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Kaisa Koivunen

Resilience in Old Age

Physical Performance and Psychosocial Factors in Changing Sociohistorical Contexts and as Resources in Adversities

UNIVERSITY OF JYVÄSKYLÄ
FACULTY OF SPORT AND HEALTH SCIENCES

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ABSTRACT

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Resilience in old age: physical performance and psychosocial factors in changing sociohistorical contexts and as resources in adversities
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Resilience refers to the process of adapting to adversity, and it may play an important role in aging well. The key features of resilience are adversity, outcome and resources enabling adaptation. The interplay between the individual and environmental factors over the life course may shape the appearance of resilience. This study explored whether sociohistorical changes influence later life physical performance by comparing two cohorts born 28 years apart. The role of physical performance and psychosocial factors was explored in two adversity contexts: as predictors of mortality after a bone fracture and as predictors of maintaining a high QoL during social distancing because of the COVID-19 pandemic.

This study utilized data generated in two study projects. The Evergreen cohort (n=617) was linked to information on the incidence of bone fractures and mortality for 15 years after baseline. The baseline measurements were repeated in the Active Aging – Resilience and External Support as Modifiers of the Disablement Outcome (AGNES) cohort (n=1 021) and the participants were followed up on using the AGNES-COVID-19 survey (n=809). The participants were initially 75-, 80-, or 85-year-old community-dwelling people.

The later-born cohort had higher walking speed and muscle strength compared with the earlier born cohort. The associations of lower walking speed and muscle strength with mortality hazard were pronounced during the first postfracture year compared with a situation without fracture exposure. Better walking speed increased the odds for maintaining a high QoL only among those who perceived the social distancing recommendations as restrictive. Better stress coping ability and not perceiving oneself as lonely increased the odds for maintaining a high QoL, regardless of how restrictive the recommendations were perceived to be. Mortality after a bone fracture and likelihood of maintaining a high QoL during social distancing recommendations did not differ between those living versus not living alone.

The results showed improved physical performance (i.e., resources) among the later-born cohort, which is most likely a result of more propitious life course exposures. In addition, this study suggests that in old age, physical performance measures may reflect the underlying physiologic and functional reserves to respond effectively to adversities.

Keywords: secular trends, adaptation, muscle strength, walking speed, social support, coping

TIIVISTELMÄ (ABSTRACT IN FINNISH)

Koivunen, Kaisa
Resilienssi ikääntyessä: fyysinen suorituskyky ja psykososiaaliset tekijät muuttuvissa yhteiskunnallisissa olosuhteissa sekä voimavaroina vastoinkäymisissä
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Resilienssi tarkoittaa sopeutumisprosessia vastoinkäymisissä ja sillä saattaa olla merkittävä rooli hyvän ikääntymisen kannalta. Resilienssin kolme keskeistä piirrettä ovat vastoinkäyminen, sopeutumisen indikaattori sekä voimavaratekijät, jotka mahdollistavat sopeutumisen. Yksilön ja ympäristön vuorovaikutus läpi elämänkaaren voi muovata voimavaroja ja siten resilienssin ilmentymistä. Tässä tutkimuksessa selvitettiin sosiohistoriallisten muutosten merkitystä myöhemmän iän fyysiselle toimintakyvylle vertailemalla kahta syntymäkohorttia. Fyysistä toimintakykyä ja psykososiaalisia tekijöitä tutkittiin kahden vastoinkäymisen yhteydessä: kuolleisuuden ennustajina luun murtuman jälkeen ja hyvän elämänlaadun säilyttämisen ennustajina COVID-19 pandemian sosiaalisen eristäytymisen suositusten aikana.

Tutkimuksessa hyödynnettiin kahden tutkimusprojektin aineistoa. Ikivihreät-kohortin (n=617) murtumainsidenssiä ja kuolleisuutta seurattiin 15 vuoden ajan alkumittausten jälkeen. Alkutilanteen mittaukset toistettiin AGNES-tutkimuksessa (n=1021), jonka osallistujia seurattiin AGNES-COVID-19 –seurantatutkimuksessa (n=809). Tutkittavat olivat kotona asuvia 75-, 80-, tai 85-vuotiaita henkilöitä.

Myöhemmin syntyneillä henkilöillä oli parempi fyysinen toimintakyky verrattuna saman ikäisiin ihmisiin 28 vuotta sitten. Alhaisen fyysisen toimintakyvyn yhteys kuoleman riskiin oli korostunut ensimmäisinä murtuman jälkeisinä vuosina verrattuna tilanteeseen ilman murtuma-altistusta. Parempi fyysinen toimintakyky ennusti hyvän elämänlaadun säilyttämistä vain niillä, jotka kokivat sosiaalisen eristäytymisen ohjeet rajoittaviksi, kun puolestaan hyvät stressin hallintakeinot ja se, ettei kokenut yksinäisyyttä ennustivat hyvän elämänlaadun säilyttämistä kaikilla. Yksin asuminen ei ollut yhteydessä elämänlaadun säilyttämiseen sosiaalisen eristäytymisen aikana tai kuolemanriskiin murtuman jälkeen.

Tulosten mukaan iäkkäillä henkilöillä on aiempaa parempi fyysinen toimintakyky, mikä on todennäköisesti seurausta myöhemmin syntyneiden parantuneista elinolosuhteista. Tulosten perusteella fyysisen toimintakyvyn mittarit voivat kertoa reservikapasiteetista, jota tarvitaan vastoinkäymisistä selviytymiseen ja sopeutumiseen.

Asiasanat: kohorttierot, adaptaatio, lihasvoima, kävelynopeus, sosiaalinen tuki, hallintakeinot

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FIGURES

TABLES

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following four original publications, which will be referred to by their Roman numbers.

I Koivunen K, Sillanpää E, Munukka M, Portegijs E, Rantanen T. 2021. Cohort differences in maximal physical performance: A comparison of 75- and 80-year-old men and women born 28 years apart. The Journals of Gerontology: Series A 76 (7): 1251-1259, doi: 10.1093/gerona/glaa224.

II Koivunen K, Sillanpää E, von Bonsdorff M, Sakari R, Törmäkangas T, Rantanen T. 2020. Mortality risk among older people who did versus did not sustain a fracture: Baseline prefracture strength and gait speed as predictors in a 15-year follow-up. The Journals of Gerontology: Series A 75 (10): 1996–2002, doi: 10.1093/gerona/glz251.

III Koivunen K, Sillanpää E, von Bonsdorff M, Sakari R, Pynnönen K, Rantanen T. 2020. Living alone vs. living with someone as a predictor of mortality after a bone fracture in older age. Aging Clinical and Experimental Research 32 (9): 1697–1705, doi: 10.1007/s40520-020-01511-5.

IV Koivunen K, Portegijs E, Sillanpää E, Eronen J, Kokko K, Rantanen T. 2021. Maintenance of high quality of life as an indicator of resilience during COVID-19 social distancing among community-dwelling older adults in Finland. Accepted to be published in Quality of Life Research, doi: 10.1007/s11136-021-03002-0.

As the first author of the original publications, while also considering the comments from the co-authors, I formulated the study questions and designs for the publications, prepared the data for statistical analyses, performed all statistical analyses except for the main analyses in Study II, and had the main responsibility of interpreting the results and writing the manuscripts. I participated in the data collection in the active aging (AGNES) study project, of which data were used in Studies I and IV. In Studies I, II, and III, I was privileged to use pre-existing data.

ABBREVIATIONS

AGNES	Active Aging – Resilience and External Support as Modifiers of the Disablement Outcome
ATS/ERS	American Thoracic Society / European Respiratory Society
CD-RISC	Connor-Davidson Resilience Scale
CES-D	Center for Epidemiologic Studies Depression Scale
CI	Confidence interval
FEV1	Forced Expiratory Volume in the first 1 second
FVC	Forced Vital Capacity
MMSE	Mini-Mental State Examination
N	Newton
OPQOL	Older People's Quality of Life questionnaire
PEF	Peak Expiratory Flow
QoL	Quality of Life
SD	Standard Deviation
SOC	Selective Optimization with Compensation
WHO	World Health Organization

CONTENTS

1 INTRODUCTION

Population aging is one of the major social trends in the twenty-first century (Kim et al. 2021). The central question of this demographic shift is whether the extended years of later life will be filled with healthy and disability-free years or if they will be shadowed by poor health and low quality of life. In recent decades, the research on aging has increasingly moved the focus away from considering old age solely as a progressive functional decline to exploring the potential of older adults maintaining well-being and functioning and to continue contributing to society. The emergence of theories in positive gerontology, such as activity theory (Havighurst 1961) and continuity theory (Atchley 1989), opened the way for multidimensional views of aging and older adults' engagement in life. These theories further propelled the development of the conceptual frameworks of aging, such as successful aging (Rowe & Kahn 1997) and productive aging (Bass & Caro 2001). Although these theoretical frameworks posit that sustained activity result in better health and positive experiences in old age, they do not fully take into account the variety of challenges that most older people face when they age, which may hinder their possibilities for activity. As the human lifespan is pushed further, the likelihood of encountering adversities, such as functional or social losses and multimorbidity, increase. The more contemporary views of aging well, such as the policy-oriented (World Health Organization 2002) and individual-focused (Rantanen et al. 2019) frameworks of active aging, encompass that activity can be achieved despite age-related challenges. However, it is still poorly understood why and how some individuals can adapt and maintain functioning and well-being despite multifaceted and accumulating losses. The concept of resilience refers to the process of adaptation in adversity and has gained increasing interest in the aging research field in recent years. Although for some individuals a given adversity may trigger a downward spiral in function, others show resilience by being able to recover, adapt, and return to their previous level of functioning or close to it (Klasa et al. 2021). Exploring the factors that foster resilience may offer targets for interventions that can enhance active engagement and well-being in later life.

In the early phases of research on resilience, the focus was on identifying children's "resilient" traits that help avoid psychopathologies despite adverse life conditions (Masten 2001). In the past few decades, research has widened from children to other age groups, including older adults, and shifted to recognize resilience more as a holistic and context-specific process instead of only as a characteristic of the individual (Windle et al. 2021). According to the socioecological model, the manifestation of resilience is the interplay between the individual features and environmental contexts, including the whole life course and sociohistorical exposure (Wister et al. 2016). However, resilience research is still fragmented across disciplines, and diverse ideas of the development of resilience in later life have arisen. Those applying physiological lenses state that resilience declines with the enervating reserves of physical capacity, whereas the psychosocial perspective posits that the ability to respond effectively to adversities may be preserved—and even improved—through growth, experiences, and learning (Wister 2021). Because both may be true, fostering resilience could include supporting the individual's high functional capacity and the "healthy lifespan" for as long as possible while also enhancing the psychosocial resources for adaptation. Therefore, research that includes both of these traditionally rather separate approaches can provide a more comprehensive picture of resilience.

With advancing age, physical capacity gradually declines, which, according to Ferrucci et al. (2018), is a result of enervated physiological adaptation mechanisms. It has been well established that physical capacity measures, such as muscle strength and walking speed, predict future health and survival (Cooper et al. 2010; Studenski et al. 2011). However, it is not clear what explains these associations (Rantanen et al. 2003) and whether adaptive mechanisms in life events play a role. It has been hypothesized that exposure to stressors demands a certain amount of energy and physiological reserves for adaptation or survival. Thus, the failure to adapt occurs if the demand exceeds the individual's reserve (Chhetri et al. 2021). Earlier studies have mainly studied physical capacity as a predictor of survival or recovery in study populations composed solely of individuals who have sustained a certain health event, for example, a fracture, without a comparison group of people who did not suffer from such an event. In addition, physical capacity is usually assessed retrospectively, when it may be confounded by the health event. Hence, we do not know whether the predictive power of better physical capacity on survival or other positive outcomes is pronounced when facing an adversity. If so, it would suggest that the reserves in physical capacity become particularly important in times of adversity and promote resilience by buffering the negative effects of the stressor.

The buffering hypothesis, which proposes that specific factors are particularly beneficial in achieving positive outcomes when facing adversity (Cohen & Wills 1985), has been central to resilience research. Thus far, most research has been done on psychosocial resources (Hildon et al. 2009; Klokgieters et al. 2018; Latham-Mintus & Aman 2019). For example, earlier studies have shown that psychosocial resources have the potential to reduce the expected negative effect of adversities on mental and general health (Cutrona, Russell & Rose 1986; Netuveli et al. 2008). In the present study, living arrangements, absence of loneliness, and stress-coping ability are investigated as potential psychosocial resources helping one adapt in the face of adversity. Living with someone may provide emotional and instrumental social support (Blozik et al. 2009), which has been recognized as an important resource for resilience in earlier studies (Fuller-Iglesias, Sellars & Antonucci 2008; Netuveli et al. 2008). However, the situational or structural factors of an individual's life, such as living arrangements, may not alone describe an individual's social milieu. Therefore, a subjective perspective on social relationships is also important (Perissinotto & Covinsky 2014), which in the current study, is targeted with perceived loneliness. Loneliness refers to "a subjective distressing emotion resulting from a discrepancy between one's actual and desired social relationships" (Cacioppo & Patrick 2008). Social support is believed to enhance individual's psychological resources, such as self-efficacy (belief in one's ability to succeed in different situations), which, in turn, is known to promote beneficial coping styles (Bandura 1982). Psychological adaptation and stress-coping ability have been central for resilience research and has been traditionally considered to indicate resilience as such. However, drawing on the broader socioecological approach and taking into account the multidimensional nature of resilience, in the present study, stress-coping ability was investigated as a potential resource for resilience.

The literature on resilience in older adults mostly concerns persistent or accumulating adversities, such as caregiving (Joling et al. 2016), cognitive impairment (Windle et al. 2021), low physical capability (Cosco et al. 2018; Klokgieters et al. 2018), and financial hardship (Pudrovska et al. 2005). However, resilience in acute or episodic adversities, such as health events, with defined starting points, remains rather scarce. To contribute to filling in this gap, the current study applied a resilience framework on two sudden but different adversities: bone fractures and the COVID-19 social distancing recommendations caused by the SARS-CoV-2 virus pandemic. The purpose was to investigate the buffering hypothesis, that is, to analyze whether physical and psychosocial factors have a more pronounced role in achieving positive outcomes in times of adversity compared with a situation without exposure to an adversity. A further objective was to investigate whether the current cohorts of older adults have better physical capacity compared with earlier cohorts, which could indicate that more propitious life course exposures build resilience in later life.

2 REVIEW OF THE LITERATURE

2.1 Resilience in the context of positive gerontology

2.1.1 Positive gerontology

The increasing life expectancy, which has led to the rise in the aging population, is one of humanity's greatest success stories, but at the same time, it is one of the greatest challenges (World Health Organization 2002). For example, in Finland, a person aged 75 in 1989 could expect to live a further 9.7 years, whereas a same-age individual in 2019 could expect to live a further 12.8 years (Official Statistics of Finland 2020). An essential question of aging populations is whether the additional years in later life are lived healthy and disability free or if they are spent in poor health. For quite a while, the study of aging was oriented toward illness and disability. There is no denying that later life is often characterized by the accumulation of deleterious physiological changes leading to deterioration of the organism, loss of function, and, finally, death. However, longitudinal studies have shown that physical aging is a heterogeneous process, and individuals follow different trajectories of health and functioning during their life courses (World Health Organization 2015; Daskalopoulou et al. 2019). Some older adults may maintain good functional abilities until a very old age, whereas among others, early or accelerated declines in functioning occur.

However, aging is not solely about physiological changes: it is also characterized by the multiform psychosocial processes that interact with physical changes but may not follow the same trajectories. Disengagement theory, as formulated by Cumming and Henry (1961), postulates that older adults withdraw from social relationships and roles and become emotionally distanced from others as they start to prepare for death. However, empirical findings have not supported this view, instead suggesting that in older age, social and emotional functioning may be equal to or even superior to younger adults

(Charles & Carstensen 2010). Therefore, aging may be seen as a life phase of personal growth, active engagement in life, and well-being. Along with the demographical transition, in which reaching higher ages is no longer rare, the central interest of gerontological research has shifted to finding answers to how to enhance aging well, despite the inevitable physiological decline and other challenges, such as social and role-related losses (World Health Organization 2002; Kim et al. 2021).

The first definition of successful aging was proposed by Havighurst (1961), who identified successful aging as "the experience of joy, happiness, and satisfaction in later life." This framework was built on activity theory, which proposes that successful aging occurs when older adults stay active and maintain their social interactions representing the opposite view of aging compared with disengagement theory. A third central theory of aging is called continuity theory, which is an extension and modification of activity theory (Atchley 1989). Continuity theory takes the life course perspective and postulates that those who age most successfully are those individuals who maintain their self-identity through continued engagement in the activities that have been central to their lives.

The successful aging framework was further developed by Rowe and Kahn (1997), who distinguished successful aging from normal aging. Successful aging was defined as having high physical, psychological, and social functioning in old age without major diseases. However, this approach drew criticism because individuals should be able to age successfully even with chronic diseases (Rowe & Cosco 2016). The concept of successful aging has also been criticized for ignoring the role of social structures and contexts in which the aging takes place, making it within the reach of advantaged persons only (Taylor & Bengtson 2001). The concept of productive aging shares a similar positive view of aging as a successful aging framework, highlighting the current and potential contributions of older adults through meaningful actions while also considering the institutional barriers and influences that social structures have on individuals (Bass & Caro 2001). This perspective proposes that it is the responsibility of both individuals and society to enhance older adults and help them achieve their potential—individuals have their responsibility to be active members of society, whereas society needs to eliminate the barriers to being productive and participating in later life (Taylor & Bengtson 2001).

Building on the earlier developments and conceptualizations of positive gerontology from the beginning of the 2000s, a framework of active aging became popular in aging research and policy. In 2002, the WHO released an active aging policy framework (World Health Organization 2002), in which active aging was stated as a "process of optimizing opportunities for health, participation, and security to enhance quality of life as people age." Although WHO's active aging framework was more policy goal oriented, Rantanen et al. (2019) proposed a new approach, focusing on active aging at the individual level, and defined it as "striving for well-being through activities relating to a person's goals, functional capacities, and opportunities." A key proposition of this framework is that active aging may be reached despite functional losses, here by compensating mechanisms via environmental or social support. In addition, when compared with the successful aging model, this framework of active aging describes aging well more as a process instead of a state.

Contemporary views of positive gerontology have challenged the idea that aging well could be achieved only by those with good health and high functioning. However, although the models, such as active aging, may also be applied to those with age-related challenges and illness, these models do not fully capture the multifaceted strategies of how positive outcomes are reached despite adversities and how these strategies are linked to developmental processes in earlier life (Smith & Hayslip 2012; Pruchno, Heid & Genderson 2015). The concept of resilience, which stems from the field of developmental psychology, has received increasing interest in the field of gerontology over the past years. However, resilience may not be a surrogate concept for the previously introduced broader concepts of positive gerontology, but it may be nested in these models (World Health Organization 2015; Cosco, Howse & Brayne 2017; Rantanen et al. 2018). By actively incorporating the component of adversity, the concept of resilience allows to focus more specifically on the processes by which positive outcomes may be achieved despite the challenges related to aging. Therefore, studying resilience helps reveal the mechanisms underlying the heterogeneity in the older population's health and functioning (Pruchno, Heid & Genderson 2015; Cosco, Howse & Brayne 2017). Consequently, applying the concept of resilience to public health and gerontology research may offer alternative views on health. Huber et al. (2011) proposed that the WHO's definition of health as an objective and stable state of "complete physical, mental, and social well-being" is no longer suitable for populations with many chronic diseases, and it should be replaced with definitions referring to changing adaptation processes.

2.1.2 The concept of resilience

The word resilience comes from the Latin verb "*resiliere*," which means "rebound" or "spring back" (Merriam-Webster 2021) and the term was originally used to describe the elastic property of physical matter. The term resilience has been used broadly in many fields to describe the responses of systems, such as ecosystems or economies, to adverse conditions or disturbances (Jain et al. 2014). In humans, the word resilience has been used to refer to a process of positive adaptation to or dealing with the adversities of life (Luthar, Cicchetti & Becker 2000; Windle 2011). The scientific study of human resilience first emerged in the field of developmental psychology in the 1970s when researchers studied children who showed an extraordinary ability to develop well despite severe adversity in early life (Masten 2001). Children who managed to go through these challenges and avoided pathologies later in life were described as being "resilient" (Garmezy, Masten & Tellegen 1984). This pioneering research focused on the qualities within individuals, and it was shaped in large by understanding and preventing the development of mental health problems (Masten 2007). In the past few decades, there has been a gradual shift away from considering resilience only as an individual characteristic to a broader perspective on complex person–environment interactions. According to this view, resilience is a process of positive adaptation emerging from an interplay between the individual and environment, including family, community, and society (Masten 2007; Wister et al. 2016). This view of resilience has become central in research on older adults, with whom acute and chronic risk exposure may accumulate and continuous adaptation to individual changes is required (Kim et al. 2021).

Three key elements need to be established when studying resilience: 1) the exposure to a stressor or adversity, 2) a response judged as positive adaptation or the avoidance of a negative outcome, and 3) the resources or mechanism(s) allowing for the positive adaptation (Windle 2011; Angevaare et al. 2020). However, there are different interpretations of what constitutes an adversity or a stressor that requires resilience for a positive outcome and how doing well in the face of adversity is defined. For example, opposite ends of the same factor may be considered either as an adversity (e.g., poverty) or a protective factor (e.g., wealth) (Smith & Hayslip 2012). Because common guidelines or golden standards may be impossible to reach, the decisions of researchers need to be conceptually guided by taking into consideration the nature of the adversity and the population being studied (Luthar, Cicchetti & Becker 2000). For example, in some cases when the adversity is very severe, even the avoidance of negative outcomes or having only low levels of symptoms may be judged as good and an indication of resilience (Windle 2011). Although identification of the adversity and response are essential in operationalizing and measuring resilience, the central interest in resilience research is how a person achieves a good outcome despite adversity. Angevaare et al. (2020) argued that the mobilization of resources, that is, the adaptive mechanisms that lead to a positive outcome, is the process of resilience itself. The contemporary view emphasizes that the manifestation of resilience is context specific, and the responses to adversities may be psychological, physiological, or social in nature (Windle 2011; Cosco et al. 2019). Because the existence of general resilience is unlikely, the research has become more specific to contexts and outcomes. In older adults, some central domains of resilience have been, for example, psychological resilience (Resnick 2014), physical resilience (Whitson et al. 2016), mobility resilience (Seetharaman, Wister & Cosco 2021), cultural-specific resilience (Ungar 2013), cognitive resilience (Stine-Morrow & Chui 2012), and multimorbidity resilience (Wister et al. 2016). However, although a domain-specific approach to the study of resilience has been recommended (Vanderbilt-Adriance & Shaw 2008; Windle 2011), it has also led to fragmentation of the concept in different fields (Klasa et al. 2021).

Another aspect of the context specificity of resilience relates to age and the life course. Despite recognizing the importance of resilience in later life, far less is known about the determinants and manifestation of resilience in older age compared with children and adolescents (Windle 2012). Advanced age is different compared with earlier life phases; hence, the manifestations of resilience most likely change across the life span. For example, exposure to adversities and having the accessible resources to respond to adversities are different in old and young ages. It is also noteworthy that what is considered old age may include individuals with a large age range. The "young-old" may be 40 years younger than the "oldest-old" and most likely also have different resources and risks. In addition, people of different age groups facing the same situation may have different experiences of stress (Hayman, Kerse & Consedine 2016). For example, among younger people, living alone may be experienced as a stressful psychosocial situation, whereas among older adults, it may be a more normative condition and indicator of functional independence (Gopinath et al. 2013).

2.1.3 Theoretical foundations and models of resilience in old age

Gerontological research has placed a large amount of emphasis on studying the adaptation processes in aging, forming the basis for the theoretical framework for the concept of resilience. The focus of many theoretical approaches lies in the specific domains or levels of functioning (e.g., psychological or physiological adaptation), and the framework of resilience aims to bridge and highlight the importance of these different aspects for adaptation in old age (Windle 2021).

Salutogenesis and psychological perspectives

The theoretical roots of resilience in later life lay in the model of salutogenesis, which was developed by Professor Aaron Antonovsky more than three decades ago (Antonovsky 1979). Salutogenesis focuses on the resources that support health and well-being rather than focusing on the pathogenesis (the causes of diseases). "Sense of coherence" reflects an individual's view of life and ability to use the available resources to cope with stress. Aligned with the idea of salutogenesis, the theories of positive and developmental psychology are also foundational to the concept of resilience. The approach of positive psychology emphasizes the positive traits and strengths of the individual, such as optimism, engagement, and meaning, in achieving adaptation and well-being (Seligman & Csikszentmihalyi 2000). Theories stemming from the field of developmental psychology focus on adaptation by balancing the gains and losses required to achieve one's optimal development during different life phases (Wister et al. 2016). According to the classic stress-coping model formulated by Pearlin et al. (1990), effective adaptation to stress is reached through the mediating effect of coping and social support at multiple points along the stress process.

The dual-process model of assimilative and accommodative coping strategies captures the different ways older adults negotiate between goal pursuit and adjustment to the changes related to aging (Brandtstädter & Rothermund 2002). Assimilation refers to the strategies in which the individual pursues goals persistently through modifying the situational factors. Accommodative strategies promote the adjustment of goals because of losses in functional abilities. The model of selective optimization with compensation (SOC) posits that these three processes are essential for successful development in aging (Baltes & Baltes 1990). SOC postulates that throughout the life span, individuals possess certain opportunities and limitations in the resources that can be controlled by selecting the most meaningful goals, optimizing the means and measures that are most suitable for achieving the goals, and compensating with substitutive processes (Freund & Baltes 1998). Originally, resilience was viewed as a way of coping. However, although being an important feature of resilience, especially when struggling with stressors requiring psychological adaptation, the coping mechanisms do not entirely cover the dynamical adaptation processes operating across multiple levels of functioning.

Physiological perspectives
The physiological perspective of resilience observes the human body's biological, physiological, and physical adaptation per se. Ferrucci et al. (2018) have proposed a hierarchical model of the metrics of aging, in which biological aging occurs at hierarchically organized levels (molecular, cellular, physiological, and functional). According to this model, biological resilience mechanisms play an important role in maintaining the dynamic equilibrium of the system between disturbing stress and homeostasis. Functional aging starts when the resilience mechanisms at the lower levels of hierarchy (molecular, cellular, and phenotypic) are enervated and can no longer buffer the damages. These aging-related changes also compromise the system's potential to respond and adapt to higher intensity adversities or stressors (e.g., hip fractures or surgery), which appear as lower physical resilience (Whitson et al. 2016). The concept of reserve capacity, which is rooted in life span developmental processes, is central to physical resilience. Reserve capacity refers to the potential capacity of a cell, tissue, or organ system to function beyond its basal level in response to alterations in physiologic demands (Whitson et al. 2016), and it may be applied to many functions, such as muscle mass and strength (Marcell 2003), aerobic (Arnett et al. 2008), or cognitive (Piccinini et al. 2018) reserves.

Life course perspectives
Aging and the manifestation of resilience in later life is not an isolated process but is a continuum for earlier life phases, experiences, and exposures. Life course theories consider the developmental pathways of resilience, addressing the interplay between the individual and environmental factors such as a lifelong process (Wister et al. 2016). Both the individual life course exposures (e.g., early life experiences, life transitions, lifestyle habits) and exposures that apply to whole cohorts (e.g., historical, institutional, or cultural factors) may all shape the aging process. According to cumulative advantage and disadvantage theory (Crystal & Shea 1990), these exposures form life course capital, which may influence the ways individuals adapt to adversities or stress (O'Rand 2006). The sensitive period model postulates that exposures during important life phases may have significant and enduring consequences on later life health and well-being (Ben-Shlomo & Kuh 2002). Both the accumulation of risk model and sensitive period model have been used to explain physical health outcomes in older age, which may influence physical adaptation to stressors. For example, the cumulative effects of heavy drinking, cigarette smoking, physical inactivity, depression, social isolation, fair or poor perceived health, prevalence of chronic

symptoms, and prevalence of chronic conditions have been shown to be associated with functional limitations in old age (Strawbridge et al. 1998). The sensitive period model originates from the fetal origins hypothesis, which was first introduced by Barker (1995), showing the association between poor nutrition in utero with increased risk of coronary heart disease and diabetes in older ages. In addition, the influence of adverse early life experiences on later life function and health has been established (Birnie et al. 2011; Nandi et al. 2012; Duchowny et al. 2020).

However, little is known about the extent to which adversities or stress exposures earlier in the life course contribute to later life resilience through a "steeling effect" or increase vulnerabilities through a "sensitization effect." It has been suggested that to some extent and at some phases in life, experiencing adversity and adapting successfully may increase the likelihood of positive adaptation to future stress. Theoretically, the psychosocial perspective on resilience assumes that the ability for adaptive responses may be preserved or even improved in old age through experiential learning and the development of adaptive coping mechanisms. In turn, the physiological perspectives draw a very opposite picture of the trajectories of resilience, with enervating reserves and increasing physical vulnerability (Wister 2021).

Socioecological perspectives

The (socio-) ecological models provide a less fragmented and more comprehensive interdisciplinary idea of the multifaceted adaptation processes during aging in the context of the person–environment interplay (Ungar 2011; Klasa et al. 2021). The study of the interactions between the person and environment is not new in aging research. The ecological model of aging (also known as the "competence-press model") by Lawton and Nahemow (1973) has been widely applied to understand the balance between individual needs and abilities and one's environmental demands. This theory posits that an optimal state of functioning and adaptation, that is, person–environment (P-E) fit, may be achieved when personal competence and environmental press converge. In addition to that environments may be seen as a source of stress, they may also provide resources and opportunities. Empirical findings support the theory demonstrating, for example, that older people with mobility limitations report more environmental mobility barriers (Rantakokko, Mänty & Rantanen 2013). The mismatch between the individual and their environment may also be shown as maladaptive behaviors, such as fear of moving, which potentially lead to the avoidance of activity and mobility limitations (Rantakokko et al. 2009; Rantakokko et al. 2012), whereas environmental facilitators may prevent mobility decline (Eronen et al. 2014). Although the application of the model is most often focused on the individual and their physical environment, it may also refer to the social environment (Aldwin & Igarashi 2012). While in the ecological model of aging this interplay has often been represented as a two-dimensional process between individual competence and the near environment that results in adaptive or maladaptive behaviors (Aldwin & Igarashi 2012), the socioecological framework aims to illustrate complex and overarching socioecological levels in which the individual is nested (Figure 1).

Many conceptual models of resilience leaning on the socioecological framework have been developed over the years, such as the ecopsychosocial model of resilience by Windle and Bennet (2012), the ecological model of resilience in late life by Aldwin and Igarashi (2012), and the life course model of multimorbidity resilience by Wister et al. (2016). Despite the recognition that resilience in old age is a result of the interactions between the individual(s) and the multilevel environmental levels, most discussions have been mainly theoretical. Although it is intuitively obvious, at the same time, it is empirically complex, and so far, the research has yielded only limited attempts to capture the broader picture of the manifestation of resilience. To contribute to filling in this gap, the present study draws on the socioecological model as a theoretical framework for studying the different aspects of the complex adaptation process.

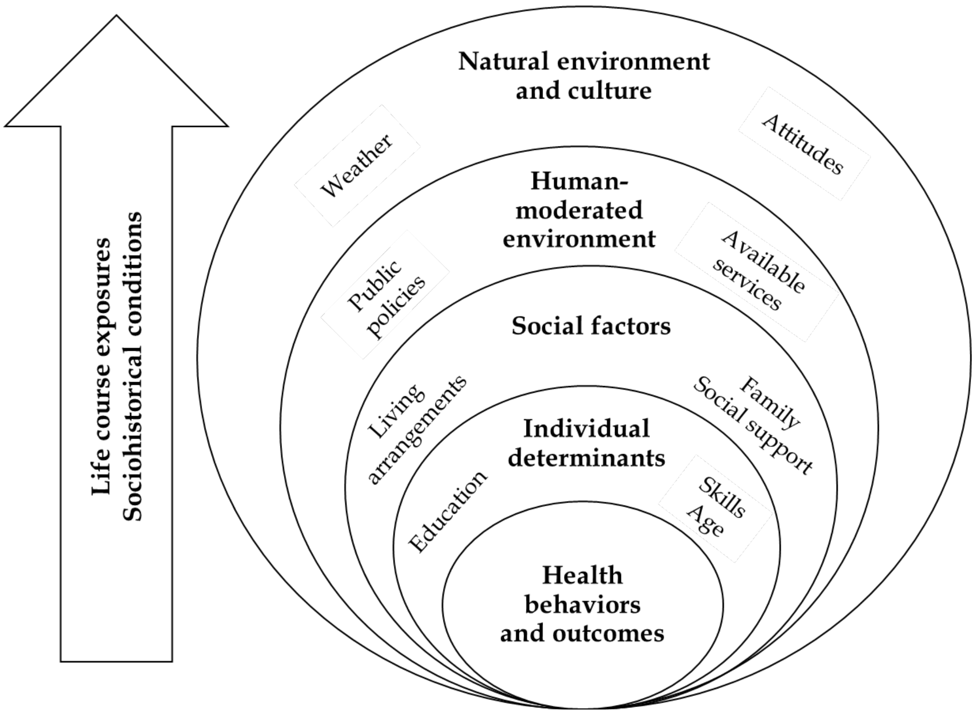


FIGURE 1 Socioecological model of resilience adapted from McLeroy et al. (1988) and Klasa et al. (2021).

2.2 Physical performance and aging

Physical capacity refers to a person's inherent ability to execute a task or an action in a specified context that requires physical actions (Jette 2006); this is a key contributor to a broader concept of physical functioning, which consists of the interplay between intrinsic capacity, environmental factors, and potential coping and compensation strategies (Tomey & Sowers 2009). Physical performance tests requiring maximum effort and administered under controlled circumstances offer more explicit information about individuals' intrinsic physical capacity. Several studies have shown that physical performance measured based on, for example, grip strength and walking speed, not only give information about the physical capacity to undertake physical tasks but are also "vital signs" that reflect the current burden of diseases and predict future health (Rantanen, Guralnik, Foley et al. 1999; Rantanen et al. 2003; Cooper et al. 2010; Studenski et al. 2011).

From the life course perspective, physical capacity increases during the first decades of life, peaks during early adulthood, and then declines progressively or sometimes suddenly because of a catastrophic event, such as a bone fracture (Guralnik et al. 2001; Peeters et al. 2013), as illustrated in Figure 2. However, sometimes after a decline, individuals may show resilience by returning to their baseline or close to it (Klasa et al. 2021). According to the disablement process model, in old age, significant loss in underlying physiological reserves and, consequently, in physical capacity is characterized by the manifestation of common problems, such as mobility impairments and difficulties with the activities of daily living through a disablement process (Verbrugge & Jette 1994). Echoing the disablement process, more recent geroscience hypotheses have posited that biological aging changes, such as molecular damages and the dysregulation of complex physiological systems, drive compromised physical resilience, that is, the capacity of the organism to resist and respond to a challenge; this leads to phenotypic aging, functional impairments, onset of diseases, and, eventually, death (LeBrasseur 2017; Ferrucci et al. 2018; Fried et al. 2021). Encompassing this hypothesis, the measures of physical resilience as an early indicator of a system's decompensation and aging are of great interest but are not yet well established (LeBrasseur 2017). However, measuring maximal physical performance may reveal the underlying state of biological and phenotypical aging-related changes and the system's capacity for adaptive responses (Chhetri et al. 2021).

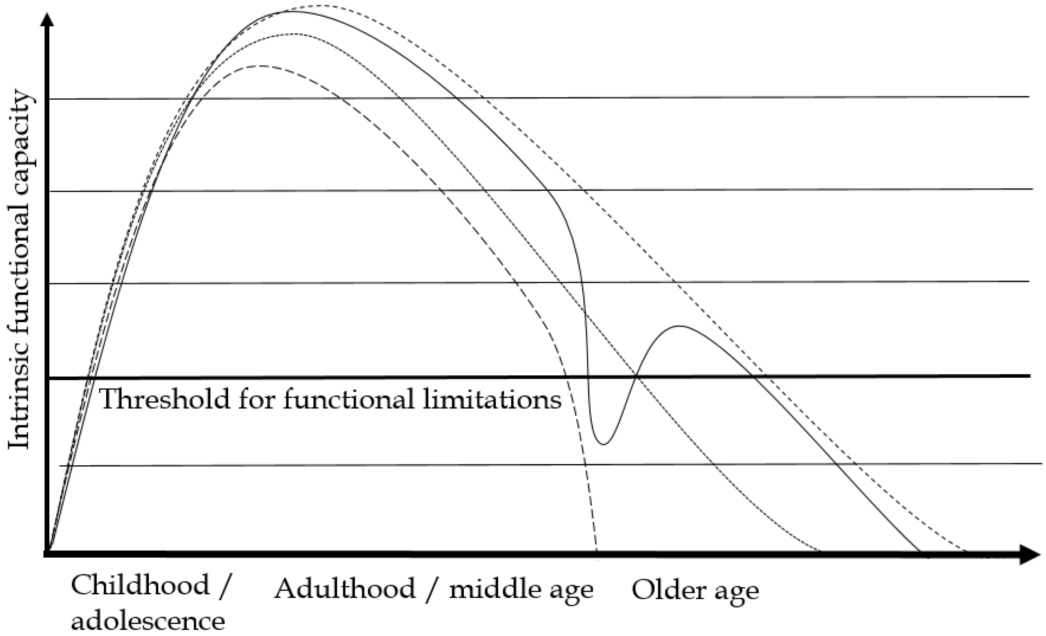


FIGURE 2 Life course trajectories of intrinsic functional capacity (adapted from Guralnik et al. 2001; Kuh et al. 2014; Klasa et al. 2021). Physical capacity increases during the first decades of life, peaks during early adulthood, and then declines progressively or sometimes suddenly because of a catastrophic event. However, sometimes, individuals may show resilience by returning to their baseline or close to it.

A large body of evidence has already demonstrated that better physical performance is associated with more positive outcomes after adverse events. However, only in a few studies has physical performance been assessed before the onset of a stressor as a way to ensure that the results are not confounded by the situational factors. For example, Afilalo et al. (2018) studied presurgery walking speed as a predictor of rehospitalization and one-year mortality in 8 287 patients undergoing cardiac surgery (median age 74 years). The results showed that every 0.1 m/s decline in walking speed was associated with a 70% higher risk for rehospitalization and a twofold risk for mortality during the first year following a surgery. To the author's best knowledge, only two studies have investigated prefracture muscle strength as a predictor of survival after suffering a fracture. Rantanen et al. (2002) studied prefracture knee extension strength as a predictor of mortality with 82 participants initially aged 75 or 80 years who suffered at least one bone fracture during a 10-year follow-up. The results showed that the risk for death after fracture was over four-fold in the lowest compared with highest tertile. In line with this, in a study by Pham et al. (2017) that included 512 participants (mean age 75 years), every 5 kg/meter decrease in height-adjusted prefracture quadriceps muscle strength was associated with a 27 % increase in postfracture mortality risk in women and a 33% increase in men, as found during a 11-year follow-up design. However, in most studies, the study populations have mainly consisted of those who have sustained an adverse event (often clinical samples); hence, it is unclear whether the associations between good physical capacity and positive outcomes are different after an adverse event compared with a situation without it. The level of physical capacities may be considered as individual reserves that have been developed during the life course as a result of the interplay between individual characteristics and environmental exposures. In addition to intracohort variation in exposures, birth cohort–related factors, such as sociohistorical factors, may have influenced the level of physical performance in old age (Wister et al. 2016) and, hence, will have a special focus in the current study.

2.2.1 Muscle strength

Skeletal muscles support the bones in maintaining posture, controlling voluntary movement, and contributing to energy metabolism and storage (Greig & Jones 2016). Muscle strength refers to the maximal amount of force a skeletal muscle produces (Bohannon 2015). Muscular contraction occurs by the sliding of the myofilaments relative to each other in the sarcomere, which is a basic contractile unit of muscle fiber. The force generated by a muscle depends on many factors, such as the neural drive to the muscle, muscle size, and biomechanical properties of the musculoskeletal system, velocity of movement, energy metabolism, and hormonal factors (Frontera & Ochala 2015). During the aging process, various factors contribute to loss of muscle strength—some of them are linked to the normal aging process (e.g., motor unit loss, hormonal changes) and diseases (Vandervoort 2002) and others more to the changes in lifestyle patterns (e.g., physical activity, nutrition) (Frontera & Ochala 2015). The loss of muscle strength has become an important public health concern in older adults because it predisposes them to functional limitations and adverse events. For example, in the Health ABC cohort including 3 075 initially 70- to 80-year-old participants, those in the lowest quartile of lower extremity muscle strength had a 65% increased risk of hospitalization during an average of 4.7 years of follow-up compared with those in the highest quartile after multivariate adjustment (Cawthon et al. 2009). Rantanen et al. (1999) studied midlife grip strength as a predictor of disability in later life among 6 089 healthy men initially aged 45 to 68 years. The results showed that those in the lowest tertile of hand grip strength had the highest odds of having functional limitations and disability 25 years later. In line, midlife hand grip strength was shown to be an independent predictor of all-cause mortality over a 30-year follow-up (Rantanen et al. 2000). Similar findings have been reported in current cohorts of older adults. In a recently published study of a large SHARE cohort, which included 13 231 community-dwelling participants aged 65 and older from 15 countries in Europe, every 5 kg decrease in grip strength was associated with 11% increased risk for all-cause mortality in men and 17% increased risk in women (Cai et al. 2021).

The first signs of a gradual decline in muscle strength are shown as early as the third decade of life, followed by a steeper deterioration after 50 years of age (Beenakker et al. 2010). In older adults, the rates of decline are mainly derived from studies assessing maximal isometric strength, which involves the contraction of muscles without any movement in the surrounding joints. Longitudinal studies have estimated that by the seventh and eight decades of life, maximal muscle strength has decreased on average by 20–40% (Doherty 2003). However, in many longitudinal studies, reported declines may be underestimated because of selective dropout. The participants with lower muscle strength are more likely to drop out of the follow-ups because of poor health or death, whereas the decline in muscle strength is estimated only with stronger and healthier participants who remain in the study (Frederiksen et al. 2006).

In older adults, grip strength measurement has been widely adopted in epidemiological settings because of its strong associations with concurrent and future health and function (Rantanen, Guralnik, Foley et al. 1999; Rantanen et al. 2003; Sallinen et al. 2010), as well as ease of use and good repeatability (Roberts et al. 2011). Although lower extremity (e.g., knee extension) strength is also known to correlate with health and mortality risk and is of great importance in the activities of daily life, its use in epidemiological studies compared with clinical trials is more unusual because of the higher demands for carrying out measurements in large study populations (Xue et al. 2010). Although hand grip strength may be used to give an approximation of overall muscular strength (Rantanen, Era & Heikkinen 1994), the age-related declines in different muscle groups may not be homogeneous. There is some evidence to show that the lower limb muscles exhibit a greater rate of decline compared with upper limb muscles, as measured by grip strength (Samuel et al. 2012; Amaral et al. 2014). These differences have been hypothesized to be attributable to changes in the activity patterns in older age because the activities carried out with lower limbs may decrease while the activities requiring upper limbs increase (Kern, Semmler & Enoka 2001; Theou et al. 2010). Therefore, monitoring muscle strength in different muscle groups may greatly improve the overall picture of individuals' muscle strength and physical capacity.

2.2.2 Walking speed

Walking is a pattern of movement composed of cyclic movement, changing support and balance from one foot to the other. In general, the walking cycle is composed of the single-support phase and double-support phase (Alamdari & Krovi 2017). The ability to walk is essential for mobility and independent living, and walking is the most common physical activity behavior in older adults. However, walking is a complex task that requires, for example, energy, and the motor control and function of the musculoskeletal, circulatory, and nervous systems (Studenski et al. 2011). The walking characteristics of older adults are often different when compared with younger people. Age-related changes in walking include, for example, slower velocity, shortening the step length, longer double-support time, and a broader walking base (Lockhart, Woldstad & Smith 2003).

Measuring walking speed is a simple assessment that has been proposed as a "functional vital sign" in old age (Middleton, Fritz & Lusardi 2015). In addition to measuring the ability to move, it has been shown to be a good summary indicator reflecting various physiological processes in the organic systems underlying health and aging (Studenski 2009; Middleton, Fritz & Lusardi 2015). Slow walking speed has been shown to be associated with many unfavorable outcomes in community-dwelling older adults. A pooled analysis of nine cohort studies by Studenski et al. (2011) including 34 485 participants aged 65 or older showed that every 0.1 m/s increase in walking speed was associated with 12% higher odds for survival. In a pooled analysis of seven studies including 27 220 participants aged 65 or older, walking speed predicted a 3-year incidence of bathing or dressing dependence and mobility difficulty (Perera et al. 2016). In addition to physical deficits, walking speed has been shown to predict cognitive decline. For example, Hackett et al. (2018) studied the association of walking speed with dementia risk in 3 643 adults aged 50 and over. The results show that the participants with the lowest baseline walking speed and greater decline in walking speed over time were at a greater risk of developing dementia independent of changes in cognition.

Although evidence of walking speed as a health indicator among older adults is well established, a recent study suggested that slower walking speed in generally healthy adults already in their 40s appears to be a valuable sign of worse physical and cognitive health and may reflect accelerated aging (Rasmussen et al. 2019). In addition to age, sex, and body height, many modifiable factors, such as lower extremity strength, standing balance, and health behaviors have been shown to be associated with walking speed in old age (Bohannon 2008; Sallinen et al. 2011). Studies have shown that average walking speed remains relatively stable in adulthood until age 65. The normal walking speed has been reported to decline 1% per year between the ages of 65 to 69, after which the decline accelerates (Himann et al. 1988; Forrest, Zmuda & Cauley 2006).

The test procedures used to measure walking speed vary hindering the comparability of the results between different studies. The protocols differ in distance (2–80 meters), start (static vs. dynamic), path (straight vs. turn), speed (normal or comfortable vs. maximal), and timing instrument (e.g., stopwatch vs. photocells) (Himann et al. 1988; Middleton, Fritz & Lusardi 2015). In addition, the standardized tests may be administered at the participant's home, outdoors, or in a laboratory environment. More recently, habitual walking speed has also been evaluated with accelerometers in free-living environments (Schimpl et al. 2011). In the present study, maximal walking speed was measured using a 10 m test in the laboratory corridor. The examination of maximal rather than habitual walking speed was selected because increasing walking speed to maximal levels may be a more appropriate indicator of intrinsic physical capacity and may reveal the latent reserves, that is, the potential that allows for change and adaptation. For example, it has been proposed that walking at fast compared with normal speed may require more muscle strength (Bohannon, Andrews & Thomas 1996), as well as greater areas of cerebral brain activation (Callisaya et al. 2017).

2.2.3 Respiratory function

Respiratory function refers to the function of the body organs and tissues involved in breathing. Lungs are the foundational organs of the respiratory system, in which oxygen is transported through the alveoli in the lungs into the capillary network, plasma, and red cells, where it binds to hemoglobin. Through the bloodstream, oxygen is further transported to other organs and tissues. In addition, during exhalation, carbon dioxide from blood is released into the air (Hedenstierna & Borges 2016). The measures of respiratory function have also been suggested to indicate general health or vitality because this function is associated with survival (Persson et al. 1986) and several diseases, such as cardiovascular diseases (Ljungquist, Berg & Steen 1996), diabetes (Engström & Janzon 2002), and dementia (Guo et al. 2006). Respiratory function peaks in young adulthood and remains stable with minimal change from ages 20 to 35, after which it starts to decline. Changes in respiratory function are related to several factors, such as lung elasticity, weakened respiratory muscle strength, increasing stiffness of the chest wall, and decreased surface area for alveolar gas exchange (Dyer 2012; Thomas et al. 2019). In addition to age, lung volumes also depend on sex and body size, especially height (Lee, Park & Han 2016), as well as lifestyle habits (e.g., smoking, physical activity) and environmental exposure (e.g., pollution). Age-related declines in respiratory function may become an important limiting factor for physical activity (Roman, Rossiter & Casaburi 2016).

Respiratory function is usually measured with spirometry, which is a physiological test assessing the maximal amount of air that an individual can inspire and expire with maximal effort and is indicated as either volume or flow as a function of time (Graham et al. 2019). The most often used measurements are forced vital capacity (FVC), forced expiratory volume in the first one second (FEV1), and peak expiratory flow (PEF). FVC refers to the maximum amount of air that can be forcibly exhaled from the lungs after full inhalation, and FEV1 refers to the amount of air that can be exhaled forcibly during the first second. Decreased values in both FVC and FEV1 may be an indication of restrictive ventilatory impairment, whereas normal FVC but decreased FEV1 may show obstructive ventilatory impairment. Two common examples of obstructive problems include chronic obstructive pulmonary disease (COPD) and asthma (Barreiro & Perillo 2004). PEF refers to the maximum speed of expiration and is also used to detect obstructive impairments (Jackson & Hubbard 2003).

2.2.4 Birth cohort differences in physical health and functioning

Earlier studies assessing cohort differences in the health and functioning of older people have given a mixed picture. The Health and Retirement Study from the United States, which included 31 568 community-dwelling adults aged 65 and older, showed an increasing prevalence of chronic conditions. The proportion reporting one or more chronic diseases increased from 87% in 1998 to 92% in 2008 (Hung et al. 2011). In line with this, a significantly higher prevalence of chronic conditions was found among adults aged 51–61 in the 2000s when compared with the 1990s (Beltrán-Sánchez, Jiménez & Subramanian 2016). These increments were particularly shown in cancer, diabetes, high blood pressure, and psychiatric disorders. However, in Finland, the representative Health 2011 survey, which included 8 135 participants, showed that the prevalence of many chronic diseases was lower compared with 11 years earlier. Positive trends were observed in, for example, diseases of the circulatory system, mental distress, and accidental injuries, whereas the prevalence of depression and asthma was shown to be unchanged. However, diabetes became more common, although the average level of glucose in the population was lower than before (Koskinen, Lundqvist & Ristiluoma 2012). Differences in the number of chronic conditions is highly dependent on diagnostic criteria and does not necessarily describe the burden of the diseases and aging-related functional changes, which may be better captured with functional status measurements and self-rated health. The majority of the earlier studies focusing on physical functioning and health have been based on self-reported data, which apart from intrinsic capacity, may be influenced by environmental circumstances (Christensen et al. 2013). In a study investigating Danish nonagenarians, a later-born cohort of older adults at 95 years scored better in activities of daily living compared with a cohort born 10 years earlier at 93 years (Christensen et al. 2013). In Finland, Heikkinen et al. (2011) found similar trends among 65–69-year-old adults between 1988 and 2004. Significant improvements were found in self-rated health and the ability to carry out the activities of daily living. Also, contradicting trends have emerged. Between 1996 and 2010, Chen and Sloan (2015) investigated the Baby Boomer generation in the United States born 1946–1964 at the age of 50 or older and their spouses or partners. In this sample, disability rates remained unchanged or increased. The mixed findings may have arisen from the differences in the age groups studied, intervals between cohorts, indicators of health and functioning, different secular trends between countries, and problems in the comparability of the earlier- and later-born cohorts.

Only a few studies have assessed cohort differences in performance-based maximum measures of physical functioning, and these results appear to be inconsistent. Strand et al. (2019) reported increased grip strength among 66–84-year-old Norwegian adults between 1994 and 2016. Similarly, small improvements in grip strength were found among 60–79-year-old Japanese adults between 1998 and 2017 (Tomkinson et al. 2020). Wranker et al. (2019), in turn, reported improved walking speed but no cohort differences in grip strength among 60-year-old Swedish adults between 2001 and 2016. Also, among Danish nonagenarians, no improvements were noted in grip strength between 1998 and 2010 (Christensen et al. 2013). Slight declines in grip strength were observed among more recent cohorts of English adults aged 50–89 between 2002 and 2013 (Dodds et al. 2019). In addition, a large population-based study investigating older adults from Germany, Sweden, and Spain found opposing trends in grip strength for different age groups. The results indicated a large improvement for older adults aged 80 years and older, while among younger cohorts of older adults, the trend stagnated or even declined (Beller et al. 2019).

When interpreting the results of birth cohort comparisons, it is noteworthy that timing and rate of age-related changes may not occur simultaneously between the organs and biological systems within and between individuals (Cooper et al. 2010; Wagner et al. 2016). Earlier studies have shown, for instance, that muscle strength declines earlier than walking speed and possibly precedes a decline in lung function (Sillanpää et al. 2014; Newman et al. 2016). To contribute to building a more comprehensive picture of the cohort differences in physical performance, the current study includes cohort comparisons in multiple measures, that is, grip strength, knee extension strength, walking speed, and lung capacity.

2.3 Psychosocial resources and aging

Psychosocial resources refer to individual psychological factors and social relationships and roles, which are strongly tied together (Taylor & Broffman 2011). It has been widely recognized that social relationships and networks are crucial for development, health, and well-being throughout the whole life course and may be considered either as protective or risk factors. Social connections to others range from close personal relationships to the societal systems. The relationships may be categorized as structural (e.g., social isolation, living arrangements), functional (e.g., perceived loneliness and social support), or according to their quality (e.g., quality of marital relationship) (Holt-Lunstad 2018). Psychological resources refer to the personal attributes of the individuals. Hobfoll (2002) described psychological resources as entities that hold value in their own right, but in the context of resilience research, psychological resources have been viewed as a means to obtain positive outcomes despite adversity.

Psychosocial resources have been suggested as influencing health through at least three biospsychosocial pathways: 1) the promotion of other psychosocial factors (e.g., stress buffering, enhancing coping skills), 2) behavioral pathways (e.g., healthy lifestyle, physical activity), and 3) biological pathways (e.g., hypothalamic-pituitary-adrenal axis, immune system, physical fitness) (Berkman et al. 2000; Kim et al. 2021). Among older adults, evidence suggests that in stressful situations, social support serves to reduce and buffer the expected negative effect of adversities on mental health. For example, Netuveli et al. (2008) studied resilience among 3 581 British adults aged 50 years or older who were bouncing back after adversity by returning to their pre-exposure level in mental health. The results indicate that receiving social support before and during adversity increased the likelihood of showing resilience by 40–60% compared with those with low social support. In a study by Hildon et al. (2009), resilience was studied in 174 participants aged 68-82 years as maintaining better-than-average quality of life (QoL) in the face of significant adversity. Good-quality relationships, integration in the community, developmental coping, and adaptive coping styles were found to be especially important among those participants showing resilience. In the current study, the role of living arrangements as an indicator of structural connections and absence of loneliness and self-rated stress-coping ability representing an individual's perceived psychosocial resources are of key interest.

2.3.1 Living arrangements and loneliness

In most countries, the number of older people living alone has been rising, primarily because of the aging population, widowhood, modernization and cultural transitions, individual values, and the accessibility to social services (Reher & Requena 2018). Studies have indicated that living alone may predispose individuals to social vulnerability, such as social isolation and loneliness (Routasalo et al. 2006; Iliffe et al. 2007), which, in turn, may lead to negative health behavior, higher blood pressure, and markers of inflammation (Rees, Karter & Young 2010; Shankar et al. 2011). Older adults living in single households may be particularly vulnerable during times of adversity, when the need for emotional and instrumental support may be increased. In turn, older adults living with someone may receive instrumental and emotional support (Blozik et al. 2009), which has been recognized as an important resource for resilience. For example, Fuller-Iglesias et al. (2008) investigated resilience with depressive symptoms and life satisfaction among 99 men and women older than age 65 who had experienced six or more major negative life events over the past 12 years. The results show that larger network size and good-quality spousal relationships increased the likelihood of having fewer depressive symptoms and greater life satisfaction. Although living alone has been a widely used proxy for social isolation and loneliness, these all form different aspects of psychosocial well-being, which cannot be entirely measured by the situational or structural factors of an individual's life (Perissinotto & Covinsky 2014). Therefore, the question of living arrangements may not alone provide a good picture of an individual's social milieu, especially about the subjective experience of isolation or belonging. Loneliness refers to a subjective distressing emotion resulting from a discrepancy between one's actual and desired social relationships (Cacioppo & Patrick 2008). While the presence of loneliness may indicate a lack of psychosocial resources, the opposite—absence of loneliness—may be an indirect indicator of satisfaction with emotional or social support. Consequently, in the present study, not perceiving loneliness is considered one of many psychosocial resources.

2.3.2 Self-rated coping ability

The concept of coping has been significant in the psychology and resilience literature in the past few decades. Coping is central in several of the cognitive processes people use to manage the demands created by stressful events (Lazarus & Folkman 1984). These cognitive processes are categorized as problem focused, aiming to eliminate the stressor itself or diminish its impact, or by taking problem-solving actions and emotion-focused processes, here aiming to minimize distress caused by the stressor (Lazarus & Folkman 1984). In addition, a third classification has been proposed by Billings and Moos (1981) as a third classification—appraisal-focus coping—which refers to attempts to define the meaning of a situation. It includes such strategies as logical analysis, cognitive redefinition, and cognitive avoidance. Theoretically, stress-coping referring to the actual efforts that are made in an attempt to adapt to stressors is strongly linked to Antonovsky's theory of salutogenesis and its central concept of sense of coherence, which refers to an individual's tendency to see the world as more or less comprehensible, manageable, and meaningful (Lindström & Eriksson 2005). In addition, many other personal qualities or traits, such as high self-efficacy and self-esteem, determination, and optimism, may underlie successful stress-coping ability. Some of these may be more stable traits, and some may be learned behaviors that develop over the life course (Resnick 2021).

Some researchers have conceptualized successful stress-coping ability as an indicator of resilience as such (Connor & Davidson 2003; Rutter 2006). However, according to the socioecological perspective, other factors may also play an important role in adaptation; therefore, in the current study, stress-coping is studied as one potential resource for resilience. Stress-coping is conceptualized as self-reliance on one's ability to manage the different adversities of life and is assessed using a scale of psychological resilience administered prior to the adversity. In their responses, the participants did not consider any specific adversity but most likely assessed their ability to cope based on their past experiences. Earlier studies have shown that a good self-rated stress-coping ability is an important characteristic in challenging circumstances. For example, Siltanen et al. (2020) reported that a higher stress-coping ability may alleviate the negative effects of early phase walking difficulties in active aging.

2.4 Framework of this study

The present study investigates birth cohort differences in physical performance, which may reveal the significance of changing sociohistorical contexts on functioning and potential resilience resources in older age. In addition, the current study applies the resilience framework in suddenly occurring but different adversities: bone fractures and COVID-19 social distancing recommendations caused by the SARS-CoV-2 virus pandemic.

2.4.1 Changing sociohistorical contexts and resources for resilience

Because resilience is a process emerging from the continuing interactions between an individual and a changing environment, the sociohistorical context in which individual development takes place may have a substantial influence on the resources and, consequently, the capacity to overcome adversity (Ungar 2013). The individuals from different birth cohorts may be exposed differently to favorable and unfavorable factors (Wister et al. 2016), and more propitious exposures during earlier life phases may build resources for resilience to later life. For example, in Finland, several societal reforms and changes have taken place over the past century. In the early 1900s, Finland was mainly an agrarian economy, and from an early age, children engaged in heavy manual work and lived through the Civil War in 1918 and the Second World War from 1939 to 1945. The Nordic welfare system have roots in the 1940s, when many reforms were implemented, such as free school meals for all children and longer obligatory education. These developments in society most likely improved, for example, the nutritional situation of individuals and delayed children's entry into the labor market. Higher education is known to be related to better jobs and financial situations, psychosocial resources, and more beneficial health behavior, all of which influence to health and functioning (Ross & Wu 1995). For instance, increased educational attainment during the past few decades has been associated with better cognitive performance in middle and old age (Karlsson et al. 2015; Munukka et al. 2020). In turn, heavy manual work in earlier life phases has been shown to be associated with an increased likelihood of health problems in later life (Kulmala et al. 2016). Therefore, birth cohort differences in health and functioning may reveal the broader sociohistorical contexts influencing the development of resilience resources in old age.

2.4.2 Bone fractures and survival

Bone fractures are common acute adversities in old age and a major public health problem globally (Compston, McClung & Leslie 2019). The occurrence of bone fractures is associated with an increased risk for several negative outcomes. For example, Wolinsky et al. (1997) studied the effect of hip fractures on mortality, hospitalization, and functional status among 7 527 participants initially over the age of 70, of whom 368 sustained a hip fracture during a 7-year follow-up. The occurrence of hip fracture was found to be associated with increased risk for mortality, especially during the first six months after the fracture. In addition, the occurrence of a hip fracture increased the likelihood of subsequent hospitalization and number of functional status dependencies. In old age, the increased mortality hazard after bone fractures is a result of several factors, such as complications and infections (Kanis et al. 2003; Farahmand et al. 2005), or other factors, such as pain commonly accompanied by inactivity, which may further complicate recovery (Resnick et al. 2011). The occurrence of a fracture often triggers progressive functional loss, leading to disability, which may elevate long-term mortality risk. Mortality is a widely used and powerful indicator of the burden of diseases and health decline, even though it does not provide direct information about recovery or positive adaptation. However, considering that bone fractures in older adults are severe injuries, simply avoiding the most negative outcome, that is, death, may indicate a good outcome (Windle, Bennett & Noyes 2011). Studying survival after bone fractures may give insights into the resilient and nonresilient responses of individuals by giving indirect information about recovery.

Previous studies have shown controversial results regarding whether a nonhip nonvertebral fracture is associated with excess mortality. Using Danish register-based data, Tran et al. (2018) reported excess mortality for about 5 years after fracture when counting for all proximal and lower leg fractures and for at least 10 years after hip fractures. Considering this, the present study takes into account several fracture types, except for fractures of the toes and fingers. Another aspect of survival after bone fractures involves the temporal dimension. In many studies, survival after bone fractures has been studied as a fixed dichotomous variable. However, most deaths after a bone fracture occur within the first postfracture year, after which the excess mortality gradually declines (Forsén et al. 1999; Tran et al. 2018). Therefore, the special interest of the current study focuses on the prefracture physical and psychosocial reserves predicting survival during the first years after fracture.

2.4.3 COVID-19 social distancing recommendations and maintenance of a high quality of life (QoL)

In the beginning of 2020, the rapid, worldwide outbreak of a novel coronavirus SARS-CoV-2 was declared a pandemic (World Health Organization 2021). To suppress disease transmission, all over the world, various social distancing measures were put into practice. The social distancing recommendations designed to curb the spread of the virus created an unforeseen natural experimental setting because an adversity was encountered by the whole population. In Finland, the government announced on March 16, 2020, that the COVID-19 epidemic in Finland constituted a state of emergency, and the Emergency Powers Act entered into force. During the spring of 2020, persons aged 70 years and older were advised to avoid close physical contact with all other people except members of their household. All social activities were suspended, and destinations of interest, such as indoor exercise facilities, restaurants, libraries, and social clubs, were closed, thereby reducing older adults' possibilities for social interactions and participation in meaningful activities. Engaging in activities of choice and maintaining social interactions in older age contribute to maintaining and achieving greater well-being and quality of life (QoL) (Havighurst 1961; Atchley 1989). According to Deci and Ryan (2000), people are naturally motivated to engage in the activities that fulfill their needs for autonomy, relatedness, and competence. Although functioning to contain the spread of the virus, social distancing imposed an intervention that, by reducing the environmental resources for activity, negatively influenced many of the components of older adults' QoL (Rantanen et al. 2020) and psychosocial functioning (Tull et al. 2020; Minahan et al. 2021).

QoL is a multidimensional construct that reflects a person's satisfaction with the essential aspects of life (Netuveli & Blane 2008). Understanding the diverse experiences of older people, including adaptation to adversities, is relevant for better understanding the formation of good QoL in old age (Hildon et al. 2008). Considering the context of COVID-19 social distancing recommendations, examining stability and changes in QoL may capture the important aspects of adaptation to changed environmental conditions. In the current study, it was assumed that maintaining a stable and high level of QoL despite reduced environmental possibilities for activity and social contacts reflects resilience amid COVID-19 social distancing measures.

In the early phases of the pandemic, the duration, consequences, and factors that help older adults adapt to social distancing recommendations were largely unknown. Subsequently, emerging research has begun to study the protective factors against COVID-19 pandemic-related stressors on psychosocial functioning among older adults. Studies have found that psychosocial resources, such as positive coping behaviors and perceiving social support despite social distancing restrictions, helped maintain well-being during the COVID-19 pandemic (Minahan et al. 2021; Müller et al. 2021). In turn, there have been concerns that older adults living in single households may be more vulnerable to social isolation and at risk of perceiving loneliness during social distancing (Minahan et al. 2021), both of which are known to have a negative influence on mental and physical health (Holt-Lunstad et al. 2015; Beutel et al. 2017). However, only a few studies have data before and amid the pandemic and, hence, can provide a longitudinal view on adaptation. In a study by Creese et al. (2020) among adults over 50 years of age, not perceiving oneself lonely but also maintaining physical activity were reported as important protective factors against declining mental health during the pandemic. Among older adults, higher out-of-home mobility has been shown to be associated with a higher amount of daily physical activity (Tsai et al. 2016). According to recent reports among Finnish older adults, life-space mobility declined during social distancing compared with two years earlier (Rantanen et al. 2020), and most of the activity destinations included walking for fitness and visiting outdoor exercise facilities that remained open (Portegijs et al. 2021). However, especially among older adults, reduced physical capacity may diminish the possibilities for salutary activity, particularly when environmental support and opportunities are limited (Portegijs et al. 2017). Although there has been more research on the role of psychosocial resources, to the best of the author’s knowledge, the role of older adults’ physical capacity predicting resilience during the COVID-19 pandemic has not been studied.

2.4.4 Conceptual framework

In the current study, the socioecological model of resilience was employed as a framework; it covers several, partly overlapping, theories and models focusing on adaptation in old age and the development of resources during the life course. The present study borrows elements from different socioecological models that have been developed in the context of resilience research (Aldwin & Igarashi 2012; Windle & Bennett 2012; Wister et al. 2016). The central idea of all models is that the process of resilience is context specific and depends on the resources within the individual and multilayered environmental spheres. In the conceptual model of the present study (Figure 3), the onset of adversity is taken as a starting point, which has the potential to lead to the disruption of well-being, health, or function. The next phase of the process is the activation of resources that need to be mobilized to successfully overcome adversity. The use of these resources further engages the adaptation processes and reintegration, which may be observed as positive outcomes, such as survival after a bone fracture or maintenance of a high QoL during COVID-19 social distancing. Finally, the resources that individuals mobilize may depend on earlier life phases and sociohistorical conditions.

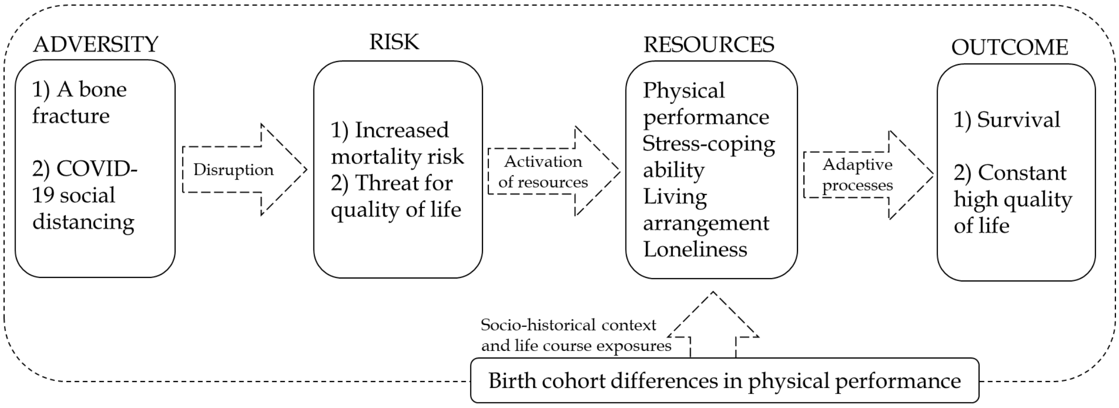


FIGURE 3 Conceptual model of the process of resilience. Adopted from Wister et al. (2016) and Windle and Bennet (2012).

3 PURPOSE OF THE STUDY

The purpose of the current study was to investigate the influence of changing sociohistorical conditions on physical performance in old age by comparing same-aged, community-dwelling older adults born 28 years apart. A further aim was to study the role of physical performance and psychosocial factors as predictors of resilience by exploiting two suddenly occurring adversities: bone fractures and COVID-19 social distancing recommendations. The research questions were as follows:

1. Do older adults nowadays have better physical performance compared with an earlier cohort measured at the same age 28 years earlier? What factors underlie the potential cohort differences? (Study I)
2. Is the predictive power of walking speed and muscle strength for mortality different after a fracture compared with time without a fracture among older adults? (Study II)
3. Is living alone in old age associated with higher mortality hazard after a bone fracture, and is the potential association different when compared with time without a fracture? (Study III)
4. Do walking speed, living arrangement, perceived loneliness, or self-rated stress-coping ability promote the maintenance of a high QoL during COVID-19 social distancing recommendations among older adults? Are some factors particularly beneficial among those who perceived the recommendations as restrictive? (Study IV)

The analytical framework is presented in Figure 4. Cohort differences in physical performance were studied by comparing the results of the Evergreen and AGNES cohorts (Study I). The associations of physical performance and psychosocial factors with mortality hazard after a bone fracture and maintenance of a high QoL during COVID-19 social distancing recommendations were studied using longitudinal study designs (Studies II, III, and IV).

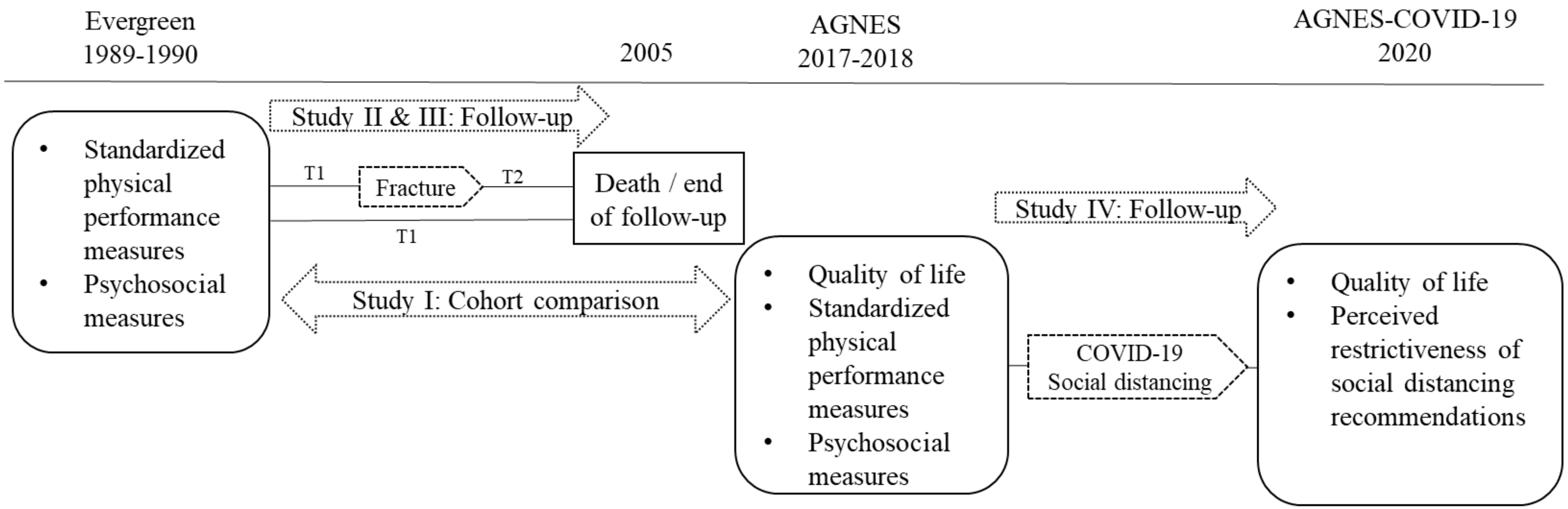


FIGURE 4 The analytical framework of the study. T1 refers to the time without a fracture and T2 the time after fracture.

4 MATERIALS AND METHODS

4.1 Study designs, participants, and nonparticipants

The data from the present study came from Evergreen and AGNES (Active Aging—Resilience and External Support as Modifiers of the Disablement Outcome) projects conducted at the University of Jyväskylä and Gerontology Research Center (GEREC). The study designs and datasets are summarized in Table 1.

TABLE 1 Summary of the study designs and participants

Dataset	Study	Design	n	Age, years, %
Evergreen	I, II, III	Observational, 15-year follow-up for fractures and mortality Birth cohort comparison	617	75yrs, 58% 80yrs, 43%
AGNES	I, IV	Observational, Birth cohort comparison	1021	75yrs, 45% 80yrs, 33% 85yrs, 22%
AGNES-COVID-19	IV	Observational, 2-year follow-up	809	75yrs, 48% 80yrs, 33% 85yrs, 20%

4.1.1 Evergreen cohort (Studies I, II, and III)

Evergreen was a collaborative research program between the University of Jyväskylä and the City of Jyväskylä in Central Finland (Heikkinen 1998; Heikkinen 2003). The baseline study was conducted in 1989–1990, for which all the 75- and 80-year-old residents of the city of Jyväskylä formed the target group

(N=679). Eligible participants (n=652) were sent a letter informing them about the study and suggesting a time for a home interview. Those who declined were asked to give their reasons for nonattendance, and the reasons were documented. Interview and questionnaire data are available for 617 persons (participation rate 95%), of whom 599 were community-dwelling and formed the sample for the survival analyses in Study III. Of these community-dwelling participants, 500 (83%) took part in research laboratory assessments and comprised the study sample for the birth cohort comparisons in Study I and survival analyses in Study II. The data have been linked with hospital records of physician-diagnosed fractures and population register data on death dates, which were utilized in the survival analyses in Studies II and III.

4.1.2 Active Aging—Resilience and External Support as Modifiers of Disablement Outcome (AGNES; Studies I and IV)

The AGNES baseline study was conducted in 2017–2018. The study comprises three age cohorts (75, 80, and 85 years at baseline) living independently in the municipality of Jyväskylä, Finland (Rantanen et al. 2018). The participants for the cohort study were recruited from the Population Information System, which was administered by the Digital and Population Data Services Agency based on their place of residence and birth year. The total population target sample was 2 791 people, of whom 2 348 were contacted by phone and informed about the study (Portegijs et al. 2019). In addition to age and place of residence, the inclusion criteria were willingness to participate and ability to communicate with researchers. Of the contacted people who refused to participate, 866 of 1324 (65%) answered a brief nonrespondent phone interview. A postal questionnaire was sent to the participants who agreed to take part in the study, and a face-to-face interview at the participants' home, including physical performance tests, was scheduled. In total, 1 021 participants completed the postal questionnaire and/or the at-home interview (participation rate 46%). The interview was administered using computer-assisted personal interviewing (CAPI). At the end of the interview, time for assessments in the research center laboratory were programmed. Subsequently, 910 participants took part in the assessments at the research center. For birth cohort comparisons (Study I), selected measurements of the AGNES study were conducted in ways comparable to Evergreen. In the cohort comparisons, only participants aged 75 and 80 years were included. Figure 4 presents the flow chart of the study samples aged 75 and 80 years of the Evergreen and AGNES cohorts attending to the assessments at the research center.

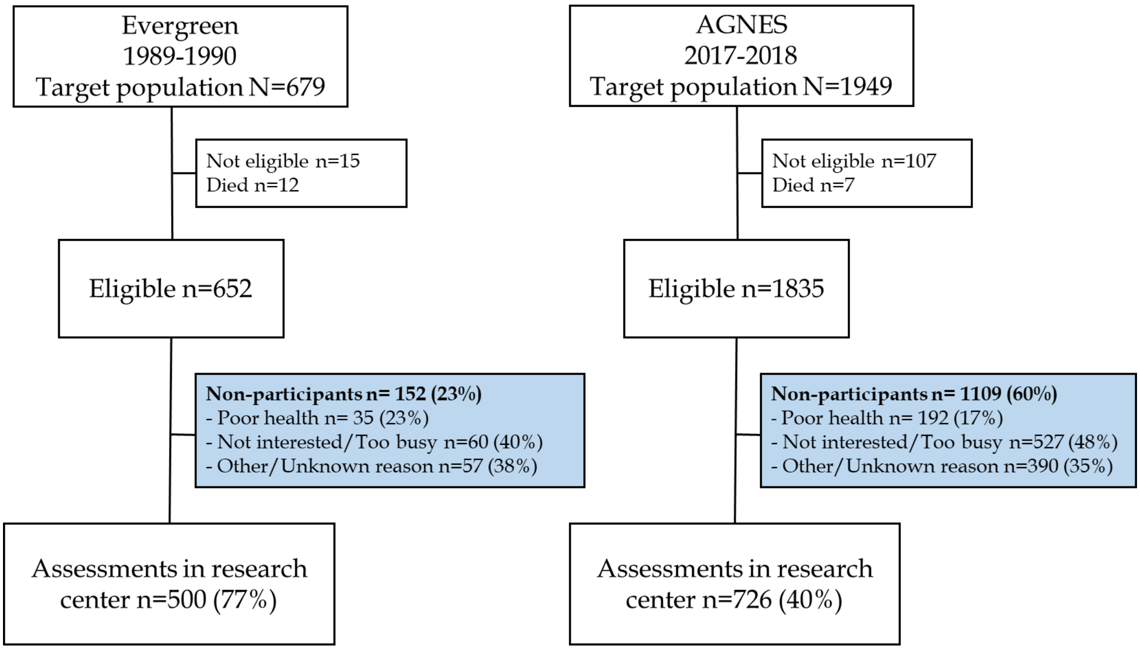


FIGURE 5 Flow chart of the study samples of the Evergreen and AGNES cohorts, including the participants aged 75 and 80 years and attending to assessments at the research center (Study IV).

The AGNES-COVID-19 follow-up survey was collected in May and June 2020 during the COVID-19 pandemic social distancing recommendations. Of the 1 021 AGNES baseline participants who had not withdrawn their consent and who had responded either to the questionnaire or home interview, 985 were alive, and they formed the target group of the survey. To avoid physical contact, data were collected by sending postal questionnaires to eligible participants and by phone interviews if the participant had difficulty answering the questionnaire or preferred an interview. In total, 809 responses were received (82% of the target group). In Study IV, longitudinal analyses of the data collected at baseline and amid COVID-19 social distancing recommendations are presented. The analyses comprise the participants for whom data were available for QoL at baseline and follow-up and all other key measures (n=685).

4.1.3 Nonparticipants

Nonparticipants' self-rated health was examined with an item— 'How would you yourself describe your health during the last year?'—using a five-option response scale ranging from very poor to very good. For statistical analyses, the responses were recoded as good, moderate, and poor. In the Evergreen study, the above question was asked during the home interview, while in AGNES, it was posed during the initial phone call. In both cohorts, the participants attending the research center assessments reported better health than those who participated only in the home interview (Portegijs et al. 2019). Because of differences in the participation rates in laboratory assessments (Figure 5), the comparability of the Evergreen and AGNES cohorts was assessed based on the data available for nonparticipants (Study I). The reasons for nonparticipation were categorized as "Poor health," "Not interested/do not have time," and "Other or unknown reasons" (participation in other study, language difficulties, poor hearing, caregiver, finding the study complicated, reason not known, or no contact). Poor health was a slightly more common reason for nonparticipation in the earlier-born cohort (Table 2). Information on self-rated health was available for 47% of the nonparticipants in the Evergreen cohort and for 73% of the nonparticipants in the AGNES cohort. No differences were found in the self-rated health between the nonparticipants of the two cohorts (chi-square test p = .539). There were no systematic differences between the nonparticipants of the cohorts, supporting the comparability of the birth cohorts.

TABLE 2 Reasons for nonparticipation of the nonparticipating 75- and 80-year-old men and women in 1989–1990 (Evergreen cohort) and 2017–2018 (AGNES cohort)

	Men		Women	
	Evergreen n (%)	AGNES n (%)	Evergreen n (%)	AGNES n (%)
75yrs, n	20	211	59	288
Poor health	3 (15)	28 (13)	13 (22)	46 (16)
Not interested/do not have time	12 (60)	109 (52)	21 (36)	141 (49)
Other or unknown reasons [a]	5 (25)	74 (35)	25 (42)	101 (35)
80yrs, n	13	236	60	374
Poor health	4 (31)	41 (17)	15 (25)	77 (21)
Not interested/do not have time	6 (46)	119 (50)	21 (35)	158 (42)
Other or unknown reasons [a]	3 (23)	76 (32)	24 (40)	139 (37)

Note. [a] Participation in another study, language difficulties, poor hearing, caregiver, finding the study complicated, reason not known, or no contact.

4.2 Ethics

All participants in the Evergreen study signed an informed consent form when they entered the study, and the research ethical principles required at the time were followed. The ethical committee of the Central Finland Hospital has evaluated and approved the research plan of the AGNES study (August 23, 2017). The same ethical committee considered (May 13, 2020) that the initially signed consent of the AGNES study would cover the AGNES-COVID-19 survey because the survey is an extension of the initial study and not a separate study. Invasive or potentially physically or psychologically harmful elements that would exceed the harm one might experience in everyday life were not included in the studies. The participants of the AGNES cohort were informed about the nature of the study and the way in which data would be used and managed, and all participants signed a written consent form. The digital data gathered for both studies were stored and treated confidentially on the University of Jyväskylä server. The pseudonymized data were accessible to the researchers behind university passwords.

4.3 Measurements

The variables used in the current study are summarized in Table 3.

TABLE 3 Summary of the variables used in the study

Variable	Study	Methods
Physical performance		
Walking speed	I, II, IV	10-meter maximal walking speed test
Grip strength	I & II	Maximal isometric test
Knee extension strength	I & II	Maximal isometric test
Respiratory function	I	Spirometry (FVC, FEV1, PEF)
Psychosocial resources		
Living arrangements	III & IV	Single item
Loneliness	IV	Single item
Stress-coping ability	IV	10-item CD-RISC questionnaire
Adversities		
Bone fractures	II & III	Patient records
Perceived restrictiveness of COVID-19 social distancing recommendations	IV	Single item
Outcomes of positive adaptation and survival		
Survival time	II & III	Digital and Population Data Services Agency
Quality of life	IV	OPQOL questionnaire
Covariates and descriptive variables		
Age	I-IV	Digital and Population Data Services Agency
Sex	I-IV	Digital and Population Data Services Agency
Height	I & II	Laboratory test
Weight	I & II	Laboratory test
Educational background	I–III	Single item
Marital status	III	Single item
Physical activity	I, II, III	Single item
Cognitive functioning	IV	MMSE
Smoking	I–III	Single item
Number of chronic conditions	II, IV	Questionnaire, ascertained in a subsequent clinical examination
Self-rated health	I & III	Single item
Depressive symptoms	III	CES-D 20-item questionnaire

Note. FVC = forced vital capacity, FEV1 = forced expiratory volume in 1 second, PEF = peak expiratory flow, CD-RISC = Connor-Davidson Resilience Scale, OPQOL= Older People's Quality of Life Questionnaire, MMSE = Mini-Mental State Examination, CES-D = Center for Epidemiological Studies Depression Scale.

4.3.1 Maximal walking speed

The 10-meter maximal walking speed was assessed in a laboratory corridor using a hand-held stopwatch (Studies I and II) and photocells (Study IV). In the Evergreen cohort, 2–3 meters were allowed for acceleration and deceleration (Sakari-Rantala et al. 1998). In the AGNES cohort, 5 m were allowed for acceleration, and walking was instructed to stop well past the finish line (Rantanen et al. 2018). In both cohorts, the participants wore walking shoes or sneakers and were allowed to use a walking aid, if needed. The test–retest reliability of the maximal walking test with a one- to two-week interval has been shown to be good in our research center (Sipilä et al. 1996).

4.3.2 Maximal isometric muscle strength

Muscle strength was assessed using maximal isometric *grip strength* and *knee extension strength*. The tests were performed in the AGNES cohort (Study I) using an adjustable dynamometer chair (Good Strength; Metitur Oy, Palokka, Finland) (Rantanen, Era & Heikkinen 1997). For the Evergreen cohort (Studies I and II), the prototype of the Good Strength device was used, including similar strain gauge technology. In both cohorts, the measurements were performed identically with similar joint angles and instructions to the participant. The measurements were performed on the side of the dominant hand in a sitting position with the lower back being supported. Hand grip strength was measured using a dynamometer fixed to the arm of the chair. Knee extension strength was measured at an angle of 60 degrees from the fully extended leg toward flexion. After a practice trial, the test was performed at least three times with a one-minute intertrial rest period until no further improvement occurred; the highest value was recorded (Rantanen et al. 2018). The test–retest reliability of both tests was found to be excellent. In the 80-year-olds, the Pearson correlation coefficients between measurements conducted 1–2 weeks apart were r = .967 for hand grip strength and r = .965 for knee extension strength (Rantanen, Era & Heikkinen 1997). The results of muscle strength tests were expressed in Newtons (N).

4.3.3 Respiratory function

Respiratory function was assessed in the Evergreen and AGNES cohorts (Study I) using spirometry. In the AGNES cohort, a Medikro Pro spirometer (Medikro Oy, Kuopio, Finland) was used, and the test was performed in a standing position with a nose clip. The FVC maneuver was performed at least two times. The participants were instructed to inhale maximally, exhale as hard and as fast as possible, and continue until there was no air left. This maneuver was continued until the criterion of the ATS/ERS (American Thoracic Society/European Respiratory Society) Taskforce was met (Miller et al. 2005) or a maximum of eight exhalations had been performed. With the Evergreen cohort, respiratory function was assessed using comparable electronic spirometry (Medikro 202; Medikro Oy, Kuopio, Finland) in a standing position, and three trials were allowed. In both cohorts, the highest volume of FVC and forced expiratory volume in one second (FEV1) were recorded in liters. PEF was recorded in liters per second.

4.3.4 Living arrangements

Living arrangements (Studies III and IV) were defined as living alone versus living with someone (a partner or another adult, e.g., family member) during baseline measurements. For the sensitivity analyses in Study III, information on possible changes in living arrangements was collected five years after the baseline. This information was available for 423 participants (95% of the survivors).

4.3.5 Loneliness

Loneliness was measured using a single structured item: "How often do you feel lonely?" The response options were placed on a 4-point scale: "Almost always," "Often," "Rarely," and "Very rarely/never" (Studies III and IV). For statistical analyses, the responses were recoded as *YES, at least sometimes* ("Almost always" to "Rarely") and *NO* ("Very rarely/never").

4.3.6 Stress-coping ability

Stress-coping ability was measured in Study IV with the 10-item Connor-Davidson Resilience scale (CD-RISC). The scale measures the self-rated ability or agency to adapt positively to changes and stressful situations in life (Connor & Davidson 2003). The scale includes items such as *"I am able to adapt when changes occur," "I can deal with whatever comes my way,"* and *"I think of myself as a strong person when dealing with life's challenges and difficulties."* The response options in the items range from 0 (not true at all) to 4 (true nearly all the time), totaling a sum score from 0 to 40 (higher scores indicate higher trust in one's own abilities to cope with stress). The scale has shown good properties in Finnish older adults in most of the psychometric domains, except for moderate test–retest reliability (ICC 0.615) (Tourunen et al. 2019). In the analyses, we included only participants who had at most three missing items in their answers. The missing items were imputed for 12 participants based on the mean of the responses they provided for the other items.

4.3.7 Bone fractures

The information on bone fractures (Studies II and III) was acquired from the patient records of the Area Health Centers and Central Hospital from the beginning of the year 1990 to the end of April 2005. The records include diagnosis, date, and area of fracture. The location of the fracture was taken into account by categorizing the fractures into proximal (hip, femur, pelvis, and spine) and distal fractures (upper extremity, lower leg and foot, head and collarbone) (Rantanen, Sakari-Rantala & Heikkinen 2002). For the participants who sustained at least one proximal fracture, the date of the first proximal fracture was chosen, while for participants who sustained distal fractures only, the date of the first distal fracture was chosen. Follow-up treatment after fracture was categorized as no follow-up treatment or treatment in an outpatient clinic versus treatment in a hospital ward (Study III).

4.3.8 Survival time

In the Evergreen project, the dates of death, as obtained from the Digital and Population Data Services Agency, included all deaths that occurred from the beginning of 1990 until the end of April 2005. Survival time was calculated as the number of days from the baseline interview date to either the date of death or the end of the follow-up period (Studies II & III). Mortality was used as an indirect indicator of the failure of recovery after bone fractures.

4.3.9 Quality of life

QoL was assessed with a 13-item version of the Older People's Quality of Life questionnaire (OPQOL-brief; Study IV) at the baseline and amid the social distancing recommendations. The scale consists of items related to life overall and more specific life domains, such as health, independence, and control over life, social relationships and leisure/social activities, home and neighborhood, psychological and emotional well-being, and financial circumstances. For example, the scale includes items such as: *"I enjoy my life overall," "My family, friends, or neighbors would help me if needed,"* or *"I have social or leisure activities/hobbies that I enjoy doing."* The response options range from 1 (strongly disagree) to 5 (strongly agree), and the total sum score ranges from 13 to 65, with higher values indicating higher quality of life. The OPQOL-brief has shown to be a valid and reliable measurement among older adults (Bowling et al. 2013). In Study IV, a constant high QoL was defined as maintaining a QoL score in the highest quartile at baseline (⩾59 points) and maintaining it at the same level amid social distancing. The participants who did not meet these criteria were considered to have low/moderate QoL. Distribution-based criteria were chosen because no validated threshold value for a high QoL exists in the OPQOL scale.

4.3.10 Perceived restrictiveness of social distancing recommendations

In Study IV, the participants assessed on a 5-point response scale ranging from 0 (not at all) to 4 (very much) the extent to which the social distancing recommendations prevented them from engaging in activities they would have liked to do. The responses "Not at all" and "Little" were categorized as NO perceived restrictiveness, indicating less severe adversity, and the responses "Somewhat," "Much," and "Very much" were categorized as YES for perceived restrictiveness, indicating more severe adversity.

For the statistical analyses, a variable from different combinations of the categories of QoL and perceived restrictiveness of the social distancing recommendations was created as follows: constant high QoL + yes perceived restrictiveness (QoL resilience), constant high QoL + no perceived restrictiveness, low/moderate QoL + yes perceived restrictiveness, and low/moderate QoL + no perceived restrictiveness.

4.3.11 Covariates and descriptive variables

Information on the participant's age and sex was drawn from the Digital and Population Data Services Agency. Height and weight were ascertained as part of the laboratory measurements on functioning. Body mass index was calculated based on measured height and weight (Study II) and was reported as kg/m^2.

Educational background was recorded as self-reported years of full-time education (Studies I–III). Marital status was examined with a single item (Study III) and was categorized as married, single, divorced, or widowed. Level of everyday physical activity was assessed with a single six-category question, where the respondent would choose the option that best described his/her typical level of physical activity, ranging from mostly sitting and resting to regular strenuous exercise (Rantanen, Era & Heikkinen 1997). For statistical analyses, in Study I, the physical activity variable was recoded in three categories based on a distribution indicating low, moderate, and high levels of physical activity. In Studies II and III, the variable was recoded into two categories indicating low and high physical activity levels. The participants whose self-reported amount of weekly physical activity did not meet the needed level of the current national physical activity guidelines for older adults (at least 2.5 h of moderate activity or at least 1.25 h of vigorous activity per week; UKK institute 2009) were assigned to the lower physical activity group.

Cognitive functioning was assessed with the Mini Mental State Examination (MMSE, Study IV), with higher scores indicating better results (Folstein, Folstein & McHugh 1975). Smoking status was examined with a single item and was classified according to whether the participant had ever been a smoker or not. Morbidity was assessed with the number of chronic conditions, which was calculated from self-reports and ascertained in a subsequent clinical examination by a physician (Studies II and III). Self-rated health (Studies I and III) was assessed with a single item, "How would you yourself describe your health during the last year?" in which there are five response options. For statistical analysis, the responses were categorized as good, moderate, and poor.

Depressive symptoms were measured with the Center for Epidemiologic Studies Depression Scale (CES-D Scale). The respondents were asked how often over the past week they experienced depressive symptoms. The response options range from 0 to 3 for each item. Scores range from 0 to 60, and higher scores indicate more depressive symptoms. Psychosocial factors were also studied with items asking the warmth of the spousal relationship and the number of close friends with single self-rated items (Study III).

4.4 Statistical analyses

All statistical analyses, except for the extended time-stratified Cox regression analyses used in Studies II and III, were done using the Statistical Package for Social Sciences (SPSS) versions 24.0–26.0 for Windows. The extended Cox regression analyses were performed using the R environment (version 3.5.1). The significance level was set at $p<.05$ in all analyses. In Studies I–III, the results are reported separately for men and women, and in Study I, the results are also reported separately for the age groups of 75- and 80-year-olds. The associations in Study IV were practically identical for both sexes, so for the final models, men and women were included in the same analyses, here adjusted for sex. In Study I, the analyses were not adjusted for any confounders because it was assumed that the differences in covariates between the birth cohorts were more likely to be factors indicating mechanisms underlying cohort differences in physical functioning and not confounding. In the other studies (II–IV), the adjusting covariates were selected in the statistical analyses based on their potential as confounders.

4.4.1 Descriptive statistics

Descriptive statistics were reported as means and standard deviations for continuous variables and as frequencies and percentages for categorical variables. Independent samples t-test, ANOVA, and a Welch test were used to analyze the differences between independent groups for continuous variables and chi-square tests for categorical variables. In Study IV, a linear regression analysis was used to describe changes in QoL between the two time points.

4.4.2 Multivariate models

Cohort comparisons and linear regression models (Study I)

To compare the physical performance results between two birth cohorts of 75- and 80-year-old men and women, t-tests for continuous variables and chi-squared test for categorical variables were used. To clarify the potential clinical significance of the cohort differences, grip strength cut points for increased risk for mobility limitation were determined separately for men and women based on Finnish reference data (37 kg for men and 21 kg for women) (Sallinen et al. 2010). The factors underlying the potential cohort differences were examined using a set of linear regression models. First, the models were fitted with each physical performance test as a dependent variable and birth cohort as an independent variable. Consequently, several models were run, adding covariates one at a time to analyze which of them attenuated the cohort differences in physical performance.

Survival analyses (II and III)
Extended Cox regression models were used to estimate the mortality hazard ratios in the participants with and without fractures in Studies II and III. A time-fixed exposure variable of having a fracture does not usually meet the proportional hazard assumption because the risk for death is the highest immediately after injury and attenuates during the following years (Forsén et al. 1999; LeBlanc et al. 2011). In addition, this covariate does not account for the "immortal time" bias related to the time spent fracture free before the fracture (Liu et al. 2012). To take into account these issues, fracture states were modeled as a time-dependent variable in a relative risk model based on a counting process formulation. The possible states for the study participants differed slightly between Studies II and III (Figure 6). In both studies, all the participants contributed to the nonfracture state until a fracture occurred or until death or end of follow-up if they did not sustain a fracture. The participants who sustained a fracture were assigned to the facture state for the first postfracture year. In Study II, a separate mortality hazard ratio was also estimated for the state after the first postfracture year until death or the end of follow-up. In Study III, the subjects were reassigned from the state of the first postfracture year to the nonfracture state unless they died or were censored because of the end of follow-up during the first-year period.

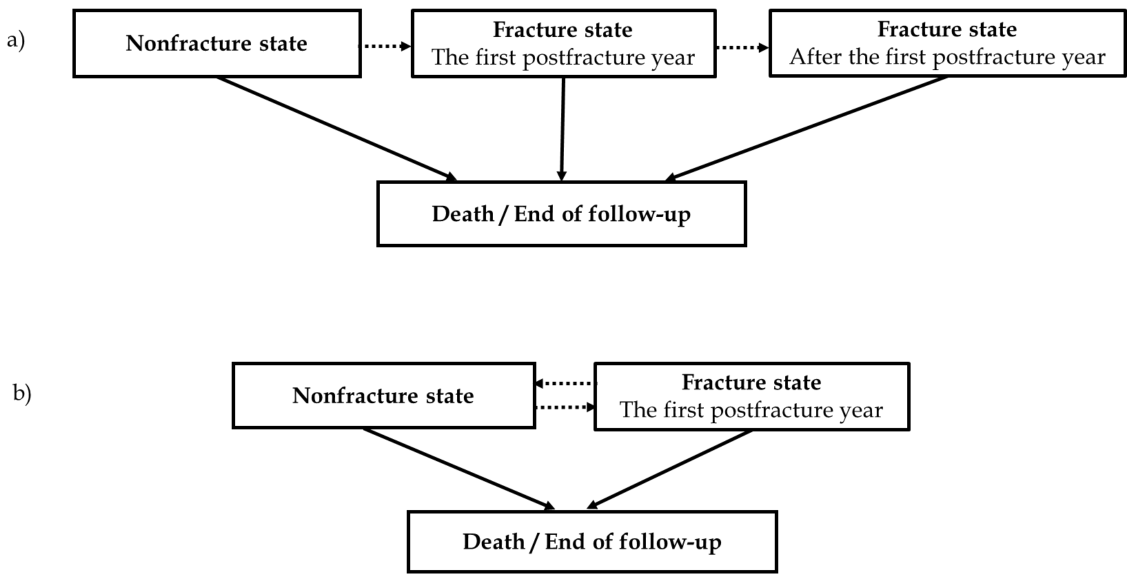


FIGURE 6 The possible states for the study participants in the extended illness–death model. a) Study II and b) Study III.

Interaction terms were used to investigate the associations between fracture state, gait speed, muscle strength, and living arrangements on hazard for mortality. In Study II, the gait speed and muscle strength variables were centered prior to entry in the model. The models were adjusted for baseline age, number of chronic conditions, and physical activity because of their association with the predictors (gait speed and muscle strength) and outcome (mortality hazard). The results are shown as aggregate hazard ratios (linear combinations) for gait speed and muscle strength in the fracture states.

In Study III, the main effects of living alone indicate the mortality hazard ratios compared with living with someone, and the main effects of fracture state indicate the mortality hazard ratios compared with nonfracture state. The interaction terms between living alone and fracture state were used to investigate whether the association between living alone and mortality hazard ratio is different in the fracture state (during the first postfracture year) compared with the association in the nonfracture state (other time periods in the follow-up) and were not presented as aggregate hazard ratios as in Study II. The associations of the living arrangements and fractures with mortality hazard, as adjusted for age at baseline, were analyzed first in the basic model. Model 2 was adjusted for age and loneliness, and model 3 was adjusted for age, loneliness, and self-rated health.

Logistic and multinomial regression models (Study IV)

A logistic regression analysis was used to identify the predictors of a constant high QoL and high perceived restrictiveness of social distancing separately. The potential predictors were baseline stress-coping ability, absence of loneliness, living arrangements, and walking speed. To test whether the associations of significant predictors with a constant high QoL vary according to perceived restrictiveness, separate logistic regression analyses for each predictor were conducted by adding the interaction term of predictor-by-perceived restrictiveness of social distancing with the main effects in the model. Finally, to identify the predictors of QoL resilience, a multinomial regression analysis was used with the nominal combination variable of QoL and perceived restrictiveness of social distancing as an outcome (reference group: low or fluctuating QoL + no perceived restrictiveness). All the predictors were added in the model simultaneously, and the model was adjusted for age, sex, MMSE, education, and chronic conditions.

5 RESULTS

5.1 Participant characteristics

The baseline characteristics of the participants in the Evergreen (I–III) and AGNES (I, IV) studies are summarized in Table 4. The participants in the AGNES cohort collected in 2017–2018 were more often married or living with someone, reported better self-rated health, had longer education, and had fewer depressive symptoms but more chronic conditions compared with the Evergreen cohort collected in 1989–1990. In the analyses, subsamples of these datasets were used. In the Evergreen cohort, 599 participants were community dwelling and formed the sample for Study III. Of these participants, 500 took part in research laboratory assessments and comprised the study sample for birth cohort comparisons in Study I and survival analyses in Study II. In the AGNES cohort, 726 participants of the 75- and 80-year-olds attended the laboratory assessments and formed another sample for the cohort comparisons (Study I). Study IV comprise the 75-, 80-, and 85-year-old participants of the AGNES-COVID-19 follow-up for whom data were available for QoL at baseline and follow-up and for all other key measures (n=685).

TABLE 4 Baseline characteristics of the participants in the different datasets

		Studies I, II, III	Study I	Study IV
		Evergreen 1989–1990 n=617	AGNES 2017–2018 n=1021	AGNES-COVID-19 2017–2018 and 2020 n=809
		%	%	%
Age				
	75	57.5	44.7	47.5
	80	42.5	32.7	32.6
	85	--	22.2	19.9
Women		68.7	57.3	58.8
Living alone		51.7	41.2	40.0
Married or cohabited		38.1	58.7	59.7
Self-rated health				
	Good	15.4	45.4	50.1
	Average	67.8	49.4	45.4
	Poor	16.8	5.0	4.4
		Mean (SD)	Mean (SD)	Mean (SD)
Cognitive function [a]		--	27.1 (2.6)	27.5 (2.1)
Education, years		5.9 (3.4)	11.6 (4.6)	11.8 (4.8)
Number of chronic conditions		1.7 (1.4)	3.4 (2.0)	3.4 (2.0)
Depressive symptoms [b]		13.9 (8.3)	8.6 (7.1)	8.3 (6.9)

Note. [a] = Mini-Mental State Examination (MMSE) points, [b] = Center for Epidemiologic Studies Depression Scale (CES-D-20) points, SD=standard deviation.

5.1.1 Birth cohort differences in physical performance (I)

Study I examined the influence of changing sociohistorical conditions on community-dwelling older adults' physical performance. The aim was to study whether adults who were 75 and 80 years old have better physical performance compared with older adults at the same age 28 years earlier. This was done by comparing similar measures of physical performance (muscle strength, walking speed, and respiratory function) in two population-based birth cohorts. In addition, the underlying factors explaining the potential cohort differences were examined.

On average, the later-born 75- and 80-year-old men and women had more of an education, were taller and heavier, reported higher daily physical activity and better self-rated health compared with the earlier-born cohort at the same age. Among 75-year-old women, the proportion of ever smokers was higher among the later-born cohort than in the earlier-born cohort. Among men, the proportion of ever smokers was lower in both age groups in the later-born cohort compared with the earlier-born cohort.

The average walking speed, grip strength, and knee extension strength were higher in the later-born cohort than in the earlier-born cohort in both sex and age groups (Table 5). The increased risk for mobility limitations was calculated based on the validated cut-offs for grip strength: 37 kg for men and 21 kg for women (Sallinen et al. 2010). According to these thresholds, the risk for mobility limitations was statistically significantly lower among the later-born cohort in both age groups in men and in 80-year-old women. In the lung function tests, the later-born men and women had better FVC, and only the 80-year-olds had better FEV1. There were no cohort differences in PEF.

The linear regression analyses revealed that the better walking speed was partially explained by higher physical activity and longer education in the later-born cohort. The better muscle strength among the later-born men and women was partially explained by the increased body size and higher physical activity level. Increased body height among the later-born cohort explained most of the observed cohort differences in respiratory function tests.

TABLE 5 Cohort differences in physical performance among 75- and 80-year-old men and women born 28 years apart

	Men				Women			
	1989–1990	2017–2018	Cohort diff.	p [a]	1989–1990	2017–2018	Cohort diff.	p [a]
	Mean (SD)	Mean (SD)	% (95% CI)		Mean (SD)	Mean (SD)	% (95% CI)	
75yrs								
Walking speed, m/s	1.8 (0.5)	2.0 (0.4)	11 (5, 18)	**<.001**	1.5 (0.4)	1.7 (0.3)	18 (13, 22)	**<.001**
Grip strength, N	373.7 (89.5)	405.9 (73.9)	9 (3, 14)	**.001**	227.1 (58.4)	238.0 (52.4)	5 (0.2, 9)	**<.001**
Knee extension strength, N	362.2 (98.9)	451.6 (102.0)	25 (18, 32)	**<.001**	241.3 (73.2)	301.7 (81.1)	25 (19, 31)	**<.001**
FVC, l	2.9 (0.7)	3.4 (0.8)	17 (12, 24)	**<.001**	2.2 (0.5)	2.5 (0.5)	14 (12, 20)	**<.001**
FEV1, l	2.5 (0.6)	2.6 (0.6)	4 (-0.7, 12)	.081	1.9 (0.4)	1.9 (0.4)	0 (-4, 4)	**<.001**
PEF, l/s	7.4 (2.0)	7.4 (2.0)	0 (-7, 6)	.841	5.0 (1.2)	4.9 (1.1)	-2 (-6, 3)	.093
Risk for mobility limitation, %	47.5	26.5		**<.001**	35.4	27.7		.052
80yrs								
Walking speed, m/s	1.5 (0.5)	1.8 (0.4)	20 (11, 33)	**<.001**	1.2 (0.3)	1.6 (0.3)	33 (22, 34)	**<.001**
Grip strength, N	309.1 (79.8)	364.0 (74.4)	18 (10, 26)	**.042**	171.9 (55.3)	215.4 (44.1)	25 (19, 32)	**<.001**
Knee extension strength, N	332.3 (72.8)	397.3 (101.2)	20 (12, 27)	**<.001**	188.2 (63.4)	276.9 (81.7)	47 (38, 56)	**<.001**
FVC, l	2.6 (0.7)	3.3 (0.6)	27 (15, 30)	**<.001**	1.9 (0.5)	2.3 (0.4)	21 (18, 29)	**<.001**
FEV1, l	2.2 (0.6)	2.5 (0.5)	14 (9, 25)	.825	1.6 (0.4)	1.8 (0.3)	12 (4, 14)	**.001**
PEF, l	6.9 (2.1)	7.4 (1.7)	7 (1, 17)	.544	4.8 (1.4)	5.0 (1.3)	4 (-3, 10)	.318
Risk for mobility limitation, %	73.9	51.9		**.012**	75.4	44.3		**<.001**

Note. CI = confidence interval, FVC = forced vital capacity, FEV1 = forced expiratory volume in one second, PEF = peak expiratory flow, [a] t-test.

5.1.2 Physical performance and psychosocial factors as predictors of survival among participants who did versus did not sustain a fracture (II & III)

In Study II, 36% of the participants (20% of men and 44% of women) sustained at least one fracture during the 15-year follow-up. The crude mortality rate was 9.8 deaths/100 person-years in men and 7.9 deaths/100 person-years in women. Of the fractured participants, 10 (31%) men and 33 (23%) women died during the first postfracture year. In Study III, 20% of the participants (22% of men and 19% of women) sustained at least one fracture during the follow-up. The crude mortality rate was 10.8/100 person-years for men and 8.7/100 person-years for women. During the first year after fracture, 13 (31%) men and 39 (24%) women died.

The baseline characteristics of the participants according to fracture status (nonfractured, survived the first postfracture year, and died during the first postfracture year) are presented in Table 6. In men, the participants who died during the first postfracture year had lower prefracture knee extension strength and reported lower self-rated health compared with first-year postfracture survivors and nonfractured participants. In women, the participants who died during the first postfracture year had lower prefracture handgrip strength compared with the other groups and lower prefracture gait speed compared with the first postfracture survivors. In addition, those who died during the first postfracture year reported lower self-rated health. Physical activity did not differ according to groups of fracture status in Study II, but in Study III, the participants who died during the first postfracture year reported the lowest physical activity. Finally, the living arrangements did not differ between the groups.

In Study II, the mortality hazard ratios were estimated for the two fracture states ("the first postfracture year" and "after the first postfracture year"), whereas in Study III, the mortality hazard was estimated only for the fracture state of "the first postfracture year," after which the participants were assigned back to the nonfracture state if they were still alive. The Cox regression analyses showed that the mortality hazard during the first postfracture year was three to four times higher in both studies compared with the nonfracture state (Study II: HR 3.86, 95% CI 1.98–7.51 and HR 3.92, 95% CI 2.66–5.77 for men and women, respectively; Study III: HR 3.74, 95% CI 2.08–6.70 and HR 3.27, 95% CI 2.32–4.63 for men and women, respectively). In Study II, after the first postfracture year, the mortality hazard attenuated but was still higher compared with the nonfracture state (HR 1.77, 95% CI 1.07–2.92 and HR 1.79, 95% CI 1.31–2.44 for men and women, respectively).

TABLE 6 Baseline characteristics of the Evergreen participants according to fracture status (nonfractured, survived the first postfracture year, and died during the first postfracture year)

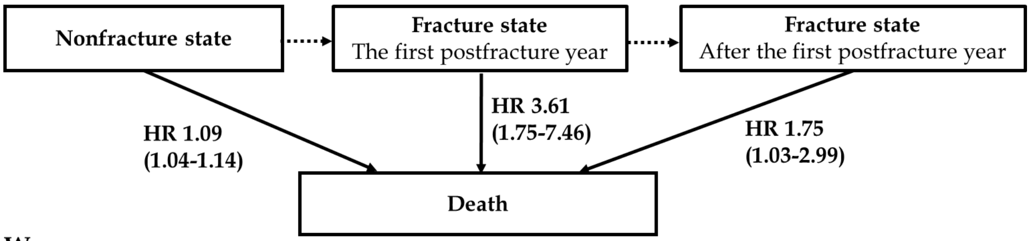
	Nonfractured	Fractured, survived the first year	Fractured, died during the first year	
	Mean (SD)	Mean (SD)	Mean (SD)	p
Men				
Walking speed, m/s [a]	1.7 (0.5)	1.6 (0.5)	1.4 (0.4)	.125
Grip strength, N [a]	351.8 (100.9)	329.0 (57.1)	295.2 (169.4)	.177
Knee extension strength, N [a]	356.3 (104.1)	320.5 (67.4)	267.4 (118.1)	**.014**
Number of chronic conditions [a]	1.7 (1.4)	1.2 (1.1)	1.8 (0.7)	.168
	%	%	%	
Living alone [b]	23.0	24.1	23.1	.991
Loneliness, no [b]	61.9	82.1	76.9	.081
Physical activity, low [b]	66.9	48.0	92.3	**.021**
Self-rated health [b]				
Good	17.1	15.4	0.0	**.018**
Moderate	68.6	76.9	53.8	
Poor	14.3	7.7	46.2	
Women				
	Mean (SD)	Mean (SD)	Mean (SD)	p
Walking speed, m/s [a]	1.4 (0.4)	1.5 (0.3)	1.2 (0.3)	**<.001**
Grip strength, N [a]	204.0 (68.3)	210.8 (58.2)	167.4 (68.1)	**.004**
Knee extension strength, N [a]	217.6 (81.7)	226.4 (68.0)	189.6 (69.6)	.053
Number of chronic conditions [a]	1.7 (1.5)	1.7 (1.4)	1.9 (1.5)	.699
	%	%	%	
Living alone [b]	63.7	74.4	64.1	.107
Loneliness, no [b]	67.9	59.3	59.0	.205
Physical activity, low [b]	70.5	61.9	84.6	**.024**
Self-rated health [b]				
Good	13.3	19.2	15.8	.065
Moderate	65.8	71.7	63.2	
Poor	20.9	9.2	21.1	

Note. [a] = n=482, [b] = n=599, SD = standard deviation, a chi-square test was used for categorical variables and one-way ANOVA for continuous variables.

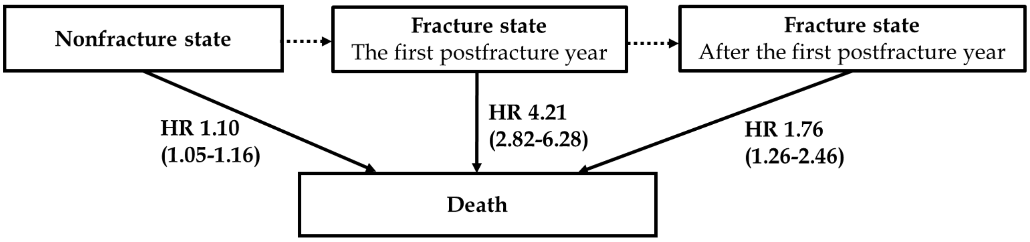
Study II investigated prefracture physical performance as a predictor of postfracture mortality. The adjusted time-stratified Cox regression analyses revealed that in both sexes, lower walking speed, grip strength, and knee extension strength were associated more strongly with the mortality hazard during the first postfracture year compared with the time without fracture exposure (nonfracture state; Figure 7). After the first postfracture year, the associations between lower walking speed and mortality hazard attenuated approximately to the level of nonfracture state, whereas the associations between muscle strength tests and mortality hazard were still somewhat elevated compared with nonfracture state (no overlapping confidence intervals).

a) Walking speed

Men

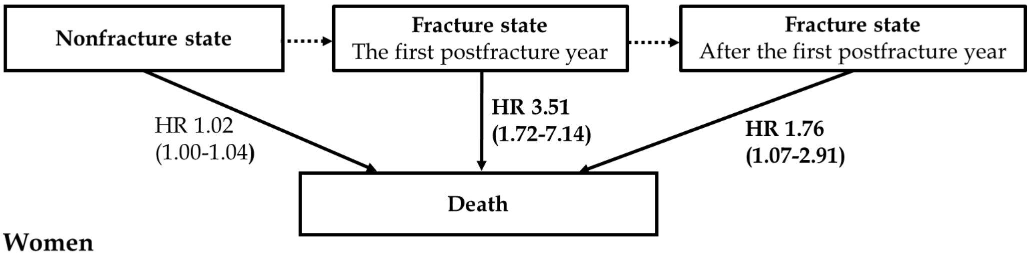


Women

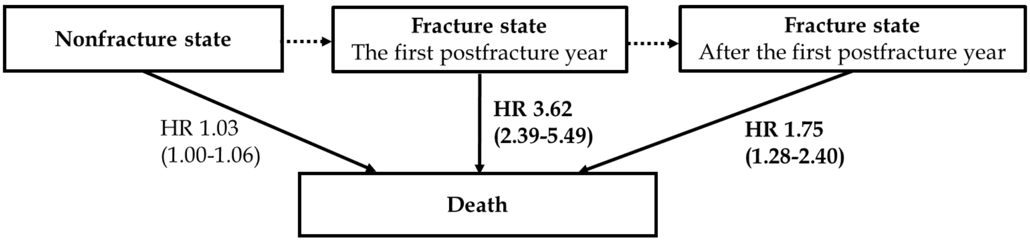


b) Grip strength

Men



Women



c) **Knee extension strength**

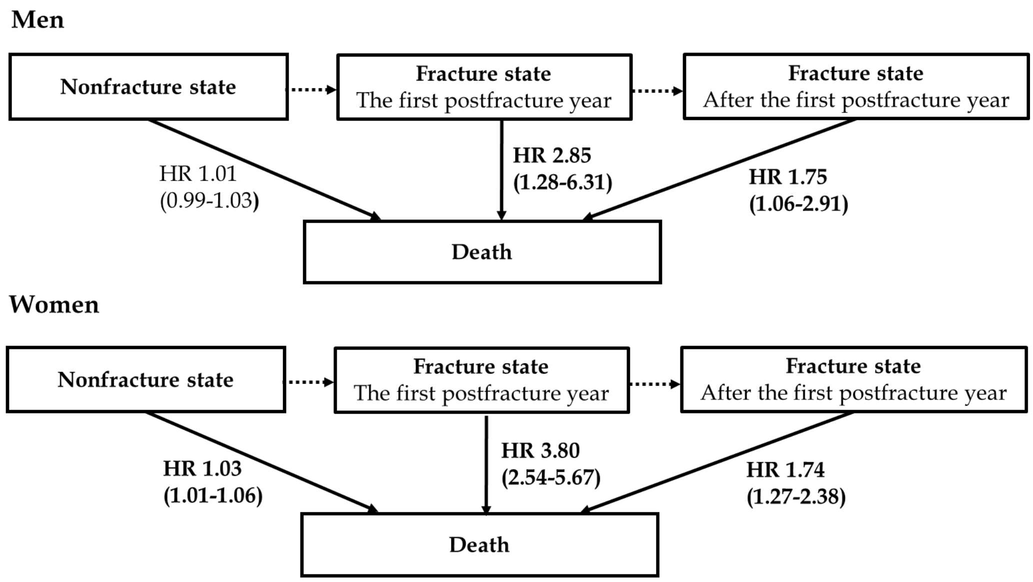


FIGURE 7 The associations of lower a) walking speed b) grip strength, and c) knee extension strength on mortality hazard during nonfracture state and fracture state (the first postfracture year and after the first postfracture year; Study II).

Note. HR = Hazard ratio (95% confidence intervals), walking speed per -0.1 m/s, muscle strength per -100N). Nonfracture state = no fracture during the follow-up and time before fracture occurrence of the participants sustaining a fracture. The model is adjusted for number of chronic conditions, age, and physical activity.

Study III assessed living arrangements as a predictor of postfracture mortality. The unadjusted Cox regression models showed that in men, living arrangements were not associated with mortality hazard (HR 1.33 95% CI 0.93–1.89). In women, living alone was associated with decreased mortality hazard (HR 0.75 95% CI 0.60–0.94), but the association vanished after adjusting for self-rated health. The extended Cox regression models showed nonsignificant interactions between living alone and fracture state, suggesting that in both men and women, the mortality hazard during the first year after fracture is similar between those living with someone and living alone.

5.1.3 Walking speed and psychosocial resources as predictors of maintenance of a high QoL during COVID-19 social distancing (IV)

In Study IV, the average QoL at baseline was 55.1 (SD 5.5) points and the average decline in QoL during the 2-year follow-up between the baseline and social distancing was 1.6 (SD 5.5) points. A linear regression analysis showed that a higher baseline QoL was associated with a higher decline in QoL (β -.236, p <.001). In addition, perceived restrictiveness of the social distancing recommendations was associated with a higher decline in QoL (β -1.931, p <.001). According to a priori set thresholds, 15% of the participants were categorized as having a constant high QoL and 85% as having low/moderate QoL. In addition, 63% of the participants were categorized as perceiving the restrictiveness of and psychosocial resources as predictors of maintenance of a high QoL during COVID-19 social distancing (IV).

The characteristics of the participants according to QoL categories are presented in Table 7. The participants maintaining a constant high QoL reported less loneliness and had higher stress-coping ability, walking speed, and cognitive functioning than participants with low/moderate QoL. In addition, the participants in the constant high QoL category were younger and had fewer chronic conditions compared with the participants in the low/moderate QoL category.

TABLE 7 Characteristics of the participants according to constant high and low/moderate Quality of Life (QoL) categories

	QoL		
	Constant high (n=104)	Low/moderate (n=581)	
	%	%	p [a]
Perceived restrictiveness of social distancing recommendation, yes	58	64	.218
Living arrangements, alone	36	39	.521
Loneliness, no	83	55	**<.001**
Age			
75 years	61	48	**.027**
80 years	30	33	
85 years	10	19	
Sex, women	56	58	
	Mean (SD)	Mean (SD)	p [b]
Stress-coping ability	35.0 (4.1)	31.0 (4.9)	**<.001**
Walking speed, m/s	1.9 (0.4)	1.8 (0.4)	**<.001**
Chronic conditions, number	2.7 (1.8)	3.4 (2.0)	**<.001**
MMSE	28.0 (1.8)	27.5 (2.1)	**.016**

Note. SD=Standard deviation, [a] = chi-square test, [b] = t-test, MMSE = Mini Mental State Examination. Category of a constant high QoL was defined as having QoL in the highest quartile at baseline (⩾59 points) and maintaining it at the same level during social distancing. The participants who did not meet this criteria were considered to have low/moderate QoL.

The logistic regression analysis showed that a higher walking speed (OR 1.08, 95% CI 1.01–1.15), better stress-coping ability (OR 1.21, 95% CI 1.14–1.28), and the absence of loneliness (OR 2.67, 95% CI 1.48–4.63) predicted a constant high QoL. In addition, the absence of loneliness reduced the likelihood of perceiving the social distancing recommendations as restrictive (OR 0.62, 95% CI 0.45–0.86), whereas stress-coping ability, living arrangements, and walking speed were not associated with the perceived restrictiveness of social distancing recommendations. The separate analyses for the predictors of a constant high QoL showed a significant interaction of walking speed and perceived restrictiveness (p=0.005), indicating a stronger association between walking speed and a constant high QoL among the participants who perceived the social distancing recommendations as being restrictive. The interactions of loneliness and perceived restrictiveness and stress-coping ability and perceived restrictiveness were not significant, indicating that the associations with a constant high QoL were similar in both categories of perceived restrictiveness.

A multinomial regression analysis was used to identify the resources for QoL resilience (Table 8). The nominal variable of the combinations of QoL and the perceived restrictiveness of social distancing recommendation categories was used as an outcome. The results indicate that the participants with a better stress-coping ability had higher odds of maintaining a constant high QoL, regardless of the perceived restrictiveness of social distancing recommendations when compared with the combination of low/moderate QoL and no perceived restrictiveness (Table 8). Better walking speed was associated with a constant high QoL only among those perceiving the restrictiveness of social distancing recommendation. In addition, no perceived loneliness was associated with decreased odds of having low/moderate QoL and perceiving social distancing recommendations as restrictive. Finally, living arrangements were not associated with maintaining a constant high QoL.

TABLE 8 Odds ratios for combinations of Quality of Life (QoL) and perceived restrictiveness of social distancing categories

	Constant high QoL + YES perceived restrictiveness (n=60)	Constant high QoL + NO perceived restrictiveness (n=44)	Low/moderate QoL + YES perceived restrictiveness (n=372)
	OR (95% CI)	OR (95% CI)	OR (95% CI)
Walking speed, per 0.1 m/s	**1.11 (1.02–1.21)**	0.96 (0.87–1.07)	0.96 (0.91–1.01)
Stress-coping ability, per 1 point	**1.20 (1.11–1.30)**	**1.20 (1.10–1.30)**	0.98 (0.95–1.02)
Loneliness, no vs. yes, at least sometimes	1.94 (0.88–4.28)	2.15 (0.85–5.39)	**0.64 (0.43–0.94)**
Living arrangements, alone vs. with someone	0.97 (0.47–2.00)	0.75 (0.33–1.71)	1.31 (0.86–1.98)

Note. Reference group: low/moderate QoL + NO perceived restrictiveness of social distancing recommendations, OR=odds ratio, CI=confidence interval, adjusted for age, sex, and chronic conditions.

6 DISCUSSION

The current study investigated the influence of changing sociohistorical conditions on physical performance in old age by comparing two birth cohorts born 28 years apart. A further aim was to study physical performance and psychosocial factors as potential resources for resilience by exploiting two suddenly occurring adversities: bone fractures and the COVID-19 social distancing recommendations. While the previous observational studies have focused mainly on the psychosocial resources for resilience, the present study contributes new knowledge on resilience in old age by investigating the role of physical performance in adversities.

The results of the present study show that older adults' physical performance is nowadays better compared with their counterparts at the same age almost three decades ago, which indicates that people are living to older ages with better physical functioning and higher resources than before. Higher physical performance was a particularly beneficial resource among those individuals exposed to a bone fracture or perceiving the restrictiveness of the social distancing, suggesting that the effect of physical resources may kick in during times of adversity and "buffer" negative effects (Cohen & Wills 1985; Kok et al. 2021). One unanticipated and important finding is that older people living alone are not necessarily more vulnerable when facing adversities than individuals living with another person because one's living arrangements were not associated with survival after a fracture or maintenance of a high QoL during social distancing recommendations. However, other psychosocial factors, that is, better stress-coping ability and not perceiving oneself as lonely, were shown to be protective resources and important for maintaining a high QoL, regardless of the experienced severity of the social distancing recommendations. The findings of the current study contribute to understanding resilience as a context-specific process in which resources across multiple levels of functioning and environment are important.

6.1 Physical performance in changing sociohistorical contexts

The results of the present study showed that the maximal isometric muscle strength and walking speed of older adults aged 75 and 80 years assessed 28 years apart were better in the later-born cohort. In grip strength, the cohort differences varied between 11 and 55 N. According to a meta-analysis by Cooper et al. (2010), 10 N or approximately 1 kg higher grip strength is associated with a 3% decline in mortality hazard. In the current sample, this estimate translates in the later-born 80-year-old men into a 12% lower mortality hazard and in the same-age women as a 15% lower mortality hazard compared with the earlier-born cohort. In addition, the percentage of the participants below the validated cut point for increased risk for mobility limitation (Sallinen et al. 2010) was lower in the later-born than earlier-born cohort. In walking speed, the cohort differences ranged from 0.2 to 0.4 m/s, depending on age and sex. It has been shown that a 0.1 m/s faster walking speed can be observed as a considerably better mobility (Perera et al. 2006). In the respiratory function tests, the findings were found to be to some extent inconsistent. The later-born cohort had better FVC, which measures the forcibly exhaled total amount. However, differences between cohorts in exhaled airflow were small or nonexistent.

These results provide us with novel information on the differences in functional aging during different historical periods. Similar positive secular trends have also been observed at other levels and domains of health and functioning, such as in postponement in cellular senescence (Vaupel 2010) and higher levels of cognitive function in the later-born cohort (Munukka et al. 2020). Various explanations may be provided for the results of the current study when reflecting on the findings against the sociohistorical environmental background and differences in the life course exposures between the two birth cohorts. The earlier cohorts were born in 1910–1915 when Finland was mainly agricultural, undeveloped, and—until 1917—part of the Russian Empire. Back then, children usually started working from early ages, and the members of the earlier cohorts experienced turmoil in childhood because of the Civil War in 1918 and in early adulthood took part in World War II. The later cohort was born in 1938–1942 and had likely more favorable exposures during their life course. In the 1940s, many societal reforms were implemented, such as providing free meals in school for all children and longer compulsory education. This may have improved the nutrition, particularly among children in deprivation, while also delaying their entry into the labor market. These changes in the societal environment may partially explain the current results of increased height and weight in the later-born cohort, which is most likely a consequence of better nutritional situation (Cole 2003). Further, in the 1950s, access to secondary and tertiary education improved, and female disadvantages in education decreased (Breen et al. 2010), which aligns with our findings of doubled education among the later-born cohort. Higher education is related to more positive working and financial situations, psychosocial resources, and more beneficial health behavior. In turn, exposure to heavy manual work in younger ages predicts health problems and difficulties in functioning in old age (Kulmala et al. 2016).

In the current study, the positive secular trends in body size, education, and physical activity all partially explained the improved walking speed and muscle strength in the later-born cohort. However, the association between physical activity and cohort differences in physical performance may be interpreted in two ways: higher physical activity may precede better physical performance or vice versa (Rantanen, Guralnik, Sakari-Rantala et al. 1999). In addition to these observations, other potential explanations for cohort differences in physical performance include improved medical care, better access to health care, large health policy interventions (e.g., North Karelia Project from 1972 to 1995), improved working conditions through legislation protecting employees, and improved technical solutions.

The current cohort comparisons, however, cannot be used to infer the differences in life course trajectories in physical performance. It is possible that the later-born cohort had a slower rate of change with increasing age, a higher lifetime maximum, or a combination of the two. However, these results support the postponement of disability at higher ages (Manton & Gu 2001) although the findings cannot be used to support or reject the compression of the morbidity hypothesis (Chatterji et al. 2015). Nonetheless, the results of this study and others (Munukka et al. 2020) suggest that more years are lived with better physical and cognitive functional capacity, at least among the studied 75- and 80-year-old adults in Finland. However, future studies will show whether this positive trend continues or can be applied to younger cohorts. For example, Beller et al. (2019) reported a contrasting trend in grip strength among younger cohorts, which may be explained by changes in health-related lifestyles, such as an increased sedentary lifestyle and obesity. Moreover, many contextual factors, such as variations in historical and economic developments and cultural aspects may also influence the different secular trends in physical performance in different countries.

6.2 "Buffering effect" of physical performance in the context of bone fractures and social distancing recommendations

The associations between physical performance and health outcomes, such as survival, have been well established. However, it is not clear what underlies these associations. Rantanen et al. (2003) reported that the association between muscle strength and mortality may not be fully explained by the known pathophysiological processes related to diseases and aging, such as inflammation, poor nutritional status, physical inactivity, and depression. Similarly, walking speed has been shown to predict mortality independently of the commonly known risk factors of death (Rolland et al. 2006; Blain et al. 2010). Thus, these measurements have been suggested as being "vital signs," indicating the integrity of the function of multiple organ systems and physiological reserve and, consequently, the capability to withstand current and future medical and nonmedical events (Blain et al. 2010; Studenski et al. 2011). The results of the present study support these hypotheses, showing that better physical performance becomes particularly important when older people are faced with adversity. The results show that higher prefracture muscle strength and walking speed had a pronounced role in predicting survival, especially during the first postfracture year, compared with a time without fracture exposure. In addition, in the context of COVID-19 social distancing recommendations, better walking speed predicted maintenance of a high QoL only among those who perceived the restrictiveness of social distancing.

The mechanisms underlying these findings probably lie in the availability and increased need for the physiological and functional reserves that individuals can tap into. The adaptation may, however, occur at different levels of functioning, from physiological mechanisms to behavioral strategies, depending on the influences of the adversity. In acute medical events, such as bone fractures, maximal physical performance, as measured by gait speed and muscle strength, may reveal an underlying state of biological and phenotypical changes in aging and the body's capacity for adaptation after the disturbance. For example, both muscle strength and walking speed measurements require the regulation of the central nervous system and may capture differences in its function, which plays an important role in the aging process (Atkinson et al. 2007; Zheng et al. 2011) and is also most likely involved in individual adaptation to stressors. In the case of COVID-19 social distancing, the importance of functional reserves as indicated by better walking speed was probably embedded more at the behavioral than physiological level of functioning. Higher walking speed also indicates the ability to move in one's environment (Studenski 2009), which is an important resource for autonomy and meaningful activities. During social distancing, when access to environmental activity resources, for example, to exercise facilities and social clubs, was reduced, older adults with a better ability to move may have had a higher readiness to substitute their suspended activities of choice with alternatives that were not blocked.

Drawing on activity theory (Havighurst 1961), older adults can maintain their well-being by staying involved in personally valued life situations and activities for as long as possible. Portegijs et al. (2021) reported that most of the older adults' activities during social distancing recommendations included walking for fitness and visiting outdoor exercise facilities that remained open. Maintaining a desired activity level by increasing outdoor exercise may have bestowed a sense of continuity while also manifesting further advantages, such as improved fitness (Brach et al. 2004) and restorative experiences (Kaplan 1995), which may have helped in maintaining a good QoL despite the perceived restrictions. However, walking speed was not an important predictor of the maintenance of a high QoL among those not perceiving social distancing recommendations as restrictive. Earlier reports using the same data as in the present study showed that those who did not perceive the social distancing recommendations as restrictive were less likely to change their physical activity behavior (Rantanen & Portegijs 2020). Many older people prefer activities that occur at home (e.g., crafting, gardening); such activities were not affected by the social distancing recommendations, and a possible explanation for the current finding is that people carrying out these activities did not need to draw on extra individual functional resources to maintain their desired activity level and a good QoL.

6.3 Role of psychosocial factors in the context of social distancing recommendations and bone fractures

Living arrangements and absence of loneliness

An important finding of the current study is that one's living arrangements were not associated with maintenance of a high QoL during social distancing recommendations or survival after a bone fracture. In many scientific and popular communications, older persons living alone have often been addressed as a vulnerable group during the COVID-19 pandemic-related social distancing. However, empirical studies have offered mixed results regarding whether social distancing places older adults living in single households at increased risk for lower levels of well-being. Other longitudinal studies, which have taken into account the changes in psychosocial well-being during social distancing compared with the situation prior to the pandemic, have shown, for example, that increases in loneliness were not higher among Austrian older adults living alone (Heidinger & Richter 2020), whereas older adults living alone in the UK reported more increases in anxiety and depression than those living with someone (Robb et al. 2020). However, the vast differences between social distancing measures between countries limit the comparability of the results. Similarly inconsistent results have been reported on whether living alone increases the risk for health decline after an adverse medical event, such as myocardial infarction or hip fracture (Schmaltz et al. 2007; Kilpi et al. 2015; Katsoulis et al. 2017). One potential explanation for the conflicting findings is that older people living in single households do not form a heterogeneous group but consist of both socially isolated and socially active persons. In many modern societies, older adults who live alone have shown to have large and diverse social networks (Djundeva, Dykstra & Fokkema 2018). Therefore, living alone does not necessarily indicate social isolation and/or loneliness, both of which are recognized as important psychosocial mechanisms influencing health and well-being outcomes (Berkman et al. 2000).

Another interesting finding related to living arrangements in the present study is that when exposure to a bone fracture was not present, living alone versus living with someone was associated with a lower mortality hazard among women. However, the association vanished after adjusting for self-rated health, suggesting that women living alone had better health, which explained the association. Some previous studies have also found that the importance of living arrangements as a risk factor for mortality declines when people become older

(Davis et al. 1992; Gopinath et al. 2013; Ng et al. 2015). Gopinath et al. (2013) have suggested that among younger people, living alone may cause psychosocial stress, whereas in older people, living alone is a more normative arrangement, at least in Western societies. In the present study, the participants were aged 75 or 80 years at baseline and at the time of potential fracture even older. The surviving cohort effect might also explain why—in contrast to many other earlier findings with younger study populations—living arrangements were not associated with mortality hazard. The participants of the current study are the healthiest individuals of their cohort, while other cohort members who had deceased could not be observed.

Because living arrangements may not offer a comprehensive picture and subjective experience of the social milieu of the individual, the current study also investigated perceived loneliness as an indirect indicator of perceived social provision and meaningful relationships. Not perceiving oneself as lonely was associated with increased odds of maintaining a high QoL during social distancing, which is in accordance with earlier studies (Musich et al. 2015; Gerino et al. 2017; Beridze et al. 2020). However, at least in this context of adversity, not perceiving loneliness was not particularly important for those perceiving restrictiveness, but it was generally significant for all for maintaining a good QoL. The buffering effect hypothesis suggesting that social support becomes particularly important when an individual is exposed to stress or adversity has been widely studied. In older adults, earlier studies have shown, for example, that higher levels of social support can reduce the negative impact of stress on mental health (Cutrona, Russell & Rose 1986) and the negative impact of depressive symptoms on life satisfaction (Adams, Sanders & Auth 2004). However, because loneliness does not directly describe the availability, quality, or different dimensions of social support, the absence of loneliness may emerge from varying aspects of psychosocial factors. Another potential explanation for the current finding lies in the nature of the measured loneliness in relation to the social distancing recommendations as an adversity. Loneliness was assessed with one item, which has been shown to correlate especially with the emotional dimension of loneliness that arises from the longing for a close emotional attachment figure, rather than social loneliness, which reflects the absence of an engaging social network (Weiss 1973, 17; van Baarsen-Heppener et al. 2001).

Self-rated coping ability

The results of the present study show that self-rated coping ability ascertained prior to the pandemic predicted maintenance of a high QoL during COVID-19-related social distancing recommendations, which is consistent with previous findings (Gerino et al. 2017). However, this association did not vary according to level of perceived restrictiveness, suggesting that, much like the absence of loneliness, good coping ability was an important psychological resource, but it did not particularly alleviate the negative effect of the perceived restrictiveness of social distancing on QoL. In the ratings of stress-coping ability, the participants did not consider any specific adversity, but most likely assessed their ability to cope based on their past experiences. Therefore, stress-coping ability, as measured in the present study, may reflect an overall optimistic view of one's personal agency in challenging situations (Windle, Bennett & Noyes 2011). In the current study, the adversity of social distancing recommendations was conceptualized as perceived restrictiveness for one's activities of choice. Although being active in old age has also been recognized as an important component of QoL during COVID-19 restrictions (Rantanen et al. 2020), good coping ability may have helped in maintaining a good QoL through other mechanisms than maintaining one's desired activity level. The items in the scale do not differentiate the exact adaptive coping strategies (e.g., emotion focused, problem focused, or appraisal focused) that the individuals used to overcome adversities. Therefore, having high self-reliance in coping ability may include different ways of managing and perceiving the COVID-19 related restrictions. In addition, it is important to keep in mind that the findings represent the experiences during the early phase of the pandemic, and the role of one's ability to cope may have changed with the prolonged pandemic and restrictions.

6.4 Methodological considerations

The strength of the current study is the unique study designs that were applied to capture the different aspects of the socioecological model of resilience. In Study I, maximal physical performance assessments of multiple functions were conducted with identical study protocols and standardized test procedures among older adults exactly the same age. In addition, the study is unique in the length of the interval between the studies that was almost three decades. The study provides us with novel information about the differences in functional aging and development of resources in people growing old in different sociohistorical contexts. In Studies II and III, the long 15-year follow-up, during which epidemiological data was linked with clinical information on bone fractures and survival, provided a unique opportunity to take into account both the situation without fracture exposure and the time-varying character of mortality hazard after a fracture. The comparison group, including individuals who had not been exposed to adversity, has often been ignored when studying resilience (Smith & Hayslip 2012). In addition, the availability of laboratory-based measures of functional status performed before a bone fracture is uncommon, meaning that the tests were not confounded by situational factors caused by the injury or treatment. Finally, in Study IV, the unforeseen natural experimental setting of the COVID-19 pandemic restrictions enabled the standardization of an adversity encountered by the whole population at the same time. This is rare in resilience research, especially in population-based representative and heterogeneous samples instead of self-selected convenience samples. In addition, the baseline data collected two years before social distancing included a wide range of information on the participants' functioning, enabling us to investigate the longitudinally preadversity resources in different life domains as predictors of adaptation.

The current study is based on data from the Evergreen and AGNES projects, which both included population-based samples of community-living older adults. Using the population register of the national Digital and Population Services Agency for recruiting the participants has helped minimize the possibility of bias that is often observed convenience samples. However, in the AGNES cohort, those participating in the study reported better health and physical functioning compared to non-participants. In addition, in both cohorts, the participants attending the research center assessments reported better health than those who participated only in the home interviews, forming a slightly healthier section of participants. However, the participants still formed heterogeneous samples with different levels of functioning. In addition, although the participation rate in the later AGNES cohort was lower than in Evergreen cohort 28 years earlier, the comparison suggested that there were no systematic differences between the nonparticipants of the cohort, supporting the comparability of the cohorts. In both projects, data were mainly collected face-to-face in the participants' homes or in the assessment center. Because of the social distancing measures, the COVID-19 follow-up was collected using a postal questionnaire, which may have biased the results. However, the follow-up questionnaires were also carefully filled in and contained only a little missing information.

Despite the relatively simple idea of the concept of resilience, that is, adaptation to adversity, the research of resilience has been criticized for lacking conceptual and operational clarity (van Kessel 2013). Researchers differ, for example, in their interpretation of what constitutes an adversity or stressor that requires resilience for a positive outcome and how to define a person doing well in the face of certain adversity. For example, Luthar and Cicchetti (2000) defined risks or adversities as negative life circumstances that are known to be statistically associated with adjustment difficulties. As expected, after bone fractures, the mortality hazard was increased and perceived restrictiveness of social distancing was associated with higher declines in QoL, supporting the premise of considering these circumstances as adversities. However, in this study, we could not rule out other possible adversities the participants were possibly facing and which may have influenced the results. For example, data on other catastrophic events, such as infections, strokes or cardiac infarctions, or social losses were not available.

The approach to operationalizing resilience during COVID-19 social distancing measures aligns with the individual-centered method using researcher-driven, distribution-based thresholds (Cosco et al. 2019). This allowed us to take into account the relationship between the perception of adversity and the outcome and to identify a conceptually meaningful subgroup of individuals assumed to show resilience. However, a major disadvantage is the absence of established thresholds that can be applied in defining resilience. Thus, because a validated cut-off value for high QoL exists in the OPQOL scale, the threshold for high QoL was set based on the distribution in the baseline QoL. The threshold was set high in the distribution (the upper quartile of the baseline QoL) because it was assumed that in its severity, the social distancing recommendations are a moderate rather than catastrophic or traumatic type of adversity (Luthar, Cicchetti & Becker 2000). In the case that the adversity is severe, avoiding negative outcomes or having only low levels of symptoms may be viewed as good outcomes and an indication of resilience (Windle 2011). However, this approach may have captured only a part of people adapting well or showing robustness during the social distancing recommendations, and other approaches quantifying the concept of resilience should also be investigated. In the context of bone fractures, which may be considered a more severe adversity, survival was used as an outcome. Mortality provides indirect information on failure of recovery and not directly on adaptation, and thus, it may not give a complete picture of resilience. However, mortality is a powerful and widely used indicator of the burden of diseases and health decline and can provide insights into the resilient or nonresilient responses of the system after experiencing chronic or acute health stressors. In addition, using survival as an outcome allowed for comparisons between fractured and nonfractured participants to be made, which could be difficult when using the other kinds of outcome variables describing recovery.

A notable strength of the current study is that it takes a comprehensive view of resilience, investigating the resources for adaptation from different domains of functioning. In the current study, the Connor-Davidson resilience scale was used as a measure of self-reliance in coping. Although the scale has been developed to assess adaptation as such, it is based on the assumption that resilience is a universal concept that can be operationalized uniformly across different contexts (Cosco et al. 2017). A growing body of literature suggests that general resilience, manifesting in all domains of life and contexts, is unlikely or even nonexistent (Vanderbilt-Adriance & Shaw 2008; Windle 2011). Hence, a subjective view of how a person usually copes with stressful situations may reflect the psychological resources available for adaptive strategies but do not fully cover the actual processes by which resilience manifests itself in specific contexts, such as social distancing. In addition, according to the socioecological framework of resilience, resources from other levels and domains of functioning are also important, which was the main reason for the selected approach. In the current study, living arrangements and absence of loneliness were used to study the social aspects of resources. However, given the complexity of social systems around the individual and subjective perceptions of them, these variables may only give a very narrow depiction of the individual's social life. Finally, the investigation of physical performance as a resource for resilience was central. Assessing physical function with maximal tests has many advantages. Measures of muscle strength, walking speed, and respiratory functions provide more explicit and standardized information on physical functioning compared with self-assessments, which may be also influenced by environmental circumstances and subjective perceptions and attitudes. However, the downside of the physical performance tests, especially those administered at the laboratory environment, is the challenge of reaching individuals with a lower functional status and health.

6.5 Future directions

The results of the current study contribute to understanding resilience as a context-specific process in which resources across multiple domains of functioning and levels of the socioecological system are important. Although resilience has sometimes been seen as an individual attribute, the contemporary perspective underlines that resilience is not simply an individual's responsibility but a shared social responsibility (Foster 2020). Although increasing one's individual agency and strengths is important to be better equipped to face adversities, the results of the current study have shown that the historical environment in which our life course takes place also has a strong influence on aging and the resources that may be achieved. The shift toward a more holistic understanding of resilience provides a broader view to promote individual adaptation through individual- and policy-level interventions (Kim et al. 2021; Klasa et al. 2021).

The present study has shown that physical resources, such as muscle strength and walking speed, here indicating the ability to move, are important resources that have the potential to alleviate the negative effects of adversities. Many gerontological studies have focused on investigating psychological adaptation to functional deficits, which is an important point of view in the context of aging-related changes and challenges. The present study also addresses the importance of social and psychological resources underlying QoL in old age. However, the perspective of physical resources should not be forgotten in studying resilience. Bearing in mind that, for example, resistance strength training is possible and beneficial in terms of gains in muscle strength and functional ability even among the oldest-old adults (Fiatarone et al. 1990; Grgic et al. 2020) and that it may also promote psychological resources (Kekäläinen et al. 2018), encouraging, familiarizing, and providing opportunities to engage in physical exercise should be considered as an important individual-level intervention to promote adaptability through the whole life course.

The present study also suggests improved physical performance and, consequently, physical resources for resilience in the more recent birth cohorts, which is most likely a result of more propitious life course exposures. Because increased life expectancy is accompanied by an increased number of years lived with good functional ability in later life, the understanding of old age may be old-fashioned. Many older adults aged 65 to 80 may not consider themselves as old. The results of the present study may help identify the potentially unrecognized resources of older adults and encourage their continued engagement in valued activities in later life. Yet again, the individuals themselves should not be the only targets for an intervention, but society must also be updated and accommodated to serve the needs of increasingly aging populations to help older adults fulfill their potential and stay active.

The concept of resilience in gerontology and public health is attractive because of its positivity, inclusiveness of a variety of populations, application to different contexts, and dynamic nature. Given that aging is accompanied by several challenges, a deeper understanding of resilience in later life is needed to promote individuals aging well. Future research should aim to better understand the interplay between the factors that play a role in allowing older adults to have positive adaptation in adversity. One theoretical approach that has recently received increasing attention in resilience research is complex systems theory and network analysis aiming to describe the dynamic interrelations between various components (Diez Roux 2011). Although this approach has been mainly applied to study biological or physiological mechanisms of aging and health, Klasa et al. (2021) proposed that adapting socioecological aspects to complex systems models could simultaneously offer ways to quantify the resilience resource factors at different levels of functioning. Although the conceptual socioecological model sheds light into a more comprehensive view of health and resilience, there is still a need for analytical approaches that help to explore the dynamic interrelations between various components. In addition, researchers applying the dynamic systems perspective have suggested that the appearance of resilience may not require a significant adversity, but it may also be observed in responses to lower intensity and potentially frequently stressors, such as daily stress (Montpetit et al. 2010; Gijzel et al. 2017). Consequently, these responses are also considered to predict resilience in times of higher intensity stressors (Gijzel et al. 2017; Angevaare et al. 2020). These relatively new perspectives on resilience and aging research could be considered in future studies, which may also have the potential to link fragmented resilience knowledge from different disciplines. In addition, collecting time series data with repeated measurements around the low- or high-intensity stressors would help in capturing the adaptation processes in natural environments. This may be challenging but attainable with state-of-the-art methods, such as accelerometers and ecological momentary assessments.

7 MAIN FINDINGS AND CONCLUSIONS

The main findings and conclusions of the present study can be summarized as follows:

1. Finnish older adults' physical performance is nowadays better compared with their counterparts at the same age almost three decades ago, which indicates that people are living to older ages with better physical functioning than before. The finding is most likely a result of more propitious life course exposures among the later-born cohort because of changing sociohistorical contexts.

2. Higher physical performance was a particularly beneficial resource for survival among those exposed to a bone fracture and for maintaining a high QoL among those perceiving the restrictiveness of COVID-19 social distancing. The results suggest that among older adults, physical performance measures may reflect the underlying physiologic and functional reserves to respond effectively to adversities.

3. Living with someone versus alone did not predict the maintenance of a high QoL during COVID-19 social distancing or survival after bone fractures, suggesting that older adults living in single households may not be particularly vulnerable in adversities.

4. Better self-rated coping ability and not perceiving oneself as lonely were generally important for maintaining a high QoL during COVID-19 social distancing, regardless of the level of perceived restrictiveness of social distancing recommendations.

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ORIGINAL PAPERS

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COHORT DIFFERENCES IN MAXIMAL PHYSICAL PERFORMANCE: A COMPARISON OF 75- AND 80-YEAR-OLD MEN AND WOMEN BORN 28 YEARS APART

by

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Research Article

Cohort Differences in Maximal Physical Performance: A Comparison of 75- and 80-Year-Old Men and Women Born 28 Years Apart

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Abstract

Background: Whether increased life expectancy is accompanied by increased functional capacity in older people at specific ages is unclear. We compared similar validated measures of maximal physical performance in 2 population-based older cohorts born and assessed 28 years apart.
Method: Participants in the first cohort were born in 1910 and 1914 and were assessed at age 75 and 80 years, respectively (N = 500, participation rate 77%). Participants in the second cohort were born in 1938 or 1939 and 1942 or 1943 and were assessed at age 75 and 80 years, respectively (N = 726, participation rate 40%). Participants were recruited using a population register and all community-dwelling persons in the target area were eligible. Both cohorts were interviewed at home and were examined at the research center with identical protocols. Maximal walking speed, maximal isometric grip and knee extension strength, forced vital capacity (FVC) and forced expiratory volume in 1 second (FEV1) were assessed. Data on non-participation were systematically collected.
Results: Walking speed was on average 0.2–0.4 m/s faster in the later than earlier cohort. In grip strength, the improvements were 5%–25%, and in knee extension strength 20%–47%. In FVC, the improvements were 14–21% and in FEV1, 0–14%.
Conclusions: The later cohort showed markedly and meaningfully higher results in the maximal functional capacity tests, suggesting that currently 75- and 80-year-old people in Finland are living to older ages nowadays with better physical functioning.

Keywords: Birth cohorts, Functional capacity, Secular trends

The life expectancy of older people is increasing. In Finland, for example, a person aged 75 in 1989 could expect to live a further 9.7 years, whereas a same-age individual in 2017 could expect a further 12.6 years (1). However, it is not clear whether a longer life accompanies improvements in functioning at specific ages. If functioning at specific ages is better than in the past, this could lead to a more positive outlook towards aging and contribute to projections on the needs of the work force and health and social care.

The earlier studies assessing cohort differences in the health and functioning of older people give an inconsistent picture. The prevalence of chronic conditions has been found to be stable or to increase among more recent than earlier cohorts of older people (2–4). The results obtained from self-rated health and disability show improved (2,5), worsened (6), and stable (7,8) trends, depending on the study. These differences may stem from differences in the age groups studied, intervals between cohorts, indicators of disability and functioning, different trends between countries, and possibly from problems of comparability between recent and earlier cohorts. Moreover, the earlier studies were often based on self-report data. Apart from an individual's intrinsic capacity, self-assessments may be influenced by environmental circumstances, which may underlie the results (5).

Compared to self-assessments, performance-based measures requiring maximum effort provide more explicit and standardized information on cohort differences in physical functioning. Muscle strength, walking speed, and respiratory function tests are informative and widely used performance-based tests of functional capacity, that capture current and preceding lifetime influences on functioning and predict disability and mortality risk (9,10). Only a few studies have assessed cohort effects in performance-based maximum measures of physical performance, and the results have been mixed. For example, 2 studies reported an improved trend in hand grip strength (11,12) whereas other studies noted no improvement (5,13) or decline (14) among the more recent cohorts. In addition, a large population-based study assessing older adults from Germany, Sweden, and Spain found contrasting trends in grip strength for different age groups. The results showed strong improvement for older adults aged 80 years and older, while younger older adults stagnated or even decreased (15). In other studies, the later-born cohorts performed better in chair stand, walking speed, and peak expiratory flow (PEF) tests (13,16,17). When interpreting these results, it is important to bear in mind that timing and the rate of age-related changes between organs or biological systems within and between individuals differ (18,19). For example, muscle strength declines earlier than walking speed and possibly precedes the decline in lung function (20,21). Incorporating multiple measures will build a more comprehensive picture of the changes accompanying aging.

The challenges in assessing cohort effects include ensuring the comparability of the assessment methods and populations studied. Researchers in Finland are in an exceptionally good position to meet these challenges. First, a population-based study conducted in our center 28 years ago with standardized maximum performance-based assessment methods provides us with a valid point of reference on the functioning of people born approximately one generation ago (22,23). Second, we can base recruitment on population registers, which reduces selection bias (11).

This study examined whether older adults born 28 years later have better physical performance compared to an earlier cohort measured at the same age. The factors underlying potential cohort differences are also investigated.

Method

Study Population

This study forms part of 2 projects conducted at the University of Jyväskylä, Finland. The dataset comprises the Evergreen cohort data collected in 1989–1990 (24) and the Evergreen II cohort data collected in 2017–2018 as part of the *Active Ageing – Resilience and external support as modifiers of disablement outcome* (AGNES) project (25). For both projects, samples were drawn from the Finnish Population Register based on birth year and place of residence. All community-living 75- and 80-year-old residents of the city of Jyväskylä formed the target group. Members of the earlier cohort examined in 1989–1990 were born in 1910 and 1914 and members of the later cohort examined in 2017–2018 were born in 1938–1939 and 1942–1943.

Recruitment, Participation, and Non-participation

The Evergreen and Evergreen II recruitment procedures are comparable. Recruitment was as inclusive as possible. All persons in the targeted age groups, who were living in the community in a non-institutional setting in the recruitment area and able to respond, and who consented to take part, were included.

The recruitment area, the City of Jyväskylä, had expanded since the first Evergreen project due to mergers with neighboring municipalities. However, we targeted people, whose addresses were within the previous city area or in similar adjacent areas, including urban areas and suburbs with apartment buildings and detached houses.

During the Evergreen study, in 1989–1990, participants were sent a letter informing them about the study and suggesting a time for a home interview. Those who declined were asked to give their reasons for non-attendance and the reasons were documented. Evergreen II participants in 2017–2018 were sent a letter informing them about the study after which we enquired about their willingness to take part by phone. For those willing to take part, the home interview was scheduled. During the phone call, those declining to take part were questioned on their reasons for non-participation. The study flow charts are shown in Figure 1. In Evergreen, 500 (77%) and in Evergreen II, 726 (40%) of those eligible participated in the home interviews and research center assessments. In both studies, self-rated health was examined with the question: "How would you yourself describe your health during the last year?" using a 5-option response scale ranging from very poor to very good. For statistical analysis, we recoded the responses as good, moderate, and poor. In the Evergreen study, the question was asked during the home interview, while in the Evergreen II, it was posed during the initial phone call.

Assessment Procedure

The implementation and assessment methods in both projects were identical for all practical purposes. The interviews were conducted in the participants' homes and the physical tests in the Sport and Health Laboratory of the University of Jyväskylä. The measurement equipment and laboratory environment were similar for both cohorts.

Physical Performance Measurements

Ten-meter maximal walking speed was assessed in the laboratory corridor using a hand-held stopwatch. Five meters was allowed for acceleration and the participant was encouraged to continue a few meters past the finish line. Participants wore walking shoes or sneakers (25).

Maximal isometric hand grip strength and maximal isometric knee extension strength were measured in the Evergreen II cohort using an adjustable dynamometer chair (Good Strength; Metitur Oy, Palokka, Finland) and the result expressed in Newtons (N) (23). For the Evergreen cohort, we used the prototype of the Good Strength device, including similar strain gauge technology. In both cohorts, the measurements were performed identically with similar joint angles and instructions to the participant. The measurements were done on the side of the dominant hand in a sitting position with the lower back supported. Hand grip strength was measured using a dynamometer fixed to the arm of the chair. Knee extension strength was measured at an angle of 60 degrees from the fully extended leg towards flexion. After a practice trial, the test was performed at least 3 times with a 1-minute inter-trial rest period until no further improvement occurred, and the highest value was recorded (25). The test-retest reliability of both tests is excellent. In the 80-year-olds, the Pearson correlation coefficients between measurements conducted 1–2 weeks apart were $r = .967$ for hand grip strength and $r = .965$ for knee extension strength (23).

Respiratory function in the Evergreen II cohort was assessed using spirometry (Medikro Pro spirometer, Medikro Oy, Kuopio, Finland) in a standing position with a nose clip. The forced vital capacity (FVC) maneuver was performed at least 2 times. Participants were instructed to inhale maximally and exhale as hard and as fast as possible and continue until there was no air left. The maneuver was continued until the criterion of the ATS/ERS Taskforce (26) was met or a maximum of 8 exhalations was performed. With

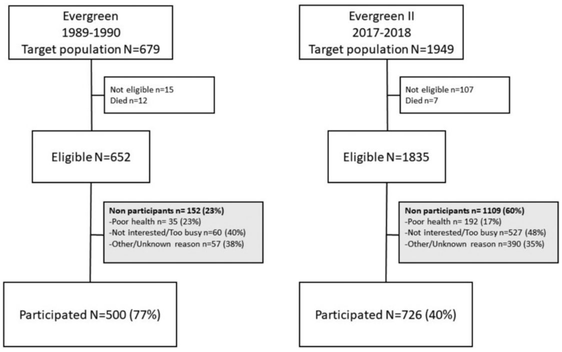

Figure 1. Flow chart for Evergreen and Evergreen II.

the Evergreen cohort, respiratory function was assessed using comparable electronic spirometry (Medikro 202; Medikro, Kuopio, Finland) in a standing position and 3 trials were allowed. In both studies, the highest volume of FVC and the forced expiratory volume in one second (FEV1) were recorded in liters. PEF was recorded in liters per second.

Covariates

Our analyses were not adjusted for any confounders. The age and gender groups were similar, and we concluded that differences in covariates between the cohorts were more likely to be factors underlying the cohort differences than confounders. To study these factors, we chose correlates of physical performance that differed between the cohorts, and that theoretically can be part of the mechanism leading to secular change. Years of full-time education is known to be associated with health and functional status (27), and was used to describe socioeconomic position. Body size, especially height, affects muscle strength, walking speed, and respiratory function (28,29). We measured height with a stadiometer in centimeters and body mass with a beam scale in kilograms. Health behavior was described with physical activity and smoking. Physical activity was assessed with a single validated self-report question with 6 response options ranging from mostly sitting and resting to regular strenuous exercise (23). For the statistical analysis, the responses were recoded as low, moderate, and high. Smoking was classified as never versus current/ former smoker.

Statistical Analysis

To compare the current and earlier same-age cohorts, we used *t* tests for continuous and chi-squared test for categorical variables. We tested whether the cohort differences varied according to age and sex by adding birth cohort-by-sex and birth cohort-by-age interaction terms into the linear regression analyses comprising all the participants. Factors underlying the potential cohort differences were studied in a set of linear regression models. First, the models were fitted with each physical test as a dependent variable and birth cohort as an independent variable. Subsequently, we run several models adding covariates one at a time to analyze which of them attenuates the cohort differences in physical performance. Self-rated health was not included in the models explaining cohort differences, as we believe that improved self-rated health is likely to be a result of better physical functioning and not an explanatory factor. To clarify the potential clinical significance of the cohort differences, hand grip strength cut points for increased risk for mobility limitation were determined separately for men and women based on the Finnish reference data (37 kg for men and 21 kg for women) (30). According to our knowledge, cut-points for knee extension strength and gait speed that predict mobility limitations have not been analyzed based on nationally representative samples in Finland, and therefore are not available for our use. Finally, we did sensitivity analyses to assess the comparability of our cohorts based on the data available for non-participants. If the non-participants were comparable, this would suggest that the cohorts were also comparable and that the differences observed between the cohorts were less likely attributable to selection bias.

Results

In men and women and in both age groups, the number of years of education had doubled in the later- compared to earlier-born cohort (Table 1). In addition, the later-born cohort reported higher daily physical activity and better self-rated health compared to the earlier-born cohort. Among men, the proportion of ever smokers was lower in the later than earlier cohort. Among the 75-year-old women, the proportion of ever smokers was higher in the later than earlier cohort.

Mean grip strength, knee extension strength, and walking speed were higher in the later- than earlier-born cohort (Table 2). In the respiratory function measures, the later-born cohort performed better in FVC and, among the 80-old men and women, in the FEV1 measures. The cohorts did not differ in PEF.

Grip strength below the validated cut-point for increased risk for mobility limitation (37 kg for men and 21 kg for women (30)) was more evident in the earlier-born cohort. Among 75-year-old men, percentage of participants below the cut-point was 48% and 27% in the earlier- and later-born cohort, respectively (between cohorts $p < .001$). Among 75-year-old women, the proportions were 35% versus 28% ($p = .052$). In 80-years-olds, 71% versus 52% in men ($p = .012$) and 75% versus 44% in women ($p < .001$), respectively, had values below the cut-points for increased risk for mobility limitation.

Table 2 shows the relative differences between the cohorts. The regression analyses comprising all participants showed significant cohort-by-sex interactions for grip strength ($p = .041$), FVC ($p = .015$), and FEV1 ($p = .008$), suggesting larger increases in the absolute values among men compared to women in these assessments. However, the relative improvements in walking speed, grip strength, and knee extension strength were greater in the 80-year-old women than in men in either age group or the 75-year-old women.

Cohort-by-age interactions were significant for walking speed ($p = .035$) and grip strength ($p = .001$), suggesting larger increases in the absolute values among the 80-year-olds than 75-year-olds. The interaction was also significant for FEV1 ($p = .004$) in which only the 80-year-olds improved. Moreover, the relative percentile differences were larger among the 80-year-olds than 75-year-olds.

The linear regression models showed that the selected covariates did not fully explain the cohort differences in walking speed and muscle strength (Tables 3 and 4). Better walking speed in the later cohort was partially explained by higher physical activity and longer education. The muscle strength differences in the later-born cohort were partially explained by their increased height, weight, and physical activity level.

In general, the associations between birth cohort and respiratory functions attenuated after adjusting for body height and education (Tables 3 and 4). The results suggest that increased body height in the later-born cohort explained a large part of the differences between the birth cohorts.

Table 1. Descriptive Statistics and Cohort Differences of 75- and 80-Year-Old Men and Women Born in 1910 and 1914 (Evergreen cohort) and Born in 1938–1939 and 1942–1943 (Evergreen II cohort)

	75 Years		Cohort Difference	80 Years		Cohort Difference
	Evergreen	Evergreen II	*p*-Value[a]	Evergreen	Evergreen II	*p*-Value[a]
Men, *n*	104	183		60	132	
Age, mean (*SD*)	75.3 (0.3)	75.4 (0.4)	.171	79.6 (0.3)	79.6 (0.4)	.626
Years of education, mean (*SD*)	6.2 (3.5)	12.2 (4.4)	<.001	5.9 (4.1)	11.9 (4.4)	<.001
Height, cm, mean (*SD*)	169.5 (6.2)	172.7 (6.0)	<.001	169.1 (6.5)	172.3 (6.1)	.001
Weight, kg, mean (*SD*)	74.1 (10.7)	80.4 (13.0)	<.001	75.3 (12.8)	80.1 (12.6)	.017
Self-rated health, *n* (%)			<.001			<.001
Very good / good	13 (13)	106 (58)		10 (17)	60 (46)	
Average	79 (76)	72 (39)		35 (59)	69 (52)	
Poor / very poor	12 (12)	5 (3)		14 (24)	3 (2)	
Physical activity, *n* (%)			<.001			<.001
Low	30 (29)	10 (6)		24 (40)	15 (12)	
Moderate	62 (60)	127 (70)		33 (55)	94 (72)	
High	12 (12)	44 (24)		3 (5)	21 (16)	
Smoking, *n* (%)						
Never	33 (34)	87 (48)	.027	19 (33)	72 (56)	.004
Current / former	64 (66)	95 (52)		38 (67)	56 (44)	
Women, *n*	191	251		145	160	
Age, mean (*SD*)	75.3 (0.3)	75.4 (0.4)	.557	79.6 (0.3)	79.7 (0.4)	.517
Years of education, mean (*SD*)	6.1 (3.2)	12.0 (4.1)	<.001	5.7 (3.1)	11.8 (6.2)	<.001
Height, cm, mean (*SD*)	155.8 (5.6)	159.4 (5.1)	<.001	155.5 (5.4)	158.2 (5.5)	<.001
Weight, kg, mean (*SD*)	67.5 (11.6)	71.1 (12.4)	.002	64.5 (10.2)	69.7 (12.0)	<.001
Self-rated health, *n* (%)			<.001			<.001
Very good / good	27 (14)	137 (55)		18 (13)	67 (42)	
Average	139 (73)	108 (43)		93 (65)	85 (53)	
Poor / very poor	25 (13)	6 (2)		33 (23)	8 (5)	
Physical activity, *n* (%)			<.001			<.001
Low	42 (22)	29 (12)		48 (34)	21 (13)	
Moderate	139 (74)	190 (76)		92 (65)	120 (76)	
High	7 (4)	30 (12)		2 (1)	18 (11)	
Smoking, *n* (%)			.005			.051
Never	167 (90)	201 (80)		133 (93)	136 (86)	
Current / former	18 (10)	49 (20)		10 (7)	22 (14)	

Note: [a]*t* test for continuous variables and chi-squared test for categorical variables.

The participation rate in the later study was lower (see Figure 1). For this reason, we compared all knowledge available on non-participants. The most common reason for non-participation at both times was lack of interest or not having time to take part (Supplementary Table 1). Poor health was slightly more common in the earlier cohort. In both studies, the proportions with unknown or other reasons for participation were practically identical. Information on self-rated health was available for 47% of the non-participants in the earlier cohort and for 73% of the non-participants in the later cohort. Self-rated health did not differ between the non-participants of the Evergreen and Evergreen II cohorts (p = .539). The result did not change when the comparisons were made separately for age groups and sex. Overall, we observed no explicit differences between the non-participants of the earlier and later cohorts, suggesting the absence of systematic selection bias between the studies.

Discussion

We observed that the maximal physical performance of men and women aged 75 or 80 years assessed 28 years apart was markedly and meaningfully better in the later-born cohort. For grip strength, the improvements varied between 11 and 55 N depending on age and sex. Inferring from a meta-analysis (18) (10 N or 1 kg higher grip strength corresponds to 3% decline in mortality), the mortality risk of the 80-year-old men in the later cohort will be 12% lower and in the same-age women 15% lower than in the earlier cohort. The walking speed improvements ranged between 0.2 and 0.4 m/s; a 0.1 m/s improvement in walking speed corresponds to substantially better mobility (31). In addition, the risk for mobility limitations due to low muscle strength is meaningfully lower in the later-born cohorts. The present results are unique in that they derive from multiple highly relevant maximal physical performance tests assessed with identical highly standardized measures in 2 comparable cohorts examined approximately 1 generation apart. These results provide us with novel information about differences in functional aging in people growing old during different historical periods.

Various explanations can be offered for the current results. The first is that the later cohort had more propitious life-course exposures that positively affected their health and functioning. The earlier cohorts were born in 1910–1915, when Finland was largely agricultural, undeveloped, and still part of the Russian empire until 1917. Children worked from an early age, experienced the turmoil

Table 2. Cohort Differences in Physical Performance of 75- and 80-Year-Old Men and Women Born in 1910 and 1914 (Evergreen cohort) and born in 1938–1939 and 1942–1943 (Evergreen II cohort)

	75 Years		Cohort		80 Years		Cohort	
	Evergreen	Evergreen II	Difference		Evergreen	Evergreen II	Difference	
	Mean (*SD*)	Mean (*SD*)	% (95% CI)	*p*-Value[a]	Mean (*SD*)	Mean (*SD*)	% (95% CI)	*p*-Value[a]
Men								
Walking speed, m/s	1.8 (0.5)	2.0 (0.4)	11 (5, 18)	<.001	1.5 (0.5)	1.8 (0.4)	20 (11, 33)	<.001
Grip strength, N	374 (89)	406 (74)	9 (3, 14)	.001	309 (80)	364 (74)	18 (10, 26)	<.001
Knee extension strength, N	362 (99)	452 (102)	25 (18, 32)	<.001	332 (73)	397 (101)	20 (12, 27)	<.001
FVC, l	2.9 (0.7)	3.4 (0.8)	17 (12, 24)	<.001	2.6 (0.7)	3.3 (0.6)	27 (15, 30)	<.001
FEV1, l	2.5 (0.6)	2.6 (0.6)	4 (−0.7, 12)	.081	2.2 (0.6)	2.5 (0.5)	14 (9, 25)	<.001
PEF, l/s	7.4 (2.0)	7.4 (2.0)	0 (−7, 6)	.841	6.9 (2.1)	7.4 (1.7)	7 (1, 17)	.093
Increased risk for mobility limitation, *n* (%)	48 (47.5%)	48 (26.5%)		<.001	39 (70.9%)	68 (51.9%)		.012
Women								
Walking speed, m/s	1.5 (0.4)	1.7 (0.3)	18 (13, 22)	<.001	1.2 (0.3)	1.6 (0.3)	33 (22, 34)	<.001
Grip strength, N	227 (58)	238 (52)	5 (0.2, 9)	.042	172 (55)	215 (44)	25 (19, 32)	<.001
Knee extension strength, N	241 (73)	302 (81)	25 (19, 31)	<.001	188 (63)	277 (82)	47 (38, 56)	<.001
FVC, l	2.2 (0.5)	2.5 (0.5)	14 (12, 20)	<.001	1.9 (0.5)	2.3 (0.4)	21 (18, 29)	<.001
FEV1, l	1.9 (0.4)	1.9 (0.4)	0 (−4, 4)	.825	1.6 (0.4)	1.8 (0.3)	12 (4, 14)	.001
PEF, l/s	5.0 (1.2)	4.9 (1.1)	−2 (−6, 3)	.544	4.8 (1.4)	5.0 (1.3)	4 (−3, 10)	.318
Increased risk for mobility limitation, *n* (%)	67 (35.4%)	69 (27.7%)		.052	104 (75.4%)	70 (44.3%)		<.001

Notes: CI = confidence interval; FEV1 = forced expiratory volume in 1 s; FVC = forced vital capacity; PEF = peak expiratory flow.
[a]*t* test.

following the Civil War in 1918, and as young adults, they took part in the Second World War. The later cohort was born in 1938–1942. During the 1940s, many reforms were implemented, including the provision of school meals for all children free of charge and longer obligatory education. This improved the nutritional situation, especially for children from lower income homes, and delayed their entry into the labor market. These societal reforms may underlie our findings of increased height and weight in the latter cohort, which is mostly a result of better nutrition (32). With the rapid development of the country in the 1950s, access to secondary and tertiary education improved and the female disadvantage in education decreased (33). This is in line with the doubling of length of education between the earlier and later cohorts. Higher education is associated with better jobs, and better economic conditions and psychosocial resources and with more beneficial health behavior, all of which contribute to better health and functioning. Heavy manual work in earlier life is associated with increased risk for problems in health and functioning in older age (34). The regression analyses indicated that positive secular trends in the covariates were important aspects underlying improved muscle strength and walking speed in the later cohort. Longer education in men and increased leisure-time physical activity levels in both sexes were associated with better walking speed, whereas increased body size and physical activity level were associated with better muscle strength. However, the association of physical activity with cohort differences in physical performance can be interpreted in 2 ways: high physical activity may result from better physical performance, or vice versa (35).

Many of the birth cohort effects remained unexplained by the variables available in our data. Other potential explanations include improved medical care and better access to health care. In addition, working conditions has improved through legislation protecting employees and improved technological solutions. However, we can probably rule out genetic differences between the cohorts as an explanation: since the resettlement of the Karelian population in Finland during the Second World War, there has been very little immigration. In addition, we do not believe that selective mortality explains the results. Mortality prior to the age 75 or 80 years was lower in the latter cohort than the earlier cohort, making the later cohort less rather than more selected.

In the lung function tests, the results were somewhat inconsistent. The later-born cohort performed better in the FVC test, which measures the total amount of air that can be forcibly exhaled. However, cohort differences in exhaled airflow were small or non-existent. In contrast to an earlier finding among 75-year-olds, we noted a positive change only among the 80-year-olds in the FEV1 test and no improvement in PEF (17). In our study, cohort differences in lung function were partly explained by the greater body size in the later-born cohort. Increased education, potentially indicating better working conditions and health habits also explained better lung function in the younger cohort. Smoking is the main reason for decreased pulmonary function and chronic airway obstruction. In our study, the proportion of ever smokers in the later cohort was lower among men and higher among women, a finding in line with previous reports (36). However, it had only a minor impact on the cohort differences. Environmental factors pertaining to pulmonary health have possibly worsened during the past few decades due to urbanization, exposures to emissions of biomass fuels, and other causes of environmental pollution. Long-term exposure to ambient air pollutants have been shown to result in impaired lung function and an increasing prevalence of obstructive lung diseases, which may explain why the improvement in FEV1 was smaller than that in FVC and not evident in the 75-year-old cohort (37).

The better physical performance in the later-born cohort can be explained by their slower rate-of-change with increasing age, a higher lifetime maximum in physical performance, or a combination of the 2. Between the years 1989 and 2017, the remaining life expectancy

Table 3. Linear Regression of the Association Between the Birth Cohort and Physical Performance Measures in Men

	Men 75 Years			Men 80 Years		
	Birth Cohort		Model	Birth Cohort		Model
	β (*SE*)	*p*-Value	Adjusted r^2	β (*SE*)	*p*-Value	Adjusted r^2
Walking speed, m/s						
Birth cohort	0.211 (0.055)	<.001	.046	0.330 (0.075)	<.001	.089
+ Education	0.029 (0.066)	.663	.105	0.226 (0.089)	.012	.106
+ Height	0.189 (0.057)	.001	.051	0.294 (0.077)	<.001	.097
+ Weight	0.256 (0.056)	<.001	.076	0.346 (0.076)	<.001	.093
+ PA	0.073 (0.054)	.176	.211	0.174 (0.072)	.016	.275
+ Smoking	0.181 (0.057)	.002	.049	0.271 (0.077)	.001	.098
Grip strength, N						
Birth cohort	32.2 (9.9)	.001	.033	54.9 (12.2)	<.001	.094
+ Education	19.1 (12.2)	.118	.036	51.4 (14.4)	<.001	.095
+ Height	19.3 (9.9)	.052	.108	41.5 (11.8)	.001	.193
+ Weight	23.8 (10.0)	.018	.069	46.4 (12.0)	<.001	.147
+ PA	16.7 (10.2)	.104	.091	50.0 (12.6)	<.001	.109
+ Smoking	25.2 (10.1)	.016	.025	49.5 (12.7)	<.001	.092
Knee extension strength, N						
Birth cohort	89.4 (12.6)	<.001	.151	65.0 (15.1)	<.001	.087
+ Education	85.1 (15.4)	<.001	.142	58.4 (17.6)	.001	.093
+ Height	81.9 (12.9)	<.001	.163	58.7 (15.4)	<.001	.101
+ Weight	83.0 (12.9)	<.001	.161	58.3 (15.1)	<.001	.114
+ PA	68.7 (12.9)	<.001	.209	54.1 (15.2)	<.001	.133
+ Smoking	85.0 (13.0)	<.001	.131	56.8 (15.3)	<.001	.100
FVC, L						
Birth cohort	0.521 (0.091)	<.001	.103	0.604 (0.103)	<.001	.158
+ Education	0.378 (0.111)	.047	.108	0.584 (0.122)	<.001	.157
+ Height	0.391 (0.089)	<.001	.199	0.451 (0.099)	<.001	.279
+ Weight	0.562 (0.093)	<.001	.117	0.580 (0.105)	<.001	.165
+ PA	0.417 (0.096)	<.001	.133	0.510 (0.108)	<.001	.192
+ Smoking	0.485 (0.095)	<.001	.097	0.548 (0.105)	<.001	.171
FEV1, L						
Birth cohort	0.135 (0.077)	.081	.007	0.364 (0.086)	<.001	.091
+ Education	−0.011 (0.094)	.905	.025	0.356 (0.103)	<.001	.084
+ Height	0.037 (0.076)	.631	.093	0.242 (0.084)	.004	.205
+ Weight	0.161 (0.079)	.044	.010	0.334 (0.088)	<.001	.093
+ PA	0.048 (0.082)	.556	.032	0.282 (0.091)	.002	.117
+ Smoking	0.097 (0.080)	.223	.022	0.282 (0.087)	.001	.128
PEF, L/s						
Birth cohort	−0.049 (0.244)	.841	.000	0.533 (0.292)	.069	.013
+ Education	−0.483 (0.296)	.104	.011	0.515 (0.346)	.138	.009
+ Height	−0.307 (0.244)	.209	.055	0.265 (0.295)	.370	.067
+ Weight	−0.028 (0.251)	.912	.000	0.390 (0.294)	.186	.042
+ PA	−0.437 (0.254)	.087	.054	0.276 (0.310)	.373	.029
+ Smoking	−0.158 (0.252)	.531	.004	0.397 (0.102)	.188	.014

Note: FEV1 = forced expiratory volume in 1 s; FVC = forced vital capacity; PA = physical activity; PEF = peak expiratory flow. Each covariate was added in the model one at a time with birth cohort; β = unstandardized beta indicates mean cohort difference (reference group Evergreen cohort).

in Finland has increased by around 3 years among 75-year-olds and 2 years among 80-year-olds (1). Having more years to death at these ages, together with the current results, suggests that today's older people are functionally younger than people of the same age one generation earlier. Our findings support the hypothesis of the postponement of disability to older ages (38), although our data cannot be used to support or reject the compression of morbidity hypothesis, which continues to be debated (39). Nevertheless, the results point toward more years spent with higher functional capacity at least among current 75- and 80-year-old adults in Finland. However, it is unclear whether this positive trend applies to younger cohorts. Beller et al. (12) showed an opposing trend in grip strength among younger cohorts, which may stem from changes in health-related lifestyles, such as increased sedentary lifestyle and obesity. In addition, differences in historical and economic developments and cultural factors may also result in mixed trends in physical performance in different countries.

The main strength of this study is the use of standardized maximal performance assessments of multiple functions conducted with identical methods 28 years apart. Muscle strength, walking speed, and respiratory functions describe the intrinsic physiological capacity of older adults. Another strength of the study is that we compared men and women of exactly the same ages. Participant recruitment was also comparable in both studies. We found that non-participants did

Table 4. Linear Regression of the Association Between the Birth Cohort and Physical Performance Measures in Women

	Women 75 Years			Women 80 Years		
	Birth Cohort		Model	Birth Cohort		Model
	β (*SE*)	*p*-Value	Adjusted r^2	β (*SE*)	*p*-Value	Adjusted r^2
Walking speed, m/s						
Birth cohort	0.261 (0.033)	<.001	.122	0.349 (0.038)	<.001	.224
+ Education	0.146 (0.041)	<.001	.151	0.318 (0.044)	<.001	.231
+ Height	0.240 (0.035)	<.001	.127	0.329 (0.039)	<.001	.228
+ Weight	0.274 (0.032)	<.001	.213	0.398 (0.037)	<.001	.287
+ PA	0.205 (0.031)	<.001	.275	0.274 (0.036)	<.001	.347
+ Smoking	0.275 (0.034)	<.001	.138	0.354 (0.038)	<.001	.224
Grip strength, N						
Birth cohort	10.8 (5.31)	.042	.007	43.5 (5.8)	<.001	.158
+ Education	9.09 (6.76)	.181	.003	41.9 (7.3)	<.001	.161
+ Height	−0.09 (5.40)	.987	.084	35.8 (5.7)	<.001	.227
+ Weight	8.71 (5.33)	.103	.022	37.0 (5.8)	<.001	.206
+ PA	6.18 (5.37)	.251	.036	38.4 (5.9)	<.001	.191
+ Smoking	11.3 (5.4)	.038	.006	43.2 (5.9)	<.001	.153
Knee extension strength, N						
Birth cohort	60.4 (7.5)	<.001	.127	88.7 (8.6)	<.001	.264
+ Education	55.0 (9.6)	<.001	.122	99.2 (10.1)	<.001	.271
+ Height	49.7 (7.8)	<.001	.159	82.6 (8.8)	<.001	.276
+ Weight	55.5 (7.4)	<.001	.165	83.5 (8.8)	<.001	.272
+ PA	54.4 (7.6)	<.001	.150	77.1 (8.7)	<.001	.308
+ Smoking	61.1 (7.6)	<.001	.127	87.6 (8.7)	<.001	.256
FVC, L						
Birth cohort	0.342 (0.046)	<.001	.115	0.439 (0.052)	<.001	.195
+ Education	0.280 (0.059)	<.001	.115	0.340 (0.066)	<.001	.201
+ Height	0.199 (0.043)	<.001	.289	0.356 (0.050)	<.001	.307
+ Weight	0.373 (0.046)	<.001	.113	0.441 (0.054)	<.001	.193
+ PA	0.304 (0.046)	<.001	.154	0.415 (0.054)	<.001	.189
+ Smoking	0.341 (0.047)	<.001	.111	0.434 (0.053)	<.001	.189
FEV1, L						
Birth cohort	0.008 (0.038)	.825	.000	0.148 (0.043)	.001	.036
+ Education	−0.024 (0.048)	.618	.000	0.086 (0.055)	.123	.044
+ Height	−0.086 (0.037)	.023	.122	0.088 (0.042)	.039	.134
+ Weight	0.008 (0.038)	.835	.000	0.142 (0.045)	.002	.033
+ PA	−0.023 (0.038)	<.001	.036	0.133 (0.045)	.004	.029
+ Smoking	0.019 (0.039)	.020	.008	0.148 (0.044)	.001	.032
PEF, L/s						
Birth cohort	−0.076 (0.122)	.535	.000	0.156 (0.156)	.318	.000
+ Education	−0.241 (0.156)	.124	.002	0.049 (0.201)	.809	−.001
+ Height	−0.277 (0.125)	.028	.052	0.048 (0.160)	.763	.022
+ Weight	−0.101 (0.123)	.412	.001	0.125 (0.162)	.441	−.002
+ PA	−0.145 (0.125)	.246	.009	0.031 (0.161)	.849	.015
+ Smoking	−0.050 (0.124)	.688	.001	0.163 (0.160)	.308	−.003

Note: FEV1 = forced expiratory volume in 1 s; FVC = forced vital capacity; PA = physical activity; PEF = peak expiratory flow. Each covariate was added in the model one at a time with birth cohort; β = unstandardized beta indicates mean cohort difference (reference group Evergreen cohort).

not differ between the studies in terms of self-rated health or reasons to decline participation, a finding that supports the comparability of the cohorts. However, we cannot rule out the possibility that some unmeasured influences underlying the participation rates may have affected the results. In addition, our study is unique in the length of the interval between the studies being almost 3 decades.

The study has also its limitations. First, the participation rate in the later study was lower than in the earlier, which could mean that the participants in the later study represent a healthier section of the target population than those in the earlier study. Because non-participants did not differ between the studies, we may assume that the cohorts were comparable. However, it is still possible that because of the smaller participation rate, the later cohort is more selected and potentially healthier group, and we cannot completely rule out the possibility of selection bias explaining partly the results. The measurement equipment for assessing grip strength and knee extension strength was identical in both times, and methodological differences probably do not explain the observed differences between the cohorts. However, we cannot rule out the possibility that for lung function test, some systematic measurement difference may have affected the results. Another possible limitation is that the cohort differences in comorbidity could not be included in the analyses due to changes in the diagnostics, treatment, and recording of chronic conditions over the past 3 decades. The results may be unique to Finland; however, it is likely that they can be generalized to other countries that have undergone similar societal changes during the last 100 years. We do not have data on life-course exposures earlier in the participants' lives, information which would have strengthened our conclusions on the possible reasons for the cohort differences.

To conclude, the present study suggests improved physical performance, especially in walking speed and muscle strength, in the more recent birth cohorts of 75- and 80-year-old Finnish adults. These functional traits underlie mobility, activities of daily living, and participation in social life. The results may help to identify potentially unrecognized resources of older adults and encourage their continued engagement in valued activities in later life.

Supplementary Material

Supplementary data are available at *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences* online.

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Conflict of Interest

T.R. serves on the *Journal of Gerontology: Medical Sciences* editorial board. Otherwise, the authors declare no conflicts of interest.

Author Contributions

K.K.: Conception and design of the study, drafting the manuscript, and data preparation, analysis, and interpretation. E.S.: Contribution to the design of the study, data analysis and interpretation, and drafting the manuscript. M.M.: Data preparation, analysis, and interpretation, and critical revision for important intellectual content. E.P.: Data collection, and critical revision for important intellectual content. T.R.: Conception and design of the study, acquiring the funding for conducting the research, conducting the study, acquiring the data, data analysis and interpretation, and drafting the manuscript.

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II

MORTALITY RISK AMONG OLDER PEOPLE WHO DID VERSUS DID NOT SUSTAIN A FRACTURE: BASELINE PREFRACTURE STRENGTH AND GAIT SPEED AS PREDICTORS IN A 15-YEAR FOLLOW-UP

by

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OXFORD

Research Article

Mortality Risk Among Older People Who Did Versus Did Not Sustain a Fracture: Baseline Prefracture Strength and Gait Speed as Predictors in a 15-Year Follow-Up

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Abstract

Background: Physiological reserve, as indicated by muscle strength and gait speed, may be especially determinant of survival in people who are exposed to a health stressor. We studied whether the association between strength/speed and mortality risk would be stronger in the time period after a fracture compared to other time periods.

Methods: Participants were population-based sample of 157 men and 325 women aged 75 and 80 years at baseline. Maximal 10-m gait speed and maximal isometric grip and knee extension strength were tested at the baseline before the fracture. Subsequent fracture incidence and mortality were followed up for 15 years. Cox regression analysis was used to estimate fracture time-stratified effects of gait speed and muscle strength on mortality risk in three states: (i) nonfracture state, (ii) the first postfracture year, and (iii) after the first postfracture year until death/end of follow-up.

Results: During the follow-up, 20% of the men and 44% of the women sustained a fracture. In both sexes, lower gait speed and in women lower knee extension strength was associated with increased mortality risk in the nonfracture state. During the first postfracture year, the mortality risk associated with slower gait and lower strength was increased and higher than in the nonfracture state. After the first postfracture year, mortality risk associated with lower gait speed and muscle strength attenuated.

Conclusions: Lower gait speed and muscle strength were more strongly associated with mortality risk after fracture than during nonfracture time, which may indicate decreased likelihood of recovery.

Keywords: Physical function, Epidemiology, Health stressors, Adverse events, Fracture

Bone fractures are common health stressors in older age, which, in turn, can lead to loss of function, institutionalization, and premature death (1–3). However, individuals differ considerably in their capability to recover from bone fractures. Understanding the factors that cause differences in postfracture recovery can help both in identifying individuals at higher risk for health decline when experiencing adverse events and in implementing preventive interventions.

In old age, the increased mortality associated with fractures is a result of several factors. The direct association of a fracture with the events causally related to it, such as complications and infections, explain part of the short-term excess mortality (3,4). Other factors, such as pain, fear of falling, and delay in tissue healing, which are commonly accompanied by inactivity, may further complicate the recovery process. The occurrence of a fracture often triggers progressive functional loss leading to disability (5,6), which may elevate long-term mortality risk. Poor health and reduced physiological reserve may play an important role in explaining the increased risk of postfracture mortality (7). However, other studies have reported an increased relative mortality risk after hip fracture even among patients without comorbidities (3,8).

An important factor in assessing the role of prefracture health in postfracture mortality is the severity of the chronic conditions.

Measurements of functional status or physiological reserve reflect the burden of diseases and progressive physiological changes in the aging process (9). The hierarchical model of the metrics of aging, recently introduced by Ferrucci and colleagues, posit that aging occurs in three interrelated domains: biological, phenotypical, and functional (10). According to their hypothesis, functional aging occurs when the reserve mechanisms of biological and phenotypical aging have been enervated.

Measures of muscle strength and gait speed are widely used indicators of functional status and physiological reserve, especially among older people (11). It is known that lower gait speed and muscle strength are associated with higher risk for bone fractures and higher mortality risk (12–16). However, little is known about how prospectively assessed prefracture functional status predicts the recovery and consequences of fracture. In most studies, functional status has been assessed retrospectively after fracture and thus may be confounded by situational factors. To the best of our knowledge, only a few studies have investigated the association between objectively measured prefracture muscle strength and subsequent survival. According to two earlier studies, participants with higher knee extension strength before a bone fracture had lower postfracture mortality risk than those with lower muscle strength (17,18). However, in those studies, the study population was composed solely of individuals who had sustained a fracture, and hence we do not know whether the predictive power of higher muscle strength on survival is different after fracture compared to time without fracture. Therefore, it is not clear whether the increased postfracture mortality risk in those with lower muscle strength is a result of low physiological reserve itself (similar situation without fracture) or if it is because of an interaction between low physiological reserve and fracture, thus indicating that physiological reserve has a more pronounced role in terms of survival. Furthermore, prefracture gait speed as a predictor of subsequent mortality has not been addressed in earlier studies.

In this study, the aim was to investigate whether the associations of gait speed and muscle strength with mortality risk were higher after fracture compared to time without a fracture. Pronounced associations after fracture would suggest that lower muscle strength and gait speed measured prior to fracture are important predictors of postfracture health decline and mortality.

Methods

Study Design

The Evergreen Study was conducted in 1989–1990 (19). All the community-living 75- and 80-year-old residents (N = 679) of Jyväskylä formed the target group. In total, 617 persons took part in interviews and laboratory examinations on functioning. Of these, 482 took part in maximal isometric strength and maximal gait speed tests and formed the study group for the present analyses.

Of the interviewed participants, 22% did not take part in laboratory examinations. The participants in our study group had better mobility and were more physically active compared to dropouts. Sixty-six percent of the participants and 83% of the dropouts did not achieve the recommended level of physical activity (20). Participants had less difficulty in independent walking outdoors than dropouts (6% vs 38%).

Ascertainment of Fractures and Death

The participants were followed up from the beginning of 1990 until the end of April 2005 for fractures and mortality. The information on bone fractures was acquired from patient records from the Health Centers in the area and the Central Hospital of Central Finland. Records include ICD-10 diagnosis code, date and scene of fractures. Death dates were obtained from the population register of Finland.

All fracture types, except fractures of toes and fingers, were included in the analysis. Fracture location was categorized into proximal (hip, pelvis, and lumbar spine) and distal (thoracic and cervical spine, upper extremity, lower leg and foot, head, and collar bone). We constructed the fracture event variable as follows. For those who sustained at least one proximal fracture, we chose the date of the first proximal fracture. For those who only sustained distal fractures, we chose the date of the first distal fracture. We opted for this approach, as earlier studies did not provide any evidence-based examples on the optimal way to categorize different fractures. Some studies have also reported associations of nonhip and nonvertebral fractures with increased mortality risk (21,22) and clinically important functional decline (5,6), while others have reported no increase in mortality following nonhip and nonvertebral fractures (23).

Assessment of Muscle Strength and Gait Speed

Ten-meter maximal gait speed, maximal isometric handgrip strength and maximal isometric knee extension strength were assessed at the research center at baseline prior to potential fracture events. Maximal gait speed was measured in the laboratory corridor using a hand-held stopwatch. Two to three meters were allowed for acceleration and deceleration (24). Maximal isometric handgrip strength and maximal isometric knee extension strength were measured using an adjustable dynamometer chair (Faculty of Sport and Health Sciences, University of Jyväskylä, Jyväskylä, Finland) (25). The measurements were performed on the side of the dominant hand in a sitting position with lower back supported. Handgrip strength was measured using a dynamometer fixed to the arm of the chair. Maximal isometric knee extension strength was measured at an angle of 60° from the fully extended leg toward flexion. The results were expressed in Newtons (N), and the best result of three trials was used in the analyses. The reproducibility of the maximal isometric strength tests has been studied with repeated measures 2 weeks apart in a subsample of 12 subjects aged 80 years. The Pearson correlation coefficients were excellent (handgrip strength r = .967 and knee extension strength r = .965) (25).

Covariates

Potential confounders were selected because of their possible association with gait speed and muscle strength or mortality risk. Data on age, body size (weight and height), smoking status (ever vs never), years of education, physical activity (low vs high), and chronic conditions were collected at baseline prior to potential fractures. Physical activity was considered low when the self-reported amount of weekly physical activity did not meet the level of national guidelines (20). Number of chronic conditions was calculated based on responses to a questionnaire and subsequent clinical examination by a physician.

Statistical Analysis

The baseline characteristics of the participants were compared using one-way ANOVA between nonfractured participants and two groups of fracture participants, one comprising those who survived and the other comprising those who died during the first year after fracture.

Mortality risks were analyzed with extended Cox's hazard regression. A time-fixed exposure variable of having a fracture does not account for the fact that subjects may enter the study with an initial fracture-free period. Such a covariate does not usually meet the proportional hazard assumption as the risk for death is highest immediately after the fracture and decreases during the following years (26,27) and does not account for the "immortal bias" related to the time spent fracture-free (28). We used an extension of the illness-death model (29) accommodating time-dependent predictors related to the postfracture recovery process. In this model, fracture states were modeled as a time-dependent variable in a relative risk model based on a counting process formulation. The possible states for study participants are shown in Figure 1. All participants contributed to the nonfracture state until a fracture occurred or until death or end of follow-up if they did not sustain a fracture. For participants who sustained a fracture, separate risks were estimated for the first postfracture year and after the first postfracture year until death or end of follow-up if they survived the first postfracture year.

Interaction terms were used to investigate the associations between fracture state, gait speed and muscle strength on mortality risk. The gait speed and muscle strength variables were centered prior to entry in the model. All models were conducted separately for men and women. The models were adjusted with baseline age, number of chronic conditions, and physical activity due to their association with the predictors (gait speed and muscle strength) and the outcome (mortality risk). The results are shown as aggregate risk ratio's (linear combinations) for gait speed and muscle strength in the fracture states. Descriptive statistics were computed in SPSS Statistics 24 for Windows and Cox regression models were constructed using the package "survival" version 2.44-1.1 in the R environment (version 3.5.1).

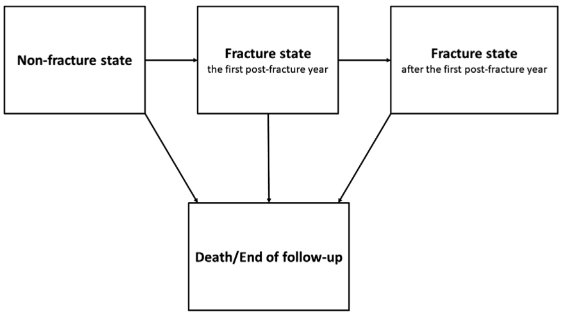

Figure 1. An extension of the illness-death model used in the analysis.

Results

During the follow-up, 176 of 482 participants (36% in total, 20% of men, and 44% of women) sustained at least one fracture. The accumulation of fractures and deaths during the follow-up is shown in Supplementary Figure 1. The majority (92%) of the fractures occurred owing to a fall and the remainder for other reasons. The average time from the baseline measures to fracture was 5.7 years (*SD* 3.9) in men and 7.0 years (*SD* 4.1) in women. Mean age at time of fracture was 83 years (*SD* 4.5) for men and 84 years (*SD* 4.7) for women. During the follow-up, 134 men and 252 women died during their respective 1,359 and 3,167 person-years of surveillance. The crude mortality rate was 9.8 deaths per 100 person-years in men and 7.9 deaths per 100 person-years in women. During the first year after fracture, 10 (31%) of the men and 33 (23%) of the women who had sustained a fracture died.

The baseline characteristics of the participants and comparisons between the nonfracture group and two-fracture groups are shown in Table 1. In men, those who died during the first year after fracture had lower prefracture knee extension strength and were heavier than the first-year postfracture survivors and nonfractured participants. In women, those who died during the first year after fracture had lower prefracture handgrip strength compared to the first-year postfracture survivors and nonfractured participants, and lower prefracture gait speed than the first-year postfracture survivors. In addition, older women had a higher probability to die during the first year after fracture. The groups showed no differences in physical activity level or smoking status.

The unadjusted Cox regression models revealed associations of higher mortality risk with lower maximal gait speed, lower maximal isometric handgrip and knee extension strength, older age and a higher number of chronic conditions, and in men, a low level of physical activity (Table 2). Therefore, age, physical activity, and number of chronic conditions were selected as covariates for the further analyses.

Table 1. Baseline Characteristics of the Participants Stratified into Those Who Did Not Sustain a Fracture, Those Who Had a Fracture and Either Survived the First Postfracture Year or Died During the First Postfracture Year

	Men				Women			
		Fractured				Fractured		
	No Fracture n = 125	Survived First Year n = 22	Died During First Year n = 10		No Fracture n = 181	Survived First Year n = 111	Died During First Year n = 33	
	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)	p*	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)	p*
Gait speed (m/s)	1.7 (0.5)	1.6 (0.5)	1.4 (0.4)	.125	1.4 (0.4)	1.5 (0.3)	1.2 (0.3)	**<.001**
Knee extension strength (N)	356.3 (104.1)	320.5 (67.4)	267.4 (118.1)	**.014**	217.6 (81.7)	226.4 (68.0)	189.6 (69.6)	.053
Grip strength (N)	351.8 (100.9)	329.0 (57.1)	295.2 (169.4)	.177[†]	204.0 (68.3)	210.8 (58.2)	167.4 (68.1)	**.004**
Body height (cm)	169.2 (6.2)	168.5 (6.3)	173.1 (5.7)	.128	155.2 (5.6)	156.5 (5.4)	155.2 (5.0)	.125
Body weight (kg)	74.2 (11.0)	71.2 (9.3)	84.1 (17.5)	**.011**[†]	66.6 (11.6)	65.6 (10.1)	65.4 (11.3)	.670
Body mass index (kg/m^2)	25.9 (3.5)	25.1 (3.1)	28.2 (6.2)	.092[†]	27.7 (4.7)	26.8 (3.9)	27.1 (4.2)	.228
Education (years)	6.3 (4.0)	5.8 (3.0)	6.0 (2.8)	.869	5.9 (3.2)	6.0 (3.5)	5.8 (2.0)	.900
Chronic conditions, number	1.7 (1.3)	1.4 (1.0)	1.7 (0.7)	.535[†]	2.1 (1.5)	1.8 (1.4)	2.0 (1.4)	.228
Time to fracture (years)[‡]	—	5.6 (4.3)	5.9 (2.9)	.803[§]	—	6.8 (4.3)	7.7 (3.9)	.270[§]

Note: *One-way analysis of variance, [†]Welch test for variables with unequal variances between groups, [‡]time after baseline measures to fracture, [§]*t* test. Bold typeface indicates statistically significant at the significance level of .05.

Table 2. Univariate Cox Regression Analysis of Risk Factors for Mortality Risk Stratified by Sex

Variable	Men *n* = 157 HR (95% CI)	Women *n* = 325 HR (95% CI)
Age at baseline (80 vs 75 years)	**1.58 (1.11–2.24)**	**1.96 (1.52–2.52)**
Physical activity (low vs high)	**2.00 (1.39–2.89)**	1.19 (0.91–1.55)
Smoker ever (yes vs no)	1.41 (0.95–2.07)	1.24 (0.85–1.82)
Maximal gait speed (per −1 m/s)	**3.16 (2.17–4.60)**	**3.48 (2.45–4.95)**
Grip strength (per −100 N)	**1.37 (1.14–1.63)**	**1.62 (1.36–1.93)**
Knee extension strength (per −100 N)	**1.31 (1.11–1.55)**	**1.44 (1.23–1.68)**
Number of chronic conditions	**1.34 (1.16–1.56)**	**1.23 (1.13–1.35)**
Height (per 1 cm)	0.99 (0.97–1.02)	0.98 (0.95–1.00)
Weight (per 1 kg)	1.00 (0.98–1.01)	0.99 (0.97–1.00)
BMI (per 1 kg/m^2)	0.99 (0.94–1.04)	0.98 (0.95–1.01)
Length of education (per 1 year)	0.99 (0.94–1.04)	0.96 (0.93–1.00)

Note: Bold typeface indicates statistically significant hazard ratios at the significance level of .05. CI = confidence interval, HR = hazard ratio.

Postfracture Mortality Risk

The risk of death during the first postfracture year compared to nonfracture state was almost fourfold in both men and women (Table 3). After the first postfracture year, increased mortality risk continued to be observed, although attenuated after the first year.

Table 4 shows the associations of maximal gait speed, maximal isometric muscle strength and fracture state on mortality risk during the nonfracture state and the fracture states. The first fracture state comprised the first postfracture year and the second the follow-up time after the first postfracture year until death or end of follow-up. In both sexes, lower gait speed was statistically significantly associated with increased mortality risk in the nonfracture state (RR 1.09, 95% CI 1.04–1.14 in men, and RR 1.10, 95% CI 1.05–1.16 in women per 0.1 m/s decrease). The association between lower gait speed and mortality risk was higher during the first postfracture year compared to the nonfracture state (RR 3.61, 95% CI 1.75–7.46 in men, and RR 4.21, 95% CI 2.82–6.28 in women). After the first postfracture year, the association between gait speed and mortality risk attenuated approximately to the level of nonfracture state (RR 1.75, 95% CI 1.03–2.99 in men, and RR 1.76, 95% CI 1.26–2.46 in women).

The associations of lower grip strength and knee extension strength with mortality risk were also higher after fracture than in the nonfracture state (Table 4). In the nonfracture state, lower muscle strength was associated statistically significantly with mortality risk only in women for knee extension strength (RR 1.03, 95% CI 1.01–1.06). During the first postfracture year, mortality risk was three- to fourfold per 100 N decrease in muscle strength in both sexes (grip strength in men RR 3.51, 95% CI 1.72–7.14 and in women RR 3.62, 95% CI 2.39–5.49; knee extension strength in men RR 2.85, 95% CI 1.28–6.31 and in women RR 3.80, 95% CI 2.54–5.67). After the first postfracture year, the mortality risk was still elevated compared to nonfracture time but it attenuated to being almost twofold (grip strength in men RR 1.76, 95% CI 1.28–6.31, and in women RR 3.80, 95% CI 2.54–5.67; knee extension strength in men RR 1.75, 95% CI 1.06–2.91 and in women RR 1.74, 95% CI 1.27–2.38).

Sensitivity analysis using weight as an additional time-dependent covariate indicated that among women, weight was not associated with fracture and mortality risk and hence it did not change the results materially. Among men, postfracture estimates for gait speed and strength were attenuated slightly, but the only risk ratio affected was the state after the first postfracture year, which was no longer statistically significant.

Finally, we repeated the analyses separately for subjects with distal and proximal fractures to ensure that the results were not driven by the higher mortality risk after proximal fractures. This did not materially change the results, but the separate analyses by fracture location lacked sufficient statistical power (data not shown).

Table 3. Relative Risks (RR) of Death After a Fracture during Fracture State Compared to Nonfracture State Stratified by Sex

	Men *n* = 157 RR (95% CI)	Women *n* = 325 RR (95% CI)
Nonfracture state	1.00	1.00
Fracture state$_{\text{the first postfracture year}}$	**3.86 (1.98–7.51)**	**3.92 (2.66–5.77)**
Fracture state$_{\text{after the first postfracture year}}$	**1.77 (1.07–2.92)**	**1.79 (1.31–2.44)**

Note: Reference group: nonfracture state (no fracture during the follow-up and time before fracture occurrence of the participants sustaining a fracture). Adjusted for age, number of chronic conditions and physical activity. CI = confidence interval, RR= relative risks.

Table 4. The Associations of Gait Speed and Muscle Strength on Mortality Risk During Nonfracture State and Fracture State (the First Postfracture Year and After the First Postfracture Year)

	Men (*n* = 157) RR (95% CI)	Women (*n* = 325) RR (95% CI)
Fracture and gait speed, per decrease of 0.1 m/s		
Gait speed$_{\text{nonfracture state}}$	**1.09 (1.04–1.14)**	**1.10 (1.05–1.16)**
Gait speed$_{\text{the first postfracture year}}$	**3.61 (1.75–7.46)**	**4.21 (2.82–6.28)**
Gait speed$_{\text{after the first postfracture year}}$	**1.75 (1.03–2.99)**	**1.76 (1.26–2.46)**
Fracture and grip strength, per decrease of 100 N		
Grip strength$_{\text{nonfracture state}}$	1.02 (1.00–1.04)	1.03 (1.00–1.06)
Grip strength$_{\text{the first postfracture year}}$	**3.51 (1.72–7.14)**	**3.62 (2.39–5.49)**
Grip strength$_{\text{after the first postfracture year}}$	**1.76 (1.07–2.91)**	**1.75 (1.28–2.40)**
Fracture and knee extension strength, per decrease of 100 N		
Knee extension strength$_{\text{nonfracture state}}$	1.01 (0.99–1.03)	**1.03 (1.01–1.06)**
Knee extension strength$_{\text{the first postfracture year}}$	**2.85 (1.28–6.31)**	**3.80 (2.54–5.67)**
Knee extension strength$_{\text{after the first postfracture year}}$	**1.75 (1.06–2.91)**	**1.74 (1.27–2.38)**

Note: Nonfracture state = no fracture during the follow-up and time before fracture occurrence of the participants sustaining a fracture. All models were adjusted for number of chronic conditions, age and physical activity. CI = confidence interval, RR = relative risk.

Discussion

In the current study, participants with lower prefracture gait speed and muscle strength had pronounced mortality risk during the first postfracture year compared to time without fracture exposure. The current results extend earlier findings on the role of prefracture muscle strength in postfracture survival (17,18) by including nonfracture time (no fracture during the follow-up and time before fracture occurrence of the participants sustaining a fracture) in the analyses. To the best of our knowledge, this was the first study to assess the association between prefracture gait speed and postfracture mortality risk.

The association of gait speed and muscle strength with mortality risk has been reported several times (13,30,31). However, it is unclear, what underlies these associations (30). In this study, comparing the different event states with and without fracture exposure revealed that lower gait speed and muscle strength were associated more strongly with increased mortality risk in the first postfracture year compared to nonfracture state. However, after the first postfracture year, for gait speed the mortality risk attenuated to approximately the nonfracture state level whereas for muscle strength although the mortality risk attenuated it remained elevated compared to nonfracture time (as indicated by nonoverlapping confidence intervals). Comparison of the mortality risks associated with gait speed and muscle strength at different fracture event states suggest that people with low physiological reserve measured with prefracture gait speed and muscle strength may be especially vulnerable to health decline during the first year after fracture. The risk may not be that high at other times although even in the absence of catastrophic events, gradual progressive physiological changes will increase vulnerability to health decline in older age.

Measuring maximal functional capacity can reveal the underlying state of biological and phenotypical aging-related changes and the system's capacity for resilient responses. In older age, maximal gait speed and muscle strength may reflect physical resilience, possibly due to their associations with underlying individual biological aging processes (10,32). Age-related biological changes reduce the capacity to produce resilient responses after stressors, which complicates recovery, accelerates functional decline and increases mortality risk. Blood-based biomarkers of aging, such as higher serum levels of inflammatory markers are associated with both age-related decline in physical function and mortality risk (33–35), and thus may be an important pathway between the functional status and physical resilience of the organism. Functional measures have also been linked with age-related changes at the molecular and DNA level (36,37), although the longitudinal evidence remains limited. In addition, earlier studies have demonstrated that age-related neurological changes are associated with alterations in physical function (38). Both grip strength and gait speed measurements require regulation of the central nervous system (CNS) and thus may reflect variations in the function of the CNS, which plays an important role in the aging processes.

Mortality provides indirect information of failure of recovery and therefore in itself may not provide a complete picture of physical resilience. However, mortality is a powerful indicator of the burden of diseases and health decline and can lead to insight into resilient or nonresilient responses of the system after experiencing chronic or acute health stressors. Linking epidemiological data with clinical information on bone fractures and survival allowed us to take both the situation without fracture exposure and the time-varying character of mortality risk after fracture into account. This in turn enabled us to investigate whether the associations of lower gait speed and muscle strength with mortality risk were more pronounced after fracture exposure, and therefore predict responses of the organism after experience of a health stressor.

Our results are in line with those of earlier studies showing that catastrophic events such as fractures in older age are followed by higher mortality incidences that gradually attenuate over the ensuing years (4,26). This attenuation may be explained by variation in individual mortality risk after a health stressor. In other words, people who are more vulnerable die more likely during the first year whereas the survivors with lower susceptibility may recover from the fracture. According to this study, measures of prefracture gait speed and muscle strength before a fracture seem to be important aspects predicting this susceptibility to mortality after a fracture. However, especially in older populations, the attenuation of postfracture mortality risk over time may be a result of the occurrence of other mortality risk factors among nonfractured individuals. Unfortunately, data were not available on other catastrophic events, such as strokes, cardiac infarctions, or recurrent fractures.

This study has some limitations. The time to fracture varied and it was not possible to capture changes in muscle strength and gait speed after the baseline measures. For people who sustained a fracture early on during the follow-up, their prefracture strength and gait speed reflect more accurately their condition at the time of fracture. In addition, the rate of change is known to be associated with mortality risk (39,40). However, strength decline without external stressors seem to be rather stable in old age. A previous study found that those with stronger grip strength in midlife were also at the top of the distribution in old age even though strength had declined (41). Consequently, we believe that it was justified to study the baseline physical performance as a predictor of mortality, even though time-varying measurements of predictors were not available for adjustment. Another limitation is the small sample size that resulted in low analytical power especially for men. The small number of specific types of fracture did not allow examination of the associations by fracture type. When interpreting the results we need to take into account that treatment and rehabilitation protocols used today differ from those at the time of the study. In addition, more recent age cohorts may have better functional status than earlier cohorts (42), and therefore their mortality risk following a fracture may be lower.

The strengths of our study are the long follow-up time and the availability of laboratory-based measures of functional status performed before a bone fracture, meaning that the tests were not confounded by situational factors caused by injury or treatment. In Finland, data on deaths are recorded in a national register and the data quality of patient records is good. A novel feature of this study is that the association of prefracture gait speed and muscle strength on mortality risk was examined with time-varying coefficients, which allowed taking into account the immortal time bias (28) and comparing the mortality risks of lower gait speed and muscle strength between the nonfracture and fracture states. The occurrence of fractures cannot be anticipated and thus in clinical practice objective measures of physical functioning cannot be performed immediately before injury. Consequently, the possibility to link epidemiological data with fracture dates and mortality records provided a unique opportunity to conduct analyses of the kind reported here.

In conclusion, higher prefracture gait speed and muscle strength may indicate higher resources for recovery and survival after acute health events, such as bone fractures. Further investigation on the biological and psychosocial processes that help people resist health decline and assist in recovery is needed.

Supplementary Material

Supplementary data is available at *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences* online.

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Conflict of Interest

T.R. serves on the *Journal of Gerontology: Medical Sciences* editorial board. Otherwise, the authors declare no conflicts of interest. .)

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Author Contributions

K.K.: Conception and design of the study, drafting the manuscript, data analysis and interpretation. E.S.: Contribution to the design of the study, critical revision for important intellectual content. M.von B.: critical revision for important intellectual content. R.S.: Data collection, critical revision for important intellectual content. T.T.: data analysis and interpretation, critical revision for important intellectual content. T.R.: Conception and design of the study, acquiring the funding for conducting the research, and critical revision for important intellectual content.

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III

LIVING ALONE VS. LIVING WITH SOMEONE AS A PREDICTOR OF MORTALITY AFTER A BONE FRACTURE IN OLDER AGE

by

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ORIGINAL ARTICLE

Living alone vs. living with someone as a predictor of mortality after a bone fracture in older age

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Abstract

Background Living alone is a risk factor for health decline in old age, especially when facing adverse events increasing vulnerability.

Aim We examined whether living alone is associated with higher post-fracture mortality risk.

Methods Participants were 190 men and 409 women aged 75 or 80 years at baseline. Subsequent fracture incidence and mortality were followed up for 15 years. Extended Cox regression analysis was used to compare the associations between living arrangements and mortality risk during the first post-fracture year and during the non-fracture time. All participants contributed to the non-fracture state until a fracture occurred or until death/end of follow-up if they did not sustain a fracture. Participants who sustained a fracture during the follow-up returned to the non-fracture state 1 year after the fracture unless they died or were censored due to end of follow-up.

Results Altogether, 22% of men and 40% of women sustained a fracture. During the first post-fracture year, mortality risk was over threefold compared to non-fracture time but did not differ by living arrangement. In women, living alone was associated with lower mortality risk during non-fracture time, but the association attenuated after adjustment for self-rated health. In men, living alone was associated with increased mortality risk during non-fracture time, although not significantly.

Conclusion The results suggest that living alone is not associated with pronounced mortality risk after a fracture compared to living with someone.

Keywords Social networks · Social support · Resilience · Health stressors · Living arrangement

Introduction

Humans are by nature social creatures and it is widely recognized that social networks are associated with health outcomes. According to the conceptual model of Berkman et al. [1], social networks operate through different psychosocial mechanisms, such as social support and social engagement, which influence health. Further, these mechanisms influence more proximate pathways to health status, such as health behavioral, psychological and physiological pathways. Living arrangements may have a substantial impact on the psychosocial mechanisms affecting health, such as the availability of social support. The number of older people living alone is rising in most countries, primarily owing to population aging, widowhood, modernization and cultural transitions, individual values, and the availability of social services [2]. In line with the conceptual model of Berkman et al. [1], studies have indicated that living alone may predispose to social vulnerability such as social isolation and loneliness [3, 4], which in turn correlate with increased likelihood of adverse health behavior, higher blood pressure, and markers of inflammation [5, 6] as well as higher mortality risk [7, 8].

Older people living in single households may be particularly vulnerable when their need for support in managing daily tasks increases with aging [2]. Hence, the consequences of sudden catastrophic health events may be more severe among older people living alone and lead

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to an increased need for health and social care services. Living with someone may provide emotional and practical social support [9], which have been recognized as important resources for resilience in older age [10]. Resilience refers to the capacity to adapt or recover mentally and physically in the face of adversity [11, 12], and is likely to be one of the key factors supporting positive aging trajectories and survival when faced with stressful events in older age [13, 14].

Bone fractures are common catastrophic adverse health events in old age and induce acute physiological and psychosocial stress. Fractures increase the risk for health decline and premature mortality [15–17]. Earlier studies have reported contradictory findings on how psychosocial factors, including social support and living arrangements, affect health outcomes following a fracture. Adequacy of post-fracture social support or a higher number of pre-fracture social contacts have been associated with better recovery and lower mortality after a fracture [18, 19]. Other studies have found no association between social support and recovery or between living arrangement and survival after hip fracture [20, 21]. These inconsistent findings may be explained by differences in the measures of social support used and timing of the observations (before vs. after fracture). However, studies with other patient groups, such as patients suffering from acute myocardial infarction [22, 23] or ischemic stroke [24] have found that living alone is associated with increased mortality risk after acute health events.

This study investigated whether living arrangement in old age is associated with mortality risk after a bone fracture and whether the potential association is different compared to mortality risk during time without fracture. Increased mortality risk after fracture among those living alone would suggest that living alone increases vulnerability and decreases the likelihood of recovery when confronted with an acute adverse health event.

Methods

Study design

The study sample comprised participants from the Evergreen Study, which has been described in detail elsewhere [25]. In brief, the study was conducted between 1989 and 1990 in Jyväskylä, Finland. All the residents aged 75 in 1989 and those aged 80 in 1990 formed the target group. In total, 617 persons took part in the study. Of this study population, 190 men and 409 women were community living and formed the sample for this study. Fracture incidence and mortality were followed up for 15 years after baseline.

Living arrangement

At baseline, living arrangement was defined as living alone versus living with someone (a partner or another adult, e.g., family member). For the sensitivity analyses, we collected information on possible changes in living arrangements 5 years after the baseline. This information was available for 423 participants (95% of the survivors).

Ascertainment of fractures and death

Fracture incidence and mortality were followed from the beginning of 1990 until the end of April 2005. Information on the ICD-10 diagnosis code, date, scene and follow-up treatment of the fracture were obtained from patient records kept by the local health centers in the health care district and in the Central Hospital of Central Finland, where all the participants' fractures were treated. Death dates were obtained from the Population Register of Finland. Fractures of toes and fingers were excluded from the analyses. Fractures were categorized by location into proximal fractures (hip, pelvis and lumbar spine) and distal fractures (thoracic and cervical spine, upper extremity, lower leg and foot, head and collar bone). For participants who sustained at least one proximal fracture, the date of the first proximal fracture was chosen while for participants who sustained distal fractures only, the date of the first distal fracture was chosen. Follow-up treatment after fracture was categorized as no follow-up treatment or treatment in an outpatient clinic versus treatment in a hospital ward.

Covariates

At baseline, information regarding participants' sociodemographic characteristics, health determinants and psychosocial well-being was obtained in interviews using standardized questionnaires. Sociodemographic items included age, sex, marital status and years of education. Marital status was categorized as married, single, divorced or widowed. Educational background was recorded as years of full-time education. Self-rated health was assessed with the single question: "How would you yourself describe your health during the last year?" with five response options. For statistical analysis, we categorized responses as good, moderate and poor. Level of everyday physical activity was studied by a single six-category question where the respondent chooses the option that best describes his/her typical level of physical activity [26]. Participants whose self-reported amount of weekly physical activity did not meet the needed level of national physical activity guidelines for older adults (at least 2.5 h of moderate activity or at least 1.25 h of vigorous activity per week) [27] were assigned to the lower physical activity group. Smoking status was classified according to whether the participant had ever been a smoker or not. Number of chronic conditions was calculated from self-reports and ascertained in a subsequent clinical examination by a physician.

Factors indicating psychosocial well-being included loneliness, warmth of the spousal relationship, number of close friends and depressive symptoms. Loneliness was measured using a single structured item with four response options. Those who reported often or almost always feeling lonely were categorized as lonely. Warmth of the spousal relationship was assessed with the question: "How close do you feel your relationship with your partner is?" were categorized the response options as "not in a relationship", "not very close" and "close". Participants were also asked to report their number of close friends. For statistical analysis, we categorized the responses into three categories as follows: "no friends", "1–3 friends" and "more than 3 friends". Depressive symptoms were assessed using the 20-item Center for Epidemiologic Studies Depression Scale (CES-D) with the cutoff value of ≥ 16 for increased risk of depressive symptoms [28].

Statistical analysis

We compared baseline characteristics between participants who were living alone and those living with someone at baseline using cross-tabulations and Chi-square tests of significance for categorical variables and *t*-tests for continuous variables. Univariate Cox regression models were carried out to examine associations between baseline characteristics and mortality risk across the entire follow-up time.

Mortality risk with and without fracture was analyzed with Cox regression analysis using an extension of the illness–death model [29]. A time-fixed exposure variable does not usually meet the proportional hazard assumption, as the risk for death is highest immediately after the injury and attenuates during the following years [30]. In our model, fracture states were modeled as a time-dependent variable in a relative risk model based on a counting process formulation (Fig. 1). All participants contributed to the non-fracture state until a fracture occurred or until death or end of follow-up if they did not sustain a fracture. Participants, who sustained a fracture, were assigned to the fracture state for the first post-fracture year. These subjects re-assigned to the non-fracture state after the first post-fracture year unless they died or they were censored due to the end of follow-up during the 1-year period. The main effects of living alone indicate the mortality risk compared to living with someone and the main effects of fracture state indicate the mortality risk compared to non-fracture state. Interaction terms between living alone and fracture state were used to investigate whether the association between living alone and mortality risk is different in fracture state (during the first post-fracture year) compared to the association in non-fracture state (other time periods in the follow-up).

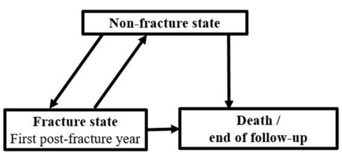

Fig. 1 An extension of the illness–death model used in the analysis

The associations of living arrangements and fractures with mortality risk adjusted for age at baseline were analyzed first in the basic model. Model 2 was adjusted for age and loneliness, and model 3 for age, loneliness and self-rated health. Covariates were selected based on their potential as confounders. The selected covariates were all associated with both the predictor (living arrangement) and outcome (mortality) in our data.

The analyses were conducted separately for men and women, as the association between living arrangement and mortality risk varies by sex [22, 31–33]. *P*-values less than 0.05 were considered statistically significant. Analyses were performed using SPSS Statistics 24 for Windows and R version 3.5.1.

Results

At baseline, 44 men (23%) and 247 (67%) women lived alone. Among both sexes, participants who lived alone were older and more likely to be widowed (Table 1). Men living alone more often reported their health as poor and good, whereas men living with someone more often reported their health as moderate. Participants living alone did not report more loneliness than those living with another person. One (1%) of the men and 52 (39%) of the women living with someone lived with someone other than a partner at baseline.

The follow-up encompassed 1544 person-years of surveillance among the men and 3790 person-years among the women. During the follow-up, 42 of the men and 164 of the women sustained at least one fracture and 167 men and 330 women died. Mean time from baseline to fracture was 5.3 years (SD 3.7) for men and 6.7 years (SD 4.1) for women and for 92% the main cause of the fracture was a fall. No differences in fracture events were observed between participants who lived alone and those living with someone (Table 1). In addition, no difference between fractured participants who lived alone and those living with someone were observed in either fracture site

Table 1 Characteristics of the participants by sex and living arrangement ($n = 599$)

	Men		*P*-value	Women		*P*-value
	Living alone ($n = 44$)	Living with someone ($n = 146$)		Living alone ($n = 274$)	Living with someone ($n = 135$)	
	Number (%)		χ^2	Number (%)		χ^2
Age, 80 vs. 75	22 (50)	48 (33)	**0.039**	131 (48)	50 (37)	**0.039**
Marital status						
Married	6 (14)	142 (97)	**< 0.001**	2 (1)	80 (59)	**< 0.001**
Single	5 (11)	2 (1)		54 (20)	9 (7)	
Divorced	8 (18)	0 (0)		28 (10)	9 (7)	
Widowed	25 (57)	2 (1)		190 (69)	37 (27)	
Spousal relationship						
Not in a relationship	35 (83)	1 (1)	**< 0.001**	264 (99)	50 (39)	**< 0.001**
Not very close	5 (12)	21 (15)		0 (0.0)	22 (17)	
Close	2 (5)	120 (85)		2 (1)	58 (44)	
Loneliness, yes	17 (40)	47 (32)	0.387	39 (29)	105 (39)	0.054
CES-D score, > 16	15 (39)	39 (29)	0.267	83 (34)	46 (36)	0.595
Number of close friends						
0	9 (21)	37 (27)	0.494	50 (19)	30 (23)	0.264
1–3	19 (45)	48 (35)		159 (60)	67 (51)	
> 3	14 (33)	51 (38)		57 (21)	34 (26)	
Self-rated health						
Good	9 (21)	19 (14)	**0.027**	44 (17)	15 (13)	0.069
Moderate	22 (52)	101 (74)		183 (69)	75 (64)	
Poor	11 (26)	17 (12)		38 (14)	28 (24)	
Physical activity, low	30 (73)	87 (64)	0.275	183 (70)	78 (67)	0.469
Smoker ever, yes	30 (71)	102 (74)	0.750	31 (12)	15 (13)	0.816
Fractures during follow-up, yes	10 (23)	32 (22)	0.910	118 (43)	46 (34)	0.081
	Mean (SD)		*t*-test	Mean (SD)		*t*-test
Number of chronic conditions	1.6 (1)	1.6 (1)	0.880	1.7 (2)	1.7 (2)	0.874
Years of education	5.6 (3)	6.4 (4)	0.116	5.9 (3)	5.8 (3)	0.735

Statistically significant values are bolded

χ^2 = Chi-square test, CES-D = Center for Epidemiologic Studies Depression Scale

(distal vs. proximal) or follow-up treatment after fracture (no follow-up treatment or treatment in an outpatient clinic vs. a hospital ward).

The crude mortality rate for men was 10.8/100 person-years and for women 8.7/100 person-years. Of the fractured participants, 13 (31%) men and 39 (24%) women died during the first post-fracture year. The baseline characteristics of participants according to fracture status (non-fractured, survived the first post-fracture year, and died during the first post-fracture year) are presented in Supplementary Table 1. Men who died during the first post-fracture year had more often rated their health as poor than non-fractured participants and first post-fracture-year survivors. Among both sexes, participants who died during the first post-fracture-year were less physically active than the non-fractured or first post-fracture-year survivors.

Table 2 shows mortality hazards obtained with the univariate Cox regression analysis. In men, living alone compared to living with someone increased mortality risk although not significantly, while in women living alone protected against death. Among both sexes, older age at baseline, poor self-rated health, lower physical activity and higher number of chronic conditions were associated with elevated mortality risk. Furthermore, among men, being divorced and reporting loneliness increased mortality risk, whereas having a close spousal relationship compared to not having a partner was a protective factor. In women, depressiveness was associated with increased mortality risk while longer education and having more than one close friend were associated with decreased mortality risk. In addition, women who reported not having a close relationship with their partner had higher mortality risk than women without a partner ($P = 0.050$).

Table 2 Unadjusted hazard ratios of risk factors for mortality risk stratified by sex

	Men ($n = 190$) HR (95% CI)	Women ($n = 409$) HR (95% CI)
Age, 80 vs. 75	**1.60 (1.17–2.19)**	**1.83 (1.47–2.28)**
Living alone, yes	1.33 (0.93–1.89)	**0.75 (0.60–0.94)**
Marital status		
Married	1.00	1.00
Single	1.04 (0.46–2.35)	0.88 (0.61–1.25)
Divorced	**2.25 (1.10–4.60)**	1.16 (0.77–1.76)
Widowed	0.88 (0.61–1.25)	0.83 (0.63–1.10)
Loneliness, yes vs. no	**1.04 (1.02–1.94)**	1.13 (0.90–1.42)
Spousal relationship		
Not in a relationship	1.00	1.00
Not very close	0.73 (0.43–1.25)	1.56 (1.00–2.44)
Close	**0.68 (0.46–0.99)**	1.04 (0.76–1.42)
Number of close friends		
0	1.00	1.00
1–3	1.48 (0.98–2.24)	**0.68 (0.52–0.90)**
> 3	1.45 (0.96–2.21)	**0.64 (0.46–0.89)**
CES-D score > 16 vs. < 16	1.10 (0.78–1.56)	**1.29 (1.01–1.63)**
Self-rated health		
Good	1.00	1.00
Moderate	1.02 (0.66–1.59)	1.11 (0.80–1.54)
Low	**2.08 (1.20–3.61)**	**2.95 (1.99–4.35)**
Physical activity, lower vs. higher	**2.13 (1.50–3.03)**	**1.31 (1.02–1.68)**
Smoker, ever	1.40 (0.98–2.01)	1.31 (0.94–1.82)
Number of chronic conditions, per one	**1.21 (1.07–1.36)**	**1.13 (1.05–1.22)**
Education, per year	0.99 (0.94–1.04)	**0.95 (0.92–0.99)**

Statistically significant values are bolded

HR hazard ratio, *CI* confidence interval, *CES-D* Center for Epidemiologic Studies Depression Scale

Table 3 Mortality risk during the first post-fracture year (fracture state) compared to non-fracture state stratified by sex

	Model 1 HR (95% CI)	Model 2 HR (95% CI)	Model 3 HR (95% CI)
	$n = 190$	$n = 188$	$n = 179$
Men			
Non-fracture state[a]	1.00	1.00	1.00
Fracture state[b]	**3.33 (1.86–5.94)**	**3.64 (2.03–6.51)**	**3.74 (2.08–6.70)**
	$n = 409$	$n = 402$	$n = 379$
Women			
Non-fracture state[a]	1.00	1.00	1.00
Fracture state[b]	**3.16 (2.22–4.37)**	**3.10 (2.21–4.35)**	**3.27 (2.32–4.63)**

Statistically significant values are bolded

Model 1: adjusted for age at baseline

Model 2: adjusted for age and loneliness at baseline

Model 3: adjusted for age, loneliness and self-rated health at baseline

HR hazard ratio, *CI* confidence interval

[a]Reference time; all other follow-up time, excluding the first post-fracture year of the participants sustaining a fracture

[b]The first post-fracture year of the participants sustaining a fracture

Mortality risk during the first post-fracture year compared to non-fracture state was almost fourfold in men and over threefold in women after adjustment for covariates (Table 3). Table 4 shows the main effects and interactions of living arrangement and fracture state on mortality. The main effect of living alone with mortality risk indicated that in women, living alone compared to living with someone was a protective factor after adjustment for age and loneliness. However, further adjustment for self-rated health attenuated the association. In men, living alone compared to living with someone was associated with an increased mortality risk, although the estimates did not reach statistical significance. Interaction effects between living alone and fracture state were not statistically significant in either men or women. The non-significant interactions suggest that after the fracture, mortality risk was similar than during the other time periods between subjects living alone and living with someone.

Sensitivity analyses

We conducted sensitivity analyses by excluding participants based on factors associated with living arrangement or fracture that could influence the results (data not shown). First, we excluded participants whose living arrangement had changed 5 years after baseline. In total, 14 men and 30 women had changed from living with someone to living alone, whereas two men and 24 women had changed from living alone to living with someone. Second, we excluded participants who lived with someone other than a partner, as they may have had worse health status than those living with a partner [34]. Third, to take account of the quality of social support at home, we excluded participants who were living with a spouse and did not have very close spousal relationship. These exclusions did not materially change the results.

We considered fracture severity by excluding participants with a potentially less severe fracture. First, we excluded participants with distal fractures and then those who had either no follow-up treatment or treatment in an outpatient clinic; however, this did not change the results. Finally, we stratified participants by age group to test whether age might influence the results. Marked differences in results were not observed between the 75- and 80-year-old participants.

Discussion

In the current community-based cohort study among 75- and 80-year-old people, mortality risk during the first year after a bone fracture increased over threefold compared to the non-fracture state, but did not differ between those who lived alone and those who lived with another person.

Inconsistent results have been reported on whether living alone increases the risk for health decline after an adverse health event [20, 22, 23]. A potential explanation for these

Table 4 Main effects and interactions of living arrangements and fracture state (the first post-fracture year) on the mortality risk stratified by sex

	Model 1 HR (95% CI) *n* = 190	Model 2 HR (95% CI) *n* = 188	Model 3 HR (95% CI) *n* = 179
Men			
Living alone[a]	1.28 (0.89–1.85)	1.20 (0.82–1.75)	1.27 (0.86–1.87)
Fracture state[b]	**3.75 (1.94–7.28)**	**3.95 (2.04–7.67)**	**4.05 (2.08–7.89)**
Living alone * fracture state[c]	0.54 (0.16–1.87)	0.71 (0.18–2.77)	0.70 (0.18–2.77)
	n = 409	*n* = 402	*n* = 379
Women			
Living alone[a]	**0.71 (0.55–0.90)**	**0.70 (0.55–0.90)**	0.84 (0.64–1.09)
Fracture state[b]	**3.50 (1.99–6.14)**	**3.38 (1.92–5.96)**	**3.72 (2.06–6.73)**
Living alone * fracture state[c]	0.85 (0.42–1.69)	0.88 (0.44–1.78)	0.83 (0.40–1.72)

Statistically significant values are bolded

Model 1: adjusted for age at baseline

Model 2: adjusted for age and loneliness at baseline

Model 3: adjusted for age, loneliness and self-rated health at baseline

HR hazard ratio, *CI* confidence interval

[a]The main effect of the living arrangements on the mortality risk (those living alone vs. those living with someone)

[b]The main effect of fracture state on the mortality risk (the mortality risk during the first post-fracture year vs. the mortality risk during other time periods in the follow-up)

[c]The interaction of living alone and fracture state on the mortality risk

mixed findings is that old people who live alone do not form a uniform group but consist of both socially isolated and socially integrated persons. In fact, in many modern societies older adults who live alone often have large and diverse social networks [35]. Therefore, living alone does not necessarily indicate social isolation and/or loneliness, both of which are important psychosocial mechanisms influencing health [1]. In the present study, women living on their own reported less loneliness than women living with someone, although the comparison did not quite reach statistical significance.

Our hypothesis was that among older people living with someone might be a source of social resilience compared to living alone and potentially predict better survival after a bone fracture. Fractures among older people are sometimes referred to as "the beginning of the end", and recovery from a fracture in old age requires psychosocial and physiological resources. Although mortality does not directly describe non-recovery from fracture nor does survival indicate recovery, they are powerful indicators of health changes and can provide further understanding of health trajectories subsequent to experiencing health stressors.

In older ages, because of their longer life expectancy, women are more likely than men to be widowed and living alone. During the non-fracture time, living alone versus living with somebody was associated with lower mortality in women; however, this association was attenuated after adjustment for self-rated health, suggesting that participants who lived alone enjoyed better health. In addition, differences between men and women in their relationship preferences and the size of their support networks outside the home may partly explain the lower mortality observed among women living alone. According to Dykstra and Fokkema [36], married women tend to feel more emotional loneliness compared to married men. The authors suggested that women are more inclined to invest in relationships with friends and relatives, whereas men are more partner-centered. In our analyses, having close friends was also associated with lower mortality risk among women. Among men, in contrast, a close spousal relationship was associated with lower, and being divorced with higher, mortality risk. It is possible that, in older ages, women have greater adaptability to manage their daily life and survive living alone than men.

Some earlier studies have also found that the importance of living arrangements as a risk factor for mortality decreases with age [33, 37–39]. The authors suggest that among younger people, living alone may be experienced as a stressful psychosocial situation, whereas in older age living alone is a more normative condition, at least in Western societies [37, 39]. In the current study, the participants were 75 or 80 years old at baseline and were even older at the time of the fracture. The surviving cohort effect might also explain why, contrary to many other earlier findings with younger study populations, living alone was not associated with higher mortality risk compared to living with someone. The participants of this study present the surviving elite of their cohort, while their birth cohort members who died at a younger age could not be observed. In addition, by including also non-fractured participants, we were unable to account for the age at the fracture to test whether the increasing age influenced the association between living arrangement and mortality after fracture.

The strengths of this study include population-based epidemiological data with a long follow-up and linkages to comprehensive patient records and a register of deaths. This enabled us to include participants also in the non-fracture state and to compare the associations between participants with and without fracture exposure. Such a comparison may reveal resources for recovery that has a more pronounced role following adverse health events. Information on both psychosocial well-being and physical functioning was collected before fracture occurrence and thus was not confounded by situational factors related to the fracture. In addition, we conducted extensive sensitivity analyses to confirm the results by controlling for factors related to living arrangement and fracture event.

This study has several limitations. First, the total sample size was small, especially among men, due to fewer males in the population in the age groups targeted. The small sample size reduced the statistical power and possibilities to control for specific fracture types and to analyze gender differences. In addition, the frequency distribution shown in the descriptive analysis was affected due to small sample size among men. Second, changes in living arrangements could not be taken into account in the main analysis. However, we had access to information on the living situation of 423 participants at 5 years after baseline. The additional analysis excluding participants whose living arrangement had changed during the first 5 years of the follow-up did not alter the results. In addition, we could not consider with whom the participants were living. It has been reported that, among older men, living with a person other than one's spouse is a risk factor for developing disability [34]. In the additional analysis, we excluded participants living with persons other than spouses, but this did not substantially change the results. The time to fracture varied among individuals, and consequently the age at fracture also varied. This may have affected the results, because older age may increase the vulnerability to mortality risk related to different living conditions. Unfortunately, age at fracture cannot be included in the model including also people who did not sustain a fracture. However, our additional subgroup analyses limited to those who sustained a fracture (not shown in the manuscript) suggested that age at fracture did not influence the difference in survival times between those living alone vs. living with someone. Finally, data on some potential confounders, such as self-perceived social support, quality of life and catastrophic health stressors other than fractures were not available.

It is important to note that the present baseline data were collected almost 30 years ago and thus may not necessarily represent social conditions in corresponding cohorts today. For instance, the proportion of older people living with someone other than a partner or living in a long-term care facility has declined dramatically [40]. Owing to a greater number of frail older people living at home with the help of home care, a fraction of the older people currently living at home may well have poorer physical and cognitive functioning than earlier cohorts. In addition, differences in life expectancy between men and women have been decreasing, a trend that is likely to affect older people's living arrangements in the future [40]. During the next few decades, the proportion of men living alone is likely to slowly increase and the proportion of women living alone to decrease. Moreover, post-fracture treatment and rehabilitation protocols may have changed, a factor that may also affect survival rates after fractures.

In conclusion, our results suggest that living with someone may not necessarily be a resource for better survival after a fracture in 75- and 80-year-old men and women. Further studies are required to confirm this result and to study whether the impact of living arrangements differs among younger or older cohorts or after different health stressors.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The ethical statement was initially received from The Ethical Committee of University of Jyväskylä (9/2004) and subsequently updated by The Central Finland Hospital District Research Ethical Committee (7/2017).

Human and animal rights The study has been performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments.

Informed consent All participants signed informed consents before the assessments.

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IV

MAINTENANCE OF HIGH QUALITY OF LIFE AS AN INDICATOR OF RESILIENCE DURING COVID-19 SOCIAL DISTANCING AMONG COMMUNITY-DWELLING OLDER ADULTS IN FINLAND

by

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Maintenance of high quality of life as an indicator of resilience during COVID-19 social distancing among community-dwelling older adults in Finland

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Resilience among older adults during COVID-19 social distancing

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Abstract

Purpose

Social distancing during the COVID-19 pandemic reduced possibilities for activities of choice potentially threatening quality of life (QoL). We defined QoL resilience as maintaining high quality of life, and studied whether walking speed, absence of loneliness, living arrangement, and stress-coping ability predict QoL resilience among older people.

Methods

Community-dwelling 75-, 80- and 85-year-old persons (n=685) were interviewed and examined in 2017-2018 and followed-up during COVID-19 social distancing in 2020. We assessed QoL using the OPQOL-brief scale and set a cut-off for 'constant high' based on staying in the highest baseline quartile over the follow-up, and categorized all others as having 'low/moderate'. Perceived restrictiveness of the social distancing recommendations was examined with one item and was categorized as 'yes' or 'no' restrictiveness.

Results

Better stress-coping ability (OR 1.21, 95% CI 1.14-1.28) and not being lonely (OR 2.67, 95% CI 1.48-4.63) increased the odds for constant high QoL from before to amid social distancing, and the odds did not differ according to the perceived restrictiveness of the social distancing recommendations. Higher walking speed predicted constant high QoL only among those perceiving restrictiveness (OR 1.16, 95% CI 1.07-1.27). Living arrangement did not predict constant high QoL.

Conclusion

During social distancing, psychosocial resources helped to maintain good QoL regardless how restrictive the social distancing recommendations were perceived to be. Better physical capacity was important for constant high QoL only among those perceiving restrictiveness presumably because it enabled replacing blocked activities with open outdoor physical activities.

Keywords: Physical function, psychosocial resources, adversity, adaptation

Introduction

Resilience refers to the process of adaptation to or dealing with adversity in a positive way [1, 2]. The manifestation of resilience is likely to vary depending on the adversity, time, life phase and life domain in question. At higher ages, the probability of encountering adversities, such as health decline or social losses increases [3], underlining the relevance of resilience for aging well. Examination of resilience needs to take into account the adversity and the indicator of positive adaptation appropriate in that specific context, as well as the resources that are important for achieving good outcomes despite adversity [2]. The ecological framework of resilience posits that resources promoting resilience may be summoned from three interacting levels of functioning: individual (e.g., psychological resources, physiological reserve), social (e.g., social support) and environmental/structural (e.g., health services and policies) [4].

The relationships between resources, adversity and positive adaptation can be modelled in various ways [5]. For example, Netuveli et al. [6] studied older adult's resilience longitudinally using a general health questionnaire. Adversity was defined as illness, change in marital status to single, or transition into poverty, and resilience as bouncing back to the pre-adversity mental health level after adversity. In majority of studies among older adults, resilience has been studied as positive psychosocial functioning in the context of accumulating and persisting health adversities such as decreased physical functioning or disability [7, 8], cognitive impairment [9], and caregiver stress [10]. Diversity in operationalizing resilience stems not only from differences in research questions and study designs, but also from challenges related to capturing adaptation processes, as the timing and types of adversities vary between individuals making it challenging to construct analytical models in observational studies.

The social distancing recommendations designed to curb the spread of the SARS-CoV-2 virus causing the COVID-19 disease has created an unforeseen natural experimental setting allowing us to specify an adversity encountered by the whole population at the same time. In Finland, during spring 2020, persons aged 70 years and older were advised to shelter at home, i.e., avoid close physical contacts with other than the immediate members of their household. All social activities were suspended and destinations of interest, such as restaurants, exercise facilities and social clubs, were closed, thereby reducing older adults' possibilities for social interaction, participation in meaningful activities and community mobility. While functioning to contain the spread of the virus, social distancing simultaneously imposed an intervention that, by reducing social and environmental resources for meaningful activity, influenced negatively on many of the components of older adults' quality of life (QoL) [11] and psychosocial functioning [12, 13]. Hence, considering the adversity related to COVID-19 social distancing among older adults, we argue that measuring stability and change in QoL may capture important aspects of the dynamics of adaptation.

Previous studies have found that psychosocial resources, such as positive coping behaviors and social support help to sustain well-being amid the COVID-19 pandemic [13, 14]. Especially older adults living in single households may be particularly vulnerable to social isolation and loneliness amid the pandemic [13], increasing the risk for mental and physical health decline [15, 16]. Creese et al. [17] reported that not perceiving oneself lonely and maintaining a higher level of physical activity protected against declining mental health during the pandemic among adults over 50 years. Especially among older people, decreased physical function may reduce their possibilities for salutary activity particularly when environmental support and opportunities are limited [18]. To the best of our knowledge, the role of older adults' physical functioning predicting resilience during COVID-19 pandemic has not been studied.

Present study

The objective of this study is to examine factors promoting QoL resilience among older people during a period of social distancing. We apply the ecological resilience framework and define the individual, social and environmental resources, the adversity and the adaptation as follows. We studied stress-coping ability and walking speed as individual resources. In this study, we conceptualized stress-coping as self-reliance in one's ability to manage with different adversities of life and assessed it using a scale of psychological resilience. Walking speed was used to indicate physiological resources, which measures the ability to move but is also a widely used summary indicator of vitality reflecting various physiological capacities underlying health and the aging process [19, 20]. Consequently, walking speed may indicate a person's physical reserve for recovery and adaption when encountering adverse events [21]. Potential social resources for resilience were identified with perceived loneliness. Loneliness is a subjective perception of social isolation or lack of connectedness with others. In this study, we conceptualized the absence of loneliness as an indicator of social connectedness and provision. Environmental resources were captured with the living arrangement. Living with someone may provide emotional and practical social support [22], which have been recognized as important resources for resilience in older ages [23]. In our analyses, social distancing recommendation was the adversity that was encountered by all. Our preliminary unpublished analyses suggested that people who had been more active perceived the social distancing recommendation more restrictive, and potentially were at a higher risk of QoL decline. We defined resilience as maintaining high QoL throughout the follow-up period from two years before to amid social distancing when the second assessment was conducted. Our idea was to test the buffering hypothesis, which proposes that specific factors are particularly beneficial in achieving positive outcomes when facing the adversity [24].

The context of social distancing in Finland

The Finnish government declared a state of emergency caused by the COVID-19 pandemic on 16 March 2020. To protect the population and the healthcare system from the consequences of a highly infectious disease, the Emergency Powers Act was passed. As a result, public gatherings were limited to no more than ten persons and avoiding spending unnecessary time in public places was recommended. All public cultural and social institutions, exercise facilities, clubs, organizations' social spaces, and other social activities were closed down. Private-sector, third sector, and religious communities were advised to do the same. Due to their higher risk for severe infection, people aged 70 and over were recommended to remain at home and to avoid close physical contacts with others outside their household. However, people were encouraged to continue outdoor activities while maintaining the recommended physical distance to others. The state of emergency remained in force in Finland for three months, ending on 16 June 2020. However, people were still advised to continue maintaining a safe physical distance to others. According to recent studies, during the first wave of the pandemic, three quarters of Finnish older adults adopted some distancing practices [25] and older adults over 70 years reported almost 90% fewer physical contacts as compared to normal conditions [26].

Methods

The present participants were drawn from the 'Active aging – resilience and external support as modifiers of the disablement outcome' (AGNES) study [27]. Here, we present longitudinal analyses of the follow-up extending from 2017-2018 (approximately two years before COVID-19 pandemic) to 2020 (amid the COVID-19 social distancing recommendations).

At the baseline, the participants comprised three age cohorts (75, 80, and 85 years) who were living independently in the city of Jyväskylä, Finland, and whose contact information was obtained from the population register of the national Digital and Population Services Agency. At baseline, the exclusion criteria were not living independently in the recruitment area and inability to communicate. Of all the people we contacted to form the baseline sample, 36.6 % took part in the study [28]. The baseline sample consists of altogether 1 018 individuals who took part in a computer-assisted personal interview (CAPI) administered in their homes. Details of the protocol, recruitment and participation in the baseline study are reported elsewhere [27, 28].

The surviving 985 baseline participants who had not withdrawn their consent, formed the target group for the AGNES-COVID-19 follow-up survey in 2020. To avoid physical contact, data were collected using a postal questionnaire or by an interview over the phone, if the participant had difficulty answering the questionnaire or preferred an interview. In total, 809 (58% women) responses were received in the follow-up survey. The participation rate (82%) did not differ by sex. Recruitment and participation in the follow-up study are reported in detail elsewhere [11] .

The analyses of the present study comprise all the participants for whom both baseline and follow-up data on QoL and all the selected predictors from the baseline were available (n=685; 290 men and 395 women).

Measurements of resilience

Quality of Life (QoL) was assessed with the 13-item version of the Older People's Quality of Life questionnaire (OPQOL-brief) at baseline and during social distancing. The items included in the scale are related to both life overall and to more specific themes such as health, independence and control over life, social relationships and leisure/social activities, home and neighborhood, psychological and emotional well-being, and financial circumstances. Response options range from one (strongly disagree) to five (strongly agree). The total sum score ranges from 13 to 65 with higher values indicating higher quality of life. The OPQOL-brief has shown to be valid and reliable measurement among older adults [29].

Operationalizing QoL resilience. We specified resilience as maintaining constant high QoL despite perceiving social distancing as restrictive. The category of *constant high QoL* was defined as a QoL score in the highest quartile at baseline (≥59 points) and maintaining it at the same level during the period of social distancing. Participants who did not meet these criteria were considered to have *low/moderate QoL*.

We considered that the perceived restrictiveness of the social distancing recommendations would indicate how troublesome this specific adversity caused by the COVID-19 situation was for the participant. We asked the participants to assess on a 5-point response scale ranging from zero (not at all) to 4 (very much) the extent to which the social distancing recommendations prevented them from engaging in activities they would have liked to do. The responses "not at all" and "little" were categorized as *NO perceived restrictiveness,* indicating less severe adversity, and the responses "somewhat", "much" and "very much" were categorized as YES *perceived restrictiveness,* indicating more severe adversity.

For the statistical analyses, we created a variable from different combinations of the categories of QoL and the perceived restrictiveness of the social distancing recommendations as follows: constant high QoL + yes perceived restrictiveness (QoL resilience), constant high QoL + no perceived restrictiveness, low/moderate QoL + yes perceived restrictiveness, and low/moderate QoL + no perceived restrictiveness.

Assessments of individual and social resources predicting QoL resilience

We assessed self-rated *stress-coping ability* at baseline using the ten-item Connor-Davidson Resilience scale (CD-RISC), which measures the perceived ability to adapt positively to changes in life [30, 31]. The scale includes items such as *"I am able to adapt when changes occur"* and *"I think of myself as a strong person when dealing with life's challenges and difficulties"*. The response scale ranges from 0 (not true at all) to 4 (true nearly all the time) totaling a sum score, which range from 0 to 40 (a higher score indicating higher self-reliance in ability to cope with adversity). The scale has shown good measurement properties among Finnish older adults in most of the psychometric domains [32]. Our analyses only included participants with at most three missing items in their answers. Scores for missing items were imputed for 12 participants based on the mean of their responses to the other items.

Both *living arrangement* and *loneliness* were asked at baseline. Living arrangement was defined as living alone versus not living alone (a partner or another adult, e.g., family member). Loneliness was measured using a single structured item with four response options: 1 (almost always), 2 (often), 3 (rarely) and 4 (very rarely/never). For statistical analyses, the responses were recoded as *yes, at least sometimes* ("almost always" to "rarely") and *no* ("very rarely/never").

Maximal *10-meter walking speed* was assessed at baseline in the laboratory corridor using photocells (Faculty of Sport and Health Sciences, University of Jyvaskyla, Jyväskylä, Finland). Participants were instructed to walk as fast as possible, without compromising safety. Five meters were allowed for acceleration. Participants wore walking shoes or sneakers and were allowed to use a walking aid if needed [27].

For the multivariate analyses, we selected potential confounders from the baseline data based on their likely association with the predictors and QoL. These variables included sex, age, cognitive functioning, and chronic conditions. Cognitive functioning was tested with Mini Mental State Examination (MMSE) with higher scores indicating better cognition [33]. Number of chronic conditions was calculated based on responses to a questionnaire and subsequently reviewed by a research nurse [27].

Statistical analysis

We used paired samples t-test and linear regression analysis to describe changes in QoL between the baseline measures and those recorded during social distancing. To compare the characteristics of the participants according to the dichotomous categories of QoL and perceived restrictiveness of social distancing, we used independent samples t-test for continuous variables and chi-square test for categorical variables. Subsequently, we studied possible predictors of constant high QoL and high perceived restrictiveness of social distancing separately using logistic regression analysis. The potential predictors were baseline stress-coping ability, absence of loneliness, living arrangement and walking speed. To test whether the associations of significant predictors with constant high QoL vary according to perceived restrictiveness, we ran separate logistic regression analyses for each predictor by adding the interaction term of predictor-by-perceived restrictiveness of social distancing with the main effects in the model. Finally, to identify the predictors of QoL resilience, we used multinomial logistic regression analysis with the nominal combination variable of QoL and perceived restrictiveness of social distancing as an outcome (reference group: low/moderate QoL + no perceived restrictiveness). All the predictors were added in the model simultaneously and the model was adjusted for age, sex, MMSE, education and chronic conditions.

To test the robustness of our findings, we stratified the main analyses according to sex. The results did not change substantially and therefore we report the models for both sexes combined. All analyses were computed using SPSS Statistics 26 for Windows.

Results

Average QoL at baseline was 55.1 points (SD 5.5) and during social distancing 53.5 points (SD 6.8). The average decline in QoL between the baseline and social distancing measurements was 1.6 points (SD 5.5, $p<0.001$). The change ranged from a 13-point decrease to a 24-point increase and was not clearly attributable to any single OPQOL-brief items. Linear regression analysis showed that a higher baseline QoL was associated with a higher decline in QoL (β -.236, $p <.001$). In addition, perceived restrictiveness of the social distancing recommendations was associated with a higher decline in QoL (β -1.931, $p <.001$). On our definition, 15% of the participants were categorized as having constant high QoL and 85% as having low/moderate QoL. In addition, 63% of the participants were categorized as perceiving restrictiveness owing to the social distancing recommendations.

Table 1 shows the characteristics of the participants according to the two QoL categories and the two categories of the perceived restrictiveness of the social distancing recommendations. On average, the participants with constant high QoL had higher self-rated stress-coping ability and walking speed at baseline compared to those with low/moderate QoL. In addition, those with constant high QoL were younger and reported less loneliness at baseline than those with low/moderate QoL. Perceived restrictiveness of the social distancing recommendations and living arrangement did not differ between the QoL categories.

A greater proportion of the participants who perceived the social distancing recommendations as restrictive were women and had on average more chronic conditions than those not perceiving restrictiveness. In addition, the participants perceiving high restrictiveness reported more loneliness, had lower self-rated stress-coping ability, and had slightly higher MMSE scores at baseline than those perceiving no restrictiveness.

The logistic regression analysis showed that higher walking speed and stress-coping ability and the absence of loneliness predicted constant high QoL (Table 2). In addition, the absence of loneliness reduced the likelihood of perceiving the social distancing recommendations as restrictive (OR 0.62, 95% CI 0.45-0.86) whereas stress-coping ability, living arrangement and walking speed were not associated with the perceived restrictiveness of social distancing recommendations. The separate analyses for the predictors of constant high QoL showed significant interaction of walking speed-by-perceived restrictiveness ($p=0.005$) indicating a stronger association between walking speed and constant high QoL among participants who perceived the social distancing recommendations to be restrictive. The interactions of loneliness and stress-coping ability by perceived restrictiveness of the social distancing recommendations with constant high QoL were not significant indicating that the associations with constant high QoL in both categories of perceived restrictiveness were similar.

The results of the multinomial logistic regression analysis with the combined categories of QoL and perceived restrictiveness of social distancing recommendations as the outcome are given in Table 3. Higher walking speed was associated with constant high QoL only among the participants who perceived restrictiveness. A 0.1 m/s increase in walking speed was associated with 16% greater odds for membership of the category combining constant high QoL and perceived restrictiveness compared to belonging to the category combining low/moderate QoL and perceived restrictiveness.

Participants with better stress coping ability had higher odds for maintaining constant high QoL regardless of how restrictive they perceived the social distancing recommendations to be when compared to those in the category combining low/moderate QoL and perceived restrictiveness. The absence of loneliness was associated with one and a half greater odds for having low/moderate QoL + no perceived restrictiveness when compared to those having low/moderate QoL + perceived restrictiveness. In addition, the absence of loneliness was associated with over threefold odds for maintaining constant high QoL in both groups of perceived restrictiveness. Finally, living arrangement was not associated with maintaining constant high QoL.

Discussion

Our analyses showed that higher self-rated stress-coping ability and the absence of loneliness predicted the maintenance of high QOL similarly among those who perceived or did not perceive social distancing as restrictive. Higher walking speed was an important predictor of maintenance of high QoL only among those who perceived social distancing as restricting their activities. Finally, living arrangement was not associated with the maintenance of high QoL. The present analyses yield important insights into the adaptive processes that older adults used in the specific context of the social distancing recommendations. The study also contributes to understanding resilience in later life, which has been recognized as an important element in aging well [34].

An association between higher walking speed and good QoL in older adults has been reported earlier [35]. To the best of our knowledge, the present study is the first to suggest that walking speed indicating physical resources may be particularly beneficial in the maintenance of good QoL when facing vs. not facing adversities. The current finding coheres with our previous study showing that walking speed was a stronger predictor of survival among participants who sustained versus did not sustain a bone fracture [21]. In the present as in the previous study, the mechanism underlying the effect of walking speed kicking in the presence of adversity and buffering the negative effects probably lies in the availability of a functional reserve that the individual can tap into. In addition to capturing health and the aging process [20], higher walking speed indicates a better capacity for all bodily movement, especially the ability to move in one's environment [19], an important resource for autonomy and meaningful activities. When access to environmental activity resources, for example, exercise facilities and social clubs, was reduced by the social distancing recommendations, older adults with a better ability to move may have had a higher readiness to substitute their suspended activities of choice with alternatives that were not blocked. According to our recent report, most of the activities reported by our participants during the studied period of recommended social distancing encompassed walking for fitness and visiting outdoor exercise facilities that remained open [36]. Maintaining a desired activity level by increasing outdoor exercise may have bestowed a sense of continuity while also manifesting further advantages, such as improved fitness [37] and restorative experiences [38]. We also recently reported that those who did not perceive the social distancing recommendations as restrictive were less likely to change their physical activity behavior [39]. Many older people prefer activities that take place at home (e.g., crafting, DIY, gardening). Such activities were not affected by the social distancing recommendations, and consequently people inclining to them did not need to draw on extra individual functional resources to maintain their QoL.

The associations of the absence of loneliness and better stress-coping ability with the maintenance of high QoL are in accordance with previous findings [40-42]. However, our results suggest that in the studied context, these factors did not have a buffering effect but were generally important for all maintaining good QoL. This may be explained by the nature of these variables in relation to the perceived restrictiveness of social distancing recommendations as the adversity. Loneliness was measured with one item, which has been shown to correlate especially with the emotional dimension of loneliness that springs from the longing for close emotional attachment figure rather than social loneliness, which arises from the absence of an engaging social network [43, 44]. In addition, self-rated stress-coping ability, as it was measured in this study, may reflect an overall optimistic view of one's personal agency in adversities general [45]. The finding that living arrangement was not associated with maintenance of high QoL is consistent with some earlier studies showing that older adults living in single households, at least in Western cultures, are not necessarily more vulnerable than individuals living with another person [46-48].

In this study, our approach in operationalizing resilience aligns with the individual-centered method using researcher-driven distribution-based thresholds [5]. This allowed us to take into account the relationship between the perception of the adversity and the outcome, and to identify a conceptually meaningful subgroup of individuals assumed to show resilience. However, a major disadvantage is the absence of any established thresholds that can be applied in defining resilience. Thus, because no standardized cut-off value for high QoL exists in the OPQOL-brief scale, we set the threshold for high QoL based on the distribution in the baseline QoL. We decided to set the threshold high in the distribution (the upper quartile of baseline QoL) as we assumed that in its severity, the social distancing recommendations is a moderate rather than catastrophic or traumatic type of adversity [1]. However, this approach may capture only a small subset of people adapting well or showing robustness in adversity, and other approaches quantifying resilience should also be explored. Future studies could investigate QoL trajectories after social distancing recommendations have ended to find out whether people with decreