991 to 2020. As living arrangements strongly reflect life course stages and change with age, we conducted separate analyses for three age groups: 30–49, 50–69, and 70 and over. Our study addressed two specific research questions: (i) How have mortality differentials by living arrangements changed in the last 30 years for men and women across age groups? (ii) To what extent did these changes arise from changes in the socioeconomic composition of living arrangement groups? In addition to all-cause mortality, we assessed external and alcohol-related deaths, as these behaviour-related causes tend to show particularly pronounced differences by both living arrangement and socioeconomic position and have been key contributors to trends in socioeconomic mortality disparities in Finland in recent decades [8, 13, 21, 29]. We considered both absolute and relative measures of differences, as well as overall mortality levels, to provide a comprehensive view of the trends.

Methods

Data

We used Finnish longitudinal population register data compiled at Statistics Finland (permission TK/3343/07.03.00/2023). The study population included individuals aged 30 years and over residing in Finland at the end of baseline years 1990, 1995, 2000, 2005, 2010, and 2015. These data, covering all permanent residents, and containing sociodemographic information from administrative individual-level records were further linked to dates and causes of death in 1991–2020 using personal identification numbers. We followed individuals for 5 years after each baseline year. Altogether, we observed 1 479 576 deaths (9% external and alcohol-related) over 95 842 256 person-years at risk between 1991 and 2020.

We studied all-cause mortality in age groups 30–49, 50–69, and 70 and over, as well as mortality due to external and alcohol-related causes for those under 70. Deaths were classified as external/alcohol-related if the underlying cause was alcohol-attributable disease, injury- or violence-related, or suicide (ICD–10: F10, G312, G4051, G621, G721, I426, K292, K70, K852, K860, O354, P043, Q860, V01–Y89).

We determined individuals' living arrangements using information on household size and composition. We formed six mutually exclusive groups: (1) living with a partner and child(ren), (2) with a partner, (3) with child(ren), (4) with someone other than partner or child(ren), (5) alone and (6) in an institution or unknown living arrangement. The categories 'with a partner' included both married and cohabiting couples. Cohabitation was defined as two non-married persons of different genders living together, who are not siblings, and with an age difference less than 16 years, following the definition of Statistics Finland. Same-sex couples were only classified as living with a partner if their partnership was registered (from 2002) or they were married (from 2017). The category 'with someone other than partner or child(ren)' was relatively small across all age groups, including, for example, adults living with their parent(s). Parents living with their child were classified as such regardless of the child's age or other adults than a partner living in the same household. While we focus on individuals in households, we also present results for those in institutions or with unknown living arrangements.

We explored the extent to which living arrangement differentials in mortality and their change over time was associated with socioeconomic factors. Two indicators were considered: educational attainment and occupation-based socioeconomic position. Information on education was based on the highest achieved qualification and categorized as basic/no qualifications (International Standard Classification of Education ISCED 2011 codes 0–2), secondary (ISCED 3–4), and tertiary (ISCED 5–8). Occupation-based socioeconomic position was grouped into five categories: upper-level employees, lower-level employees, manual workers, self-employed and farmers, and others/unknown. Information on retrospective socioeconomic position was used to categorize the economically inactive by previous occupation, if available. All covariates were measured at the start of each follow-up.

Statistical analysis

First, we assessed distributional changes in living arrangements by calculating population proportions in each group at the start of the six follow-up periods. We then describe age-, gender-, and living arrangement-specific mortality trends using directly age-standardized mortality rates with 95% confidence intervals (CIs) calculated for six 5-year periods between 1991 and 2020. Separate standard populations for each age group (30–49, 50–69, and 70 and over) were created by aggregating person-years by 1-year age groups across all study periods for men and women combined. From these rates, we calculated absolute differences between individuals living with a partner and children (reference) and other living arrangement groups.

We used Poisson regression to examine relative mortality differences between living arrangements, assess changes over time, and evaluate the effect of socioeconomic factors using data from 1991–95 and 2016–20. Period-specific rate ratios (RR) with 95% CIs were estimated for each living arrangement category using a model that included an interaction term between living arrangement and period. To obtain easily interpretable estimates for living arrangements for both periods, the model was run twice, each time changing the reference period. Specifically, individuals living with a partner and children were used as the reference living arrangement category, first estimating the model with 1991–95 as the reference period and then re-estimating the model again with 2016–20 as the reference. This reparameterization allowed us to estimate period-specific rate ratios while maintaining a consistent model structure for comparability. Model 1 adjusted for age in 5-year categories, while Model 2 further incorporated education and occupation-based socioeconomic position. Analyses were conducted separately for men and women. All-cause mortality was examined separately across all age groups (30–49, 50–69, and 70+), while external and alcohol-related mortality was analysed only for those under 70 due to the small number of such deaths in the oldest age group. All analyses were performed in Stata, version 17.0.

Results

Figure 1 shows that while living arrangement distributions varied by sex and age group, the main trends were consistent over time (further descriptive information on the sample in Table S1). A sustained decline was observed in the proportion of individuals living with a partner and children. However, this group remained the largest among the 30- to 49-year-olds, with at least 50% of both men and women living with a partner and children in 2015. Living with a partner increased, particularly among women, and notably at ages 70 and over. Single parenthood increased slightly to 12% among women aged 30–49 by 2015 but stayed below 2% among men. The group of individuals living with someone other than a partner or child was relatively small (<12%) and decreased over time across all age groups. Individuals in institutions or with unknown living arrangements remained stable at under 8%. Living alone increased among men, especially those under 70, while increases were more modest among women.

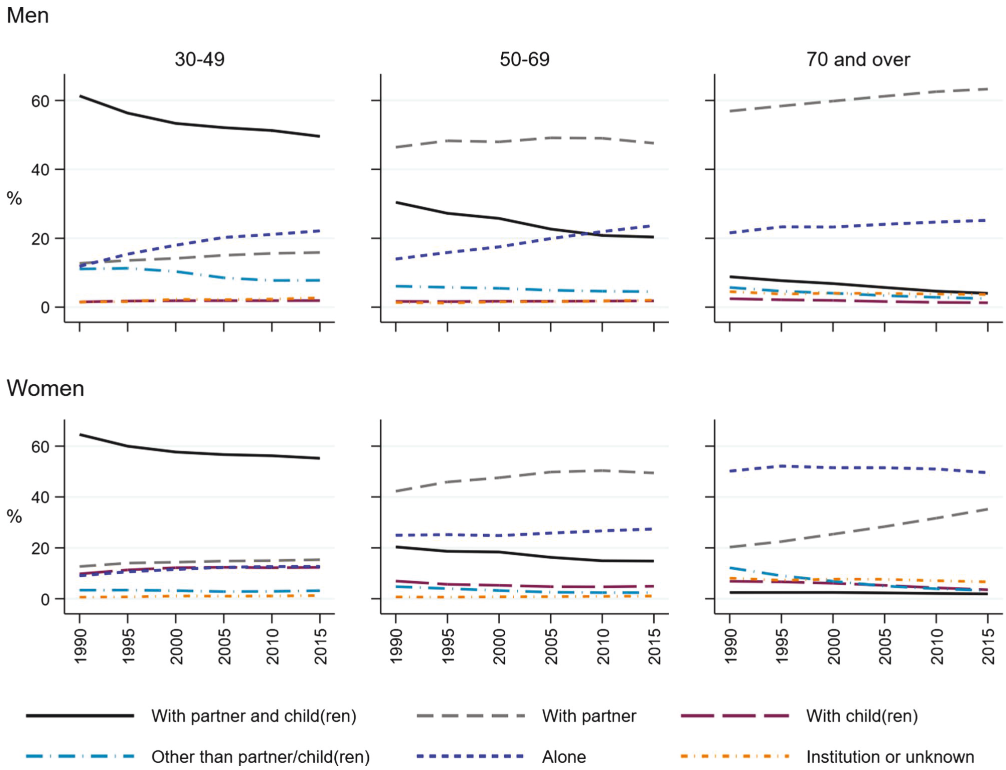

Figure 1. Proportions of population by living arrangement and age group at each baseline year between 1990 and 2015 for men and women aged 30 and over.

Mortality rates by living arrangements

Over the 30 years, mortality rates were consistently highest among those living alone or those living with others, except for women in the oldest age group, where living alone was associated with lower mortality (Fig. 2; institutions/unknown not included). Below age 70, mortality was lowest among those living with a partner and children, while for those aged 70 and above, rates were lowest among those living with a partner. At younger ages, especially among men, the absolute declines in mortality between 1991–95 and 2016–20 were larger in high-mortality groups, particularly those living alone or with someone other than a partner or children, while among older individuals, largest declines were among those living with a partner. While the absolute gap (the difference in rates) between mortality for those living with a partner and children and those in other living arrangements generally decreased between 1991–95 and 2016–20, it did not do so across all groups. For women aged 50–69 and men aged 70 and over the absolute excess mortality compared to those living with a partner and children even increased, particularly for those living alone (Table S2).

Relative differences in mortality and the role of socioeconomic factors

Those living alone or with others were lower educated and less often held upper-level employee positions than those living with a partner (Fig. 3; see Table S3 for occupation-based social position). Over time, these differences in the socioeconomic composition of the living arrangement groups remained or even widened.

Overall, adjusting for socioeconomic characteristics led to a modest attenuation of the relative excess mortality among those living alone or with others (Table 1). During 1991–95, attenuation was stronger among men. At ages 30–49, excess mortality was reduced by up to 25% after adjustment, depending on the living arrangement category. Similar attenuation was observed among 50- to 69-year-old men but not among women. In the oldest age group, where relative differences by living arrangement were less pronounced, adjusting for socioeconomic factors made little difference.

Relative mortality differentials by living arrangement widened over time. Thus, in 2016–20, rate ratios comparing the mortality of those not living with a partner and children to those who were, were higher than in 1991–95, especially at ages 50 and over (Table 1; see Table S4 for interaction terms for the change between periods). This increase in relative mortality disadvantage appeared somewhat more pronounced among women and particularly sharp for those living alone, e.g. an increase from RR 1.35 (CI 1.30, 1.41) to RR 2.12 (CI 2.00, 2.25) for women aged 50–69. In 2016–20, socioeconomic adjustments accounted for up to a third of the relative mortality differences by living arrangement, a slight increase from three decades earlier.

For external and alcohol-related mortality below age 70, age-adjusted relative differences by living arrangement were greater than those observed for all-cause mortality (Table S5). In 1991–95, the relative excess for those not living with a partner and children appeared mostly higher among men. Over time, relative differences increased in both genders, and by 2016–20, the excess in the younger age group appeared even somewhat larger among women.

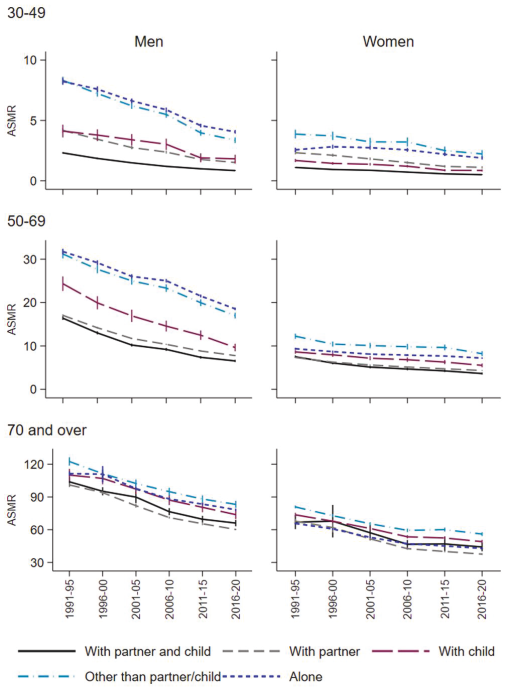

Figure 2. Directly age-standardized mortality rates (per 1000 person-years) by living arrangements, gender, age group, and period; age adjustment using person-years among men and women in the broad age group across all periods as the standard for men and women aged 30 and over.

Adjusting for socioeconomic factors reduced the excess external and alcohol-related mortality of those not living with a partner and children similarly to all-cause mortality.

Discussion

Main findings

Our findings showed declining mortality across all living arrangement groups over three decades, but persistent excess mortality among those living alone and with others than a partner. While the mortality decline differed in magnitude across sub-groups—being larger in high-mortality groups at younger ages and in low-mortality groups at older ages—the absolute gap between the mortality of individuals living with a partner and children and those in other living arrangements mostly decreased. Relative mortality differences, however, increased. Although socioeconomic adjustment attenuated mortality differentials slightly more in the more recent period, growing socioeconomic differentiation did not account for the growing relative disparities by living arrangement.

Interpretation of the results

The scarcity of long-term studies on changes in living arrangement differentials in mortality limits direct comparisons with earlier research. Nevertheless, our findings resonate with studies on mortality trends by marital status [1, 10, 12, 26, 30]. These studies, covering high-income countries from around 1950s to 2000, have shown growing relative mortality disparities between married individuals and those in non-married groups. Among them, those also considering overall mortality trends have attributed the developments to slower mortality declines, or even increases, in some of the non-married groups [12, 26]. Our findings for the recent decades showed some differences in the pace of change, but declining mortality across all living arrangement groups. The widening relative differences in mortality observed in this study, are in fact likely to

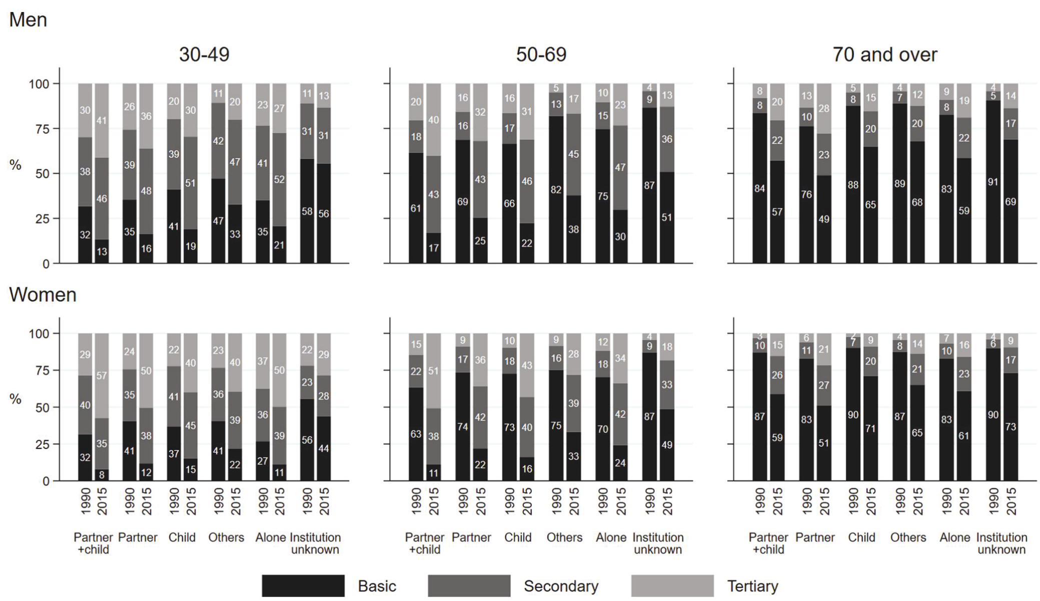

Figure 3. Educational distribution of each living arrangement category by age group in 1990 and 2015 for men and women aged 30 and over.

Table 1. Relative all-cause mortality differences by living arrangement in 1991–95 and 2016–20 by age group for men and women aged 30 and over

	1991–95[a] Model 1 RR (CI)	Model 2 RR (CI)	2016–20[a] Model 1 RR (CI)	Model 2 RR (CI)
Men				
30–49				
Partner and children	1.00	1.00	1.00	1.00
Partner	1.78 (1.69, 1.87)	1.67 (1.58, 1.76)	1.75 (1.61, 1.92)	1.62 (1.48, 1.77)
Children	1.78 (1.57, 2.01)	1.64 (1.45, 1.85)	2.12 (1.78, 2.51)	1.93 (1.62, 2.29)
Others	3.60 (3.45, 3.76)	3.02 (2.89, 3.16)	3.99 (3.66, 4.34)	3.15 (2.89, 3.43)
Alone	3.55 (3.41, 3.71)	3.25 (3.11, 3.39)	4.82 (4.53, 5.13)	4.09 (3.84, 4.35)
Institution/unknown	7.34 (6.85, 7.87)	5.76 (5.37, 6.19)	7.26 (6.58, 8.02)	5.13 (4.63, 5.67)
50–69				
Partner and children	1.00	1.00	1.00	1.00
Partner	1.13 (1.10, 1.16)	1.11 (1.08, 1.14)	1.32 (1.27, 1.37)	1.27 (1.23, 1.32)
Children	1.60 (1.49, 1.72)	1.56 (1.45, 1.67)	1.54 (1.40, 1.69)	1.47 (1.34, 1.61)
Others	2.08 (2.00, 2.16)	1.91 (1.84, 1.99)	2.87 (2.73, 3.02)	2.52 (2.39, 2.65)
Alone	2.09 (2.03, 2.15)	1.94 (1.88, 2.00)	3.12 (3.00, 3.24)	2.82 (2.71, 2.93)
Institution/unknown	4.29 (4.08, 4.52)	3.66 (3.47, 3.85)	6.67 (6.34, 7.02)	5.58 (5.30, 5.88)
70 and over				
Partner and children	1.00	1.00	1.00	1.00
Partner	0.96 (0.93, 0.99)	0.96 (0.93, 1.00)	0.92 (0.89, 0.95)	0.94 (0.90, 0.97)
Children	1.03 (0.98, 1.10)	1.03 (0.97, 1.09)	1.25 (1.18, 1.33)	1.23 (1.16, 1.31)
Others	1.14 (1.09, 1.19)	1.14 (1.09, 1.19)	1.35 (1.28, 1.42)	1.32 (1.26, 1.40)
Alone	1.06 (1.02, 1.09)	1.05 (1.02, 1.09)	1.27 (1.22, 1.32)	1.26 (1.21, 1.31)
Institution/unknown	2.18 (2.09, 2.27)	2.15 (2.06, 2.24)	3.51 (3.36, 3.66)	3.44 (3.30, 3.59)
Women				
30–49				
Partner and children	1.00	1.00	1.00	1.00
Partner	2.04 (1.90, 2.19)	1.89 (1.76, 2.03)	2.14 (1.92, 2.38)	1.97 (1.77, 2.19)
Children	1.55 (1.42, 1.70)	1.49 (1.36, 1.62)	1.68 (1.49, 1.90)	1.50 (1.32, 1.69)
Others	3.59 (3.24, 3.97)	3.22 (2.92, 3.57)	4.31 (3.70, 5.03)	3.44 (2.95, 4.02)
Alone	2.38 (2.20, 2.57)	2.44 (2.26, 2.64)	3.80 (3.45, 4.18)	3.43 (3.12, 3.77)
Institution/unknown	9.89 (8.62, 11.34)	7.74 (6.73, 8.90)	10.41 (8.93, 12.13)	7.27 (6.22, 8.50)
50–69				
Partner and children	1.00	1.00	1.00	1.00
Partner	1.05 (1.01, 1.10)	1.05 (1.01, 1.10)	1.30 (1.23, 1.38)	1.26 (1.19, 1.34)
Children	1.25 (1.17, 1.33)	1.21 (1.14, 1.28)	1.51 (1.37, 1.65)	1.44 (1.31, 1.57)
Others	1.73 (1.63, 1.84)	1.70 (1.60, 1.81)	2.47 (2.26, 2.70)	2.20 (2.01, 2.41)
Alone	1.35 (1.30, 1.41)	1.36 (1.31, 1.42)	2.12 (2.00, 2.25)	2.00 (1.89, 2.13)
Institution/unknown	6.64 (6.16, 7.16)	5.95 (5.51, 6.42)	10.17 (9.43, 10.98)	8.32 (7.70, 8.98)
70 and over				
Partner and children	1.00	1.00	1.00	1.00
Partner	1.01 (0.95, 1.06)	1.02 (0.97, 1.08)	0.86 (0.81, 0.91)	0.88 (0.83, 0.93)
Children	1.14 (1.08, 1.21)	1.15 (1.08, 1.21)	1.34 (1.26, 1.42)	1.32 (1.24, 1.40)
Others	1.27 (1.20, 1.34)	1.29 (1.22, 1.36)	1.57 (1.48, 1.66)	1.57 (1.48, 1.66)
Alone	1.03 (0.97, 1.08)	1.05 (1.00, 1.11)	1.15 (1.09, 1.21)	1.16 (1.09, 1.22)
Institution/unknown	2.34 (2.21, 2.47)	2.38 (2.25, 2.51)	3.59 (3.40, 3.80)	3.58 (3.39, 3.79)

Model 1: Adjusted for age; Model 2: Adjusted for age, educational level, and occupation-based socioeconomic position.
a: Interaction terms and confidence intervals for the change in rate ratios from 1991–95 and 2016–20 provided in Table S4.

originate in part from the general mortality decline, as relative differences are often larger at lower levels of overall mortality [31].

Lower mortality among those living with a partner has been attributed to a combination of social and health selection, as well as protective effects of health behaviours, economic advantages, and social support [7, 14, 32, 33]. In this study, adjusting for education and occupation-based social class partially attenuated mortality differences between living arrangements, confirming that these differences are partly due to individuals not living with a partner being socioeconomically disadvantaged—consistent with studies based on data from the late 1990s and early 2000s [8, 34]. Despite widening differences in the socioeconomic composition of the living arrangements, including a greater increase in higher education and upper-level occupations among those living with a partner and children, these compositional shifts were only modestly reflected in our results. While socioeconomic factors accounted for a slightly larger share of mortality differences in the more recent period, increased socioeconomic differentiation between living arrangements did not explain the widening relative mortality differences. Similar findings have been reported regarding trends in marital status differences [12, 28], but our study extends this perspective by considering living arrangements that may better reflect the everyday household environment in which people live. Given that socioeconomic factors played only a minor role, other mechanisms likely underlie the increasing disparities.

Previous studies have often reported larger and more consistent mortality differences among men [8, 34–37], commonly concluding they gain greater benefits from cohabiting with significant others. Our results support these findings, most consistently in the 50-69 age group. However, not only the presence of a partner but also that of children may have mortality protective effects among working-age adults [8, 20]. While living with children is believed to encourage healthier behaviours and reduce risky ones, especially for men [38], our findings suggest these benefits may be increasingly important for women. This is further supported by the rising excess mortality from external and alcohol-related causes among women not living with a partner and children, whereas among men, relative differences in these causes showed more modest increases. For men aged 30–49, mortality was similar whether living as a single parent or with a partner, but for women, living with a partner was linked to higher excess mortality than living with a child. This could also reflect differences in selection mechanisms into partnered parenthood, which may affect men and women differently.

Previous research has shown that relative mortality differences between living arrangement categories are greater in younger than older age groups [37]. Our results not only confirm this but also highlight that living arrangements may be becoming increasingly relevant for mortality at older ages. With the growth of the older population, this observation gains particular importance and underscores the need to better understand the impact of living arrangements for health in later life. We found the largest increases in relative mortality differences over time among those aged 70 and over. Notably, compared to men living with a partner, even absolute mortality differences widened for those living alone or with their children.

Living alone has been increasing globally. In Finland—along with other Nordic countries—where welfare state housing subsidies and societal norms such as early independence, informal partnerships, and high divorce rates favour living alone, this trend has been particularly strong, with nearly a half of all Finnish households consisting of just one person in 2023 [39]. Numerous studies have linked living alone to an increased mortality risk and other health adversities [21, 22, 40]. Our analysis showed that in the late 2010s, individuals under age 70 living alone experienced a two- to five-fold excess in mortality compared to those living with a partner and children. Moreover, this group also experienced the largest increases in relative excess mortality over three decades, despite somewhat larger absolute mortality declines among younger men. Although individuals living alone are a diverse group, our analysis indicated that they were, on average, at a disadvantage in terms of education and occupation. While this disadvantage only explained a minor part of their excess mortality, its role became more evident over time, particularly among women. Combined with evidence of a substantial double burden for those living alone with low education or low income [20], this highlights that as single-person households continue to increase, recognizing possible interactions with socioeconomic factors and other vulnerabilities (e.g. loneliness) will become increasingly important.

Findings concerning mortality among older adults living alone are mixed. This has been suggested to indicate that living alone at advanced ages may be selective for those in better health, as serious health issues for those without a partner may lead to an earlier transition to institutional living arrangements. However, selection into living alone depends on both personal and partner health. With increasing survivorship, declining sex differences in mortality, and a reduced risk of widowhood, the dynamics of who ends up living alone—and for how long—have likely changed. While excess mortality among those aged 70+ living alone was low in the 1990s, it has since increased in both men and women. This may reflect shifts in health thresholds for transitioning to institutional care, as suggested by a recent study. Finland's policy of supporting independent living for older adults for as long as possible—reflecting both cultural values of autonomy and the practical need to manage care for an ageing population—may have contributed to these changes, and thus the older adult population living alone today may include individuals in worse health compared to previous decades. Alternatively, the role of a partner in navigating increasingly fragmented health services may have become more critical over time.

Methodological considerations

The total population register data used in this study are comprehensive with virtually no loss to follow-up, providing reliable measurements of living arrangements along with demographic and socioeconomic characteristics and mortality over three decades. The reliance on register data eliminates biases typically associated with individuals' retrospective self-reports, making it a valuable resource for examining long-term trends in the association between living arrangements and mortality. While our data offer advantages, certain limitations merit attention.

To provide more streamlined insights on trends, we did not separate cohabiting and married couples. However, we acknowledge that research has shown slightly higher mortality rates among cohabiters compared to married individuals [8, 16]. Our analyses also ignored same-sex couples living in non-registered partnerships. In Finland, children in shared custody can be registered to reside at only one address. Since this is more often the mother, particularly some of the men classified as not living with children may do so part-time.

Not only partnership status and living arrangements but also transitions—particularly those due to life events such as bereavement or couple dissolution—are associated with mortality. As living arrangements diversify, so may their histories. We used a cross-sectional indicator of current living arrangement and did not cover these histories, which should be considered when interpreting our findings. This may be especially relevant for individuals living alone or with others than a partner, whose mortality disadvantage may to a larger extent reflect past experiences rather than the characteristics of their current living arrangement. Living arrangement transitions during the 5-year follow-up may introduce downward bias to our estimates. [Sensitivity analysis with a 2-year follow-up showed qualitatively similar results, though relative mortality differences were somewhat more pronounced in the youngest age group (see Table S6)].

Conclusion

Living arrangements remain significant in determining mortality outcomes across different stages of life. The advantage of living with a partner has persisted over the past three decades. Encouragingly, mortality has declined across all living arrangements, accompanied by mostly diminishing absolute mortality differentials between groups. However, relative mortality inequalities have widened, particularly affecting those living alone. This growing relative disadvantage is especially concerning as the number of one-person households continues to rise. While the role of socioeconomic factors in explaining mortality differences grew somewhat over time, other factors beyond socioeconomic differentiation appear to be contributing to the growing disparities.

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Supplementary data

Supplementary data are available at *EURPUB* online.

Conflict of interest: None declared.

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Data availability

Data may be obtained from a third party and are not publicly available. Due to data protection regulations of the register holder, the authors are unable to make the data available to third parties. In order to use the data, researchers and research institutions need to apply for a licence that authorizes its use for research purposes. Access to the data can be requested by contacting the register holder.

Key points

- Mortality declined across all living arrangement groups over three decades.
- Relative inequalities between groups widened over time, especially affecting those living alone, posing a growing public health burden as the number of one-person households rises.
- Socioeconomic factors explained only a minor part of the widening disparities in mortality between living arrangements.

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Excess winter mortality in Finland, 1971–2019: a register-based study on long-term trends and effect modification by sociodemographic characteristics and pre-existing health conditions

Ulla Suulamo ,[1,2,3] Hanna Remes,[1,2] Lasse Tarkiainen,[1,2] Michael Murphy,[4] Pekka Martikainen[1,2,5]

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For numbered affiliations see end of article.

Correspondence to
Ulla Suulamo;
ulla.suulamo@helsinki.fi

ABSTRACT

Objectives Excess winter mortality is a well-established phenomenon across the developed world. However, whether individual-level factors increase vulnerability to the effects of winter remains inadequately examined. Our aim was to assess long-term trends in excess winter mortality in Finland and estimate the modifying effect of sociodemographic and health characteristics on the risk of winter death.

Design Nationwide register study.

Setting Finland.

Participants Population aged 60 years and over, resident in Finland, 1971–2019.

Outcome measures Age-adjusted winter and non-winter death rates, and winter-to-non-winter rate ratios and relative risks (multiplicative interaction effects between winter and modifying characteristics).

Results We found a decreasing trend in the relative winter excess mortality over five decades and a drop in the series around 2000. During 2000–2019, winter mortality rates for men and women were 11% and 14% higher than expected based on non-winter rates. The relative risk of winter death increased with age but did not vary by income. Compared with those living with at least one other person, individuals in institutions had a higher relative risk (1.07, 95% CI 1.05 to 1.08). Most pre-existing health conditions did not predict winter death, but persons with dementia emerged at greater relative risk (1.06, 95% CI 1.04 to 1.07).

Conclusions Although winter mortality seems to affect frail people more strongly—those of advanced age, living in institutions and with dementia—there is an increased risk even beyond the more vulnerable groups. Protection of high-risk groups should be complemented with population-level preventive measures.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ We used high-quality, individual-level register data spanning nearly 50 years with minimal attrition and no recall bias.
- ⇒ The use of register data allowed us to examine risk factors at the individual level.
- ⇒ We used data on healthcare visits and reimbursement for medicine costs to examine whether those with pre-existing health conditions are particularly vulnerable.
- ⇒ Using only the underlying cause of death may underestimate the total impact of respiratory infections and influenza-like illnesses on excess winter mortality.

INTRODUCTION

In temperate climates, mortality rates tend to be higher in winter compared with other times of the year. Although studies on long-term trends indicate that this winter excess has weakened over time,[1–4] it remains a significant public health burden in many high-income countries, with winter increases in deaths of up to 28%.[5] This burden—likely driven both by the direct effects of winter conditions on the most frail individuals, as well as increased seasonal pressure on the healthcare system and knock-on effects on other patients—may grow even greater in ageing populations, considering that the risk of winter death increases with age and is highest among the oldest old.[6 7]

The increased risk of dying in winter is attributed to multiple factors, most importantly influenza-like communicable illnesses[8 9] and low temperatures.[10] Consistent with these proximate risk factors, a winter peak in mortality is apparent for most major causes of death, but the largest seasonal fluctuations are seen for circulatory and respiratory diseases.[11] While such external effects drive the overall seasonal pattern, several non-seasonal risk factors have been found to importantly modify an individual's vulnerability to the effects of winter. Previous evidence is clear in relation to age:

excess winter mortality especially affects older people, gradually increasing with age.[12] Besides age, factors such as low income, inadequate housing conditions and fuel poverty[13] have been associated with increased adverse health outcomes in winter, especially in countries with thermally inefficient housing stocks such as Portugal[14] and the UK.[15] Although based on limited evidence, living arrangements are another potentially important factor in differential mortality, and some previous findings suggest a higher risk of excess winter mortality for those living alone[12] or in institutions.[16–18]

The importance of non-seasonal risk factors is further demonstrated by cross-country comparisons, which suggest that absolute winter temperatures matter little, as countries with milder winters generally experience much greater wintertime excess than countries with colder climates.[5 19] These somewhat counterintuitive findings have led investigators to suggest that populations' ability to protect themselves is what ultimately determines the extent of winter mortality,[20] and indicate that winter excess deaths are, to an important degree, preventable.[5 7 21]

Despite the avoidable character of a substantial fraction of excess winter mortality, uncertainty still exists whether the winter excess mainly affects frail individuals who are at greater risk of dying soon in any case. Those with pre-existing health conditions are often considered particularly vulnerable, but empirical evidence to confirm this remains scarce. One previous study[22] assessing the determinants of vulnerability to excess winter mortality found evidence for an increased risk of winter death only for those with a history of respiratory illness but not for those with other health conditions. Addressing whether excess winter mortality mainly affects the frail remains thus an important area of further inquiry with potentially important policy implications: identifying those most affected may help evaluate how preventable these excess deaths are and guide the development of targeted prevention measures.

In international comparison, northern European countries with relatively cold winters show lower levels of excess winter mortality which has been interpreted to arise from a combination of socioeconomic, housing and behavioural factors.[19] Despite lower levels of excess, the winter period is nevertheless acknowledged to pose a range of health challenges,[23] and population ageing makes it likely that these challenges will become more pressing. Little is, however, known about how excess winter mortality differs by individual-level social and health characteristics in a societal context with high-quality housing at all income levels and universal access to healthcare services. Using individual-level data on the total population, we examined long-term trends in excess winter mortality in Finland at ages 60 and above in 1971–2019 and assessed differences in the winter excess by cause of death and the modifying effect of sociodemographic characteristics and pre-existing health conditions in 2000–2019.

METHODS

Data

The study was based on individual-level data for the total population of Finland from August 1971 to July 2019. These data were drawn from censuses and population registers that Statistics Finland had linked to cause-of-death records and healthcare registers using personal identification numbers. For 1971–1987, sociodemographic information was obtained from the end-of-year census records (1970/1975/1980/1985) and from the year 1988 onwards from the end-of-year population records. We restricted the analysis to individuals aged 60 years and over at the end of each year from 1971 to 2018.

We defined winter as December–March following previous studies in the northern hemisphere.[13] These months also meet the definition of thermal winter in Finland with daily mean temperatures below 0°C (32°F). On average, in central and southern Finland, where most of the population resides, thermal winter begins around late November and ends in late March. Non-winter months were defined as the 4 months on each side of this winter period (August–November, April–July). Following this definition, our study period to analyse trends over time ran from August 1971 to July 2019, 48 years in total. For each year, we followed mortality from the beginning of August to the end of July next year.

For the more recent 19-year period August 2000–July 2019, we assessed whether and how excess winter mortality was modified by sex, age, living arrangement, income, region and pre-existing health conditions. Age was categorised into groups 60–69, 70–79, 80–89 and 90 years and over. Living arrangement distinguished between those living in households with at least one other person, alone or in institutions. Household disposable income was categorised into quartiles in the population aged 60 and over and adjusted for the household composition.[24] For persons living in institutions, we used personal disposable income. Information on region of residence (n=19) was aggregated into four larger regions (coastal, southern, central and northern) according to average winter temperatures. Living arrangement, income and region were measured at the end of the preceding calendar year, whereas age corresponded to attained age in July of each year.

We used 11 dichotomous indicators of pre-existing health conditions: dementia, mental disorders, cancer, diseases of the nervous system, diabetes, diseases of the circulatory system, diseases of the respiratory system, alcohol-related causes, injuries due to accidents and violence, other health conditions and an overall measure of any health condition. These conditions were identified from two sources covering the years 1999–2017: the healthcare register of the Finnish Institute for Health and Welfare and the medication reimbursement register of the Social Insurance Institution of Finland. We included data on inpatient and specialised outpatient care episodes that occurred during the preceding calendar year (at least 7 months before the start of mortality follow-up) and for which any of the aforementioned conditions were recorded as the primary discharge diagnoses. The health conditions were classified based on the International Classification of Diseases (ICD) 10th Revision. Information on the right to special reimbursement for medicine costs due to diagnosed chronic medical conditions during the preceding calendar year was collected from the medication reimbursement register of the Social Insurance Institution of Finland following their disease and medication classification. For exact coding of care episodes and reimbursement categories, see online supplemental table S1. A pre-existing health condition was considered present if there was a record in either of the two registers and each individual could contribute to several categories.

In addition to all-cause mortality, we assessed winter excess mortality separately for deaths due to diseases of the circulatory system (ICD-10 codes I00–I425, I427–I99), diseases of the respiratory system (J00–J64, J66–J99), dementia (F01, F03, G30, R54), other internal causes and external causes (V01–X44, X46–Y89). The coding of causes of death was based on Statistics Finland's cause of death classification, which is harmonised across different revisions of the ICD.

Patient and public involvement

All data were collected for routine administrative purposes and, therefore, public involvement was not feasible.

Statistical analysis

To obtain person-days at risk for each winter and non-winter period, we created an expanded dataset by splitting each year on 1 April and 1 December. Deaths were allocated to the appropriate winter and non-winter periods using exact dates of death.

To assess trends over time, we collapsed the expanded dataset by summing the death and person-time counts over sex, age, year, and winter and non-winter periods. We then calculated and plotted age-adjusted annual winter and non-winter death rates with 95% CIs in 1971–2019 using the age structure of the entire period as the standard population. Both absolute and relative differences between winter and non-winter rates were computed. To identify shifts in the trends, we explored the presence and location of breakpoints in the series of absolute and relative differences. We applied segmented linear regression analysis with one break on the cumulative values using the 'segmented' package[25] in R software V.4.2.2 (R Core Team).

To study the extent to which individual characteristics modified the risk of excess winter mortality, we focused on the more recent period from August 2000 to July 2019. We assessed effect modification using Poisson regression with interactions between the winter indicator and the covariates. These interaction effects, interpreted as relative risks, show how the effect of winter varies in multiplicative terms between different categories of modifying factors and the baseline reference group. Each potential effect modifier was studied separately, adjusting the

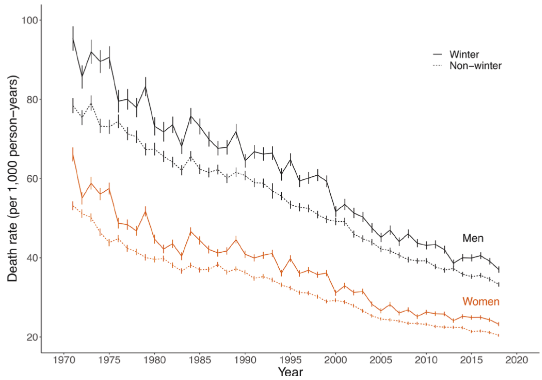

Figure 1 All-cause winter and non-winter mortality rates, Finland 1971–2019, men and women aged 60 and over.

models for all the other covariates. To address potential issues of overdispersion in the Poisson regression models, robust, clustered SEs were employed, with each cluster defined as an individual.

RESULTS

Over the study period from August 1971 to July 2019, 1 902 824 deaths were recorded, of which 36% occurred during winter.

The age-adjusted winter death rate fell from 95 deaths per 1000 person-years among men and 66 among women in 1971 to 37 and 23 in 2018, respectively (figure 1). The non-winter death rate was consistently below that of winter throughout the observation period and decreased from 78 to 33 among men and from 53 to 20 among women.

Absolute and relative differences between winter and non-winter mortality (figure 2) showed considerable year-to-year fluctuations. Overall, mortality declined over

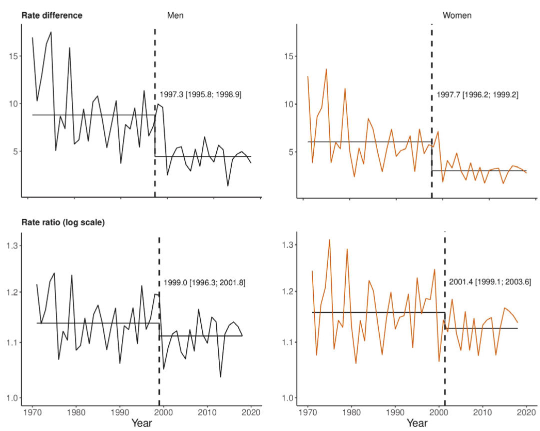

Figure 2 Rate differences and rate ratios of winter and non-winter mortality rates with detected breakpoints (vertical dashed lines) and their 95% CIs, Finland 1971–2019, men and women aged 60 and over.

time, as did the absolute difference between winter and non-winter mortality rates—from an average of around 15 deaths per 1000 person-years to below five. Relative differences fluctuated between a winter excess of 31% (women year 1975) and only 4% (men year 2013), showing a clear downward trend. Changes in absolute differences for women were somewhat smaller than for men, and vice versa for relative differences, but peaks and troughs occurred in the same years for both sexes.

The values of both absolute and relative differences oscillated at lower levels towards the end of the study period, and the year-to-year variation became less pronounced. A breakpoint analysis indicated a change in the series around the year 2000 for both absolute and relative differences. The drop in the mean rate difference after the estimated break was nearly 50%, whereas for rate ratios (RRs), the drop was smaller.

Descriptive information about the study population at the end of the more recent period 2000–2019 shows population ageing and an increasing share of men (table 1). Most health conditions have become more common, except diseases of the circulatory system. The percentage of individuals recorded with dementia increased from 1.4% to 3.7%, reflecting the ageing population. However, the proportion with any recorded health condition during the previous calendar year remained at two-thirds. Living arrangements were stable, with around 3% living in institutions, one-third alone, and the rest with at least one other person.

In 2000–2019, all-cause mortality during winter occurred at an age-adjusted and sex-adjusted rate of 49.5 per 1000 person-years among men, and 31.4 per 1000 person-years among women, which was 11% and 14% higher than in the non-winter period, respectively (table 2). The winter excess varied by cause of death. It was observed for all cause of death groups, except for external causes among men, and was strongest for respiratory disease deaths. For both men and women, more deaths due to a respiratory cause occurred during the winter period (26% and 40% excess, respectively) than expected based on the non-winter average. Those who died from dementia showed the second-highest winter excess (men 21%, women 22%), exceeding that of circulatory disease deaths (men 13%, women 14%).

Table 3 shows age-adjusted winter and non-winter death rates and the winter/non-winter RRs for different categories of potential effect modifiers, adjusted for the other sociodemographic characteristics. For the winter/non-winter RRs, we also show the multiplicative interaction effects for each covariate, that is, the effect of winter relative to the ratio of the baseline reference group. The adjusted risk of dying in winter was slightly higher for women (1.14) than men (1.11), translating to a relative excess winter mortality that was 1.03 times higher among women than men (RR 1.03, 95% CI 1.02 to 1.04). The differences were clear between age groups with the most notable winter effects among the oldest-old, but there was no evidence that the risk of excess winter mortality varied by income and only weak evidence of differences between regions. The risk of dying in winter was relatively higher for persons living in institutions (RR 1.07, 95% CI 1.05 to 1.08), but those who lived alone did not differ much from those living with at least one other person. Overall, simultaneous adjustment for all covariates had very minor

Table 1 Changes in sociodemographic characteristics and pre-existing health conditions between 2000/2001 and 2018/2019, population aged 60 and over

	2000/2001 (%)	2018/2019 (%)
Sociodemographic characteristics		
Mean age (SD)	71.2 (8.1)	71.6 (8.4)
Sex		
Men	40.8	45.0
Women	59.2	55.0
Age category		
60–69	47.2	46.8
70–79	35.9	34.0
80–89	14.7	15.9
90 and over	2.1	3.2
Income quartile		
1 (lowest)	25.0	25.0
2	25.0	25.0
3	25.0	25.0
4 (highest)	25.0	25.0
Living arrangement		
Household of >1	63.3	63.2
Alone	33.4	33.8
Institution	3.3	3.0
Large regions		
Coast	36.4	38.7
South	29.0	27.8
Centre	19.2	17.9
North	15.5	15.6
Pre-existing health conditions		
Dementia	1.4	3.7
Mental health disorders	3.7	3.8
Cancer	4.3	7.5
Diseases of the nervous system	4.4	6.7
Diabetes	7.4	15.0
Diseases of the circulatory system	44.4	35.5
Diseases of the respiratory system	9.4	11.4
Alcohol-related causes	0.3	0.5
Accidents and violence	4.4	6.4
Other than specified above	27.8	33.4
Any health condition	65.9	67.2
Total	100.0	100.0
N	1 035 643	1 559 165

Table 2 Age-adjusted and sex-adjusted death rates in winter and non-winter periods and rate ratios, by cause of death and sex

	Men				Women			
		Rate per 1000 person years				Rate per 1000 person years		
	Deaths	Winter	Non-winter	Winter-non-winter rate ratio	Deaths	Winter	Non-winter	Winter-non-winter rate ratio
Circulatory	160087	21.7	19.3	1.13 (1.12, 1.14)	190933	13.5	11.8	1.14 (1.13, 1.15)
Respiratory	24943	3.5	2.8	1.26 (1.23, 1.30)	18236	1.5	1.1	1.40 (1.35, 1.44)
Dementia	36659	6.0	4.9	1.21 (1.18, 1.24)	82108	5.7	4.7	1.22 (1.20, 1.24)
Other internal	132285	14.9	14.3	1.04 (1.03, 1.06)	131892	9.4	8.9	1.06 (1.05, 1.07)
External	30191	3.3	3.2	1.01 (0.99, 1.04)	17590	1.3	1.2	1.06 (1.03, 1.10)
All causes	384165	49.5	44.8	1.11 (1.10, 1.11)	440759	31.4	27.6	1.14 (1.13, 1.14)

Finland 2000–2019, aged 60 and over.

effects on the results (results from unadjusted models not shown).

All analysed categories of pre-existing health conditions were associated with higher risk of death during both winter and non-winter periods. However, the multiplicative interaction effects of winter remained modest for nearly all health conditions. The most substantial excess mortality in winter was found for persons with a history of dementia with an adjusted winter/non-winter RR of 1.17 (95% CI 1.16 to 1.19) and a winter effect that was 1.06 times higher than among those without dementia (RR 1.06, 95% CI 1.04 to 1.07). Other categories of health conditions that seemed to slightly increase the risk of dying in winter included diseases of the respiratory system (RR 1.02, 95% CI 1.01 to 1.03) and mental disorders (RR 1.02, 95% CI 1.00 to 1.04). For alcohol-related causes and those with cancer, the effect was the other way around with relative risks of 0.93 (95% CI 0.89 to 0.98) and 0.93 (95% CI 0.92, 0.94), respectively.

Additional age-category-specific results (online supplemental tables S2 and S3) showed that while excess winter mortality increased with age, indications of effect modification by the analysed sociodemographic and health characteristics were mostly similar. Differences in the effect of winter were, however, more apparent among the younger age categories, whereas among 90 years, no effect modification was observed.

DISCUSSION

Main findings

With individual-level total population data covering nearly half a century, we examined long-term trends in excess winter mortality in Finland and assessed how individual-level characteristics may modify the risk of dying in winter. We showed that both winter and non-winter death rates steadily declined in 1971–2019, but winter rates remained above non-winter rates through the period. All-cause mortality was 11% and 14% higher during winter compared with non-winter months in 2000–2019 for men and women, respectively, with the highest excess in respiratory and dementia-related causes of death. We found modest effect modification by sociodemographic characteristics and pre-existing health conditions. Advanced age, living in institutions and dementia increased the risk of winter mortality, while income level and most health conditions made no difference.

Interpretation of the results

Previous research has documented downward trends in excess winter mortality during most of the 20th century.[2 3 26 27] The declining trend has been attributed to general socioeconomic progress, improved housing conditions and healthcare systems. According to previous research, differences between winter and summer mortality started to decline relatively early in Finland, in the 1930s,[28] and a slowly decreasing trend was also reported during the latter part of the century, until 1995.[29] Although not directly comparable to ours because of different definition of the winter excess (deaths in September–March compared with the month of lowest mortality) and age ranges considered, these previous results do align with our findings. In addition, with our results extending over 20 years further, we report a clear attenuation in the year-to-year variability during the last two decades and a downturn in the RRs around the year 2000.

Influenza-like illnesses are an important contributor to excess winter mortality, some studies showing that it is especially these—and not cold severity—that nowadays explains the year-to-year variations in the winter excess.[30 31] There are at least two influenza-related factors that may have contributed to the smaller winter mortality fluctuations observed towards the end of the study period. During the first decade of the 21st century, seasonal influenza activity and related mortality were relatively low compared with previous decades.[32] Also, since 2002, influenza vaccines have been administered as part of the national vaccination programme in Finland for all those aged 65 years and older. Vaccination is considered the best available intervention to prevent influenza illness, and some previous studies have reported that

Table 3 Death rates in winter and non-winter periods, rate ratios and relative risks of excess winter mortality by individual characteristics

	Age adjusted rate per 1000 person years			
	Winter (n=295 236)	Non-winter (n=529 688)	Full adjusted winter-non-winter rate ratio (95% CI)*	Full adjusted relative risk (RR) (95% CI)*†
Sociodemographic characteristics				
All	37.8	33.7	1.12 (1.12 to 1.13)	
Sex				
Men	49.5	44.8	1.11 (1.10 to 1.11)	1.00
Women	31.4	27.6	1.14 (1.13 to 1.14)	**1.03 (1.02 to 1.04)**
Age category				
60–69	11.9	11.2	1.06 (1.05 to 1.07)	1.00
70–79	30.7	27.9	1.10 (1.09 to 1.11)	**1.04 (1.02 to 1.05)**
80–89	94.6	83.2	1.14 (1.13 to 1.15)	**1.07 (1.06 to 1.09)**
90 and over	269.8	228.0	1.19 (1.17 to 1.20)	**1.12 (1.10 to 1.13)**
Income quartile				
1 (lowest)	41.5	37.2	1.12 (1.11 to 1.13)	1.00
2	38.5	34.3	1.12 (1.11 to 1.13)	1.00 (0.99 to 1.02)
3	37.9	33.7	1.12 (1.11 to 1.13)	1.01 (0.99 to 1.02)
4 (highest)	32.9	29.2	1.13 (1.11 to 1.14)	1.01 (0.99 to 1.02)
Living arrangement				
Household of >1	31.0	28.0	1.10 (1.10 to 1.11)	1.00
Alone	34.3	30.6	1.12 (1.11 to 1.13)	**1.01 (1.00 to 1.02)**
Institution	110.1	93.6	1.18 (1.16 to 1.19)	**1.07 (1.05 to 1.08)**
Region				
Coast	36.8	33.1	1.11 (1.10 to 1.12)	1.00
South	37.5	33.2	1.13 (1.12 to 1.14)	**1.02 (1.00 to 1.03)**
Centre	38.9	34.8	1.12 (1.11 to 1.13)	1.01 (0.99 to 1.02)
North	39.3	34.7	1.13 (1.12 to 1.15)	**1.02 (1.01 to 1.03)**
Pre-existing health conditions				
Dementia				
No	34.0	30.6	1.11 (1.11 to 1.12)	1.00
Yes	78.9	67.2	1.17 (1.16 to 1.19)	**1.06 (1.04 to 1.07)**
Mental health disorders				
No	36.5	32.6	1.12 (1.12 to 1.13)	1.00
Yes	69.6	60.9	1.14 (1.12 to 1.16)	**1.02 (1.00 to 1.04)**
Cancer				
No	34.9	30.7	1.14 (1.13 to 1.14)	1.00
Yes	74.1	70.4	1.05 (1.04 to 1.07)	**0.93 (0.92 to 0.94)**
Diseases of the nervous system				
No	36.1	32.2	1.12 (1.12 to 1.13)	1.00
Yes	65.6	58.7	1.12 (1.10 to 1.13)	0.99 (0.98 to 1.01)
Diabetes				
No	35.2	31.4	1.12 (1.12 to 1.13)	1.00
Yes	57.0	50.5	1.13 (1.12 to 1.14)	1.01 (1.00 to 1.02)
Circulatory				
No	29.9	26.8	1.12 (1.11 to 1.13)	1.00

Continued

Table 3 Continued

	Age adjusted rate per 1000 person years			
	Winter (n=295 236)	Non-winter (n=529 688)	Full adjusted winter-non-winter rate ratio (95% CI)*	Full adjusted relative risk (RR) (95% CI)*†
Yes	45.5	40.4	1.13 (1.12 to 1.13)	1.01 (1.00 to 1.02)
Respiratory				
No	34.7	31.0	1.12 (1.11 to 1.12)	1.00
Yes	61.2	53.6	1.14 (1.13 to 1.15)	**1.02 (1.01 to 1.03)**
Alcohol related				
No	37.5	33.4	1.12 (1.12 to 1.13)	1.00
Yes	169.7	161.8	1.05 (1.00 to 1.10)	**0.93 (0.89 to 0.98)**
Accidents and violence				
No	36.4	32.5	1.12 (1.12 to 1.13)	1.00
Yes	56.0	49.7	1.13 (1.11 to 1.14)	1.00 (0.99 to 1.02)
Other than specified above				
No	34.1	30.1	1.13 (1.13 to 1.14)	1.00
Yes	44.2	39.9	1.11 (1.10 to 1.12)	**0.98 (0.97 to 0.99)**
Any health condition				
No	19.2	17.2	1.12 (1.11 to 1.13)	1.00
Yes	43.7	38.9	1.12 (1.12 to 1.13)	1.00 (0.99 to 1.02)

Finland 2000–2019, men and women aged 60 and over.
Bold values indicate estimates with 95% CIs that do not contain 1.
*Models are adjusted for sex, age, income, living arrangement, region and year.
†RRs in the last column are the interaction terms of the winter indicator and the effect modifier. These show the relative differences in the effect of winter on mortality between effect modifier categories.

the influenza vaccine significantly reduces mortality.[33 34] Although more research is needed as the mortality benefits of influenza vaccine, especially among the older population, have been questioned,[35 36] our results are consistent with the idea that both lower influenza activity of recent decades and the introduction of vaccinations may have reduced excess winter mortality peaks.

Age is known to play an important role for excess winter mortality,[12 37] and of all the individual-level effect modifiers included in our analysis, older age showed the strongest and clearest influence. The increasing risk with age is commonly interpreted as a reflection of increasing frailty and vulnerability towards adverse environmental stresses as age advances.[38] Accordingly, we found that persons living in institutions were likelier to die in winter. As previous studies with similar findings from France,[16] Netherlands[17] and England and Wales[18] note, those living in institutions are rarely exposed to outside weather and cold. However, they are likely to spend more time indoors within confined environments, which may increase the spread of infections.[39] Furthermore, the prevalence of frailty is considerably high among older adults living in residential care,[40] indicating their increased risk of mortality and vulnerability to external stressors.[41]

Apart from frailty associated with advanced age, it is generally assumed that excess winter mortality most importantly affects persons with pre-existing health conditions. Nevertheless, previous literature approaching the topic by including information about the prior health of those dying in winter is scarce. In general, our findings showed very weak or no evidence for increased risk for dying in winter among those with pre-existing conditions. Only persons with dementia emerged as being at greater risk, a finding in line with few previous studies. Our results concerning dementia mortality also support these findings, as those who died from dementia showed the second-highest winter excess of around 21%. Previously, Liddell *et al*[42] have also reported almost a third more dementia deaths in winter compared with non-winter times in the UK. While a tendency to attribute deaths to the underlying chronic condition instead of a respiratory infection could explain some of the excesses, another possible interpretation is that those with dementia have difficulties in communicating changes in their health status to relatives and care staff. In a study on susceptibility to cold, Zanobetti *et al*[43] found that in the USA, persons with previous admission for dementia were at greater risk of dying on extremely cold days and it has been speculated that this may relate to reduced perception of and protection from cold.[44] Living in institutions, as discussed above, has also been suggested to play a role. A recent study[45] on COVID-19 pandemic-related excess mortality in the UK proposed that the highest relative increases of death for individuals with dementia may be attributed to higher exposure to seasonal respiratory viruses due to their more frequent residency in institutional settings. However, supplementary analyses (online supplemental table S4) in this study showed that effect modification of winter mortality by age or pre-existing diagnosis of dementia was in fact modest or non-existent among those living in institutions. These findings suggest that the elevated excess winter mortality in individuals with pre-existing dementia cannot be solely attributed to institutional living.

The risk of dying in winter was not significantly increased for those with other pre-existing health conditions. Not even those with respiratory or circulatory conditions seemed significantly more vulnerable, although persons with these conditions are traditionally assumed to face a particularly high risk of death in winter. This common assumption may partly arise from considering stated causes of death on the death certificate as evidence of pre-existing conditions and thus interpreting the findings that show high excess winter mortality for cardiovascular and respiratory causes as an indication that individuals with pre-existing cardiovascular or respiratory disease are more susceptible to the adverse effects of winter. We also found the highest excess winter mortality in deaths due to diseases of the respiratory system and a somewhat lesser excess risk in deaths due to circulatory diseases, but a similar excess risk did not apply to people diagnosed with these conditions in the preceding year. Previous evidence on the effect of pre-existing health conditions—primarily based on studies on cold-related mortality and not on excess winter mortality specifically—is conflicting. For example, while Wilkinson *et al*[22] found that pre-existing respiratory disease increased the risk of a winter death, and Schwartz[46] reported elevated risks on cold days for persons with chronic obstructive pulmonary disease, other empirical studies have found no higher risks than average[47] and even lower than average risks have been reported.[43] Similarly, for cardiovascular conditions, there is some evidence both for[48 49] and against[46 50 51] an increased risk of winter death. One possible explanation for not detecting higher risks for most of the pre-existing health conditions may be that persons with a diagnosis and previous healthcare contacts are the ones who receive the most benefit from preventive measures. If true, this suggests potential for prevention among the apparently healthy population.

While there is a well-known link between socioeconomic position and overall mortality,[52] we found no evidence to suggest a socioeconomic gradient in vulnerability to excess winter mortality when measured by income. Instead, the increase in mortality in winter was similar in all income categories. Previous studies regarding the association between socioeconomic factors and excess winter mortality have provided conflicting results.[13] Hales *et al*,[53] for example, found that the risk of winter death in New Zealand was higher for those in the lowest income tertile compared with those in the highest tertile. Many of the proposed mechanisms through which lower socioeconomic position and income may increase the risk of winter death are linked to housing conditions and factors such as central heating and fuel poverty.[13] However, it has also been noted that low socioeconomic position does not always go hand in hand with the poorest quality housing, as in some countries, or example, the UK, social housing may even have better than average energy efficiency characteristics.[22] In Finland, housing is generally of high quality, and conditions are relatively good at all income levels. Homes and buildings are well insulated, and most households can keep their homes adequately warm regardless of low outside temperatures,[54] which probably partly explains why no income gradient was observed in our study. Similar conclusions were drawn from a previous study in another Nordic country, Denmark.[12] Future studies should, however, assess possible interactions between income and living arrangements in diverse social settings to gain a more comprehensive understanding of their effects on excess winter mortality.

Methodological considerations

Our study is based on full-coverage high-quality, population-level register data with minimal attrition and no underreporting or recall bias. The use of register data allowed us to examine risk factors at the individual instead of aggregate level, overcoming a key limitation of most previous work on excess winter mortality. Nevertheless, we recognise that identifying persons with pre-existing health conditions based on healthcare visits in specialised care and reimbursement for medicine costs may present some limitations as these records may partly reflect differences in health-seeking behaviour and ignore less severe health problems. Another potential cause of concern relates to the timing of the measurement. If we measured health too close to death, we might be capturing the beneficial effect of being monitored by healthcare professionals or the results could be affected by a survivor bias. Our main results were based on measuring health conditions during the preceding calendar year (a 7-month 'quarantine' period from January to July). We replicated the analysis measuring health closer (no quarantine period before start of follow-up) and further back (quarantine period extended to 2 years). Results, however, remained unchanged, indicating that the timing of the measurement is not driving the small effects.

Our analyses on winter excess mortality in different causes of death were based solely on the underlying cause of death. Thus, our findings may significantly underestimate the total impact of respiratory infections and influenza-like illnesses on excess winter mortality.[21] Deaths are rarely coded as influenza in death certificates[55] but instead attributed to chronic diseases, especially among the older population. Nevertheless, respiratory infections are important triggers of, for instance, cardiovascular problems.[56] To better understand the mechanisms behind excess winter mortality, future research should consider information on contributory causes of death to assess the indirect triggering effect of respiratory diseases.

CONCLUSIONS AND IMPLICATIONS

In conclusion, with high-quality individual-level total population data, we showed that winter mortality has declined since 1971, and particularly after year 2000, but the winter mortality rates have remained above non-winter rates throughout the past five decades. We provide robust evidence that those with advanced age, living in institutions and dementia had a particularly high risk of winter mortality. The subgroup differences were relatively small overall, suggesting an increased risk of winter death even beyond the more vulnerable subgroups. In the context of population ageing and increasing numbers of individuals surviving into ages where excess winter mortality reaches high levels, public health action to protect high-risk groups may have major population-level benefits.

Author affiliations
[1]Helsinki Institute for Demography and Population Health, University of Helsinki Faculty of Social Sciences, Helsinki, Finland
[2]Max Planck – University of Helsinki Center for Social Inequalities in Population Health, Helsinki, Finland
[3]International Max Planck Research School for Population, Health and Data Science, Rostock, Germany
[4]The London School of Economics and Political Science Department of Social Policy, London, UK
[5]Max-Planck-Institute for Demographic Research, Rostock, Germany

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ORCID iD
Ulla Suulamo http://orcid.org/0000-0002-5417-3236

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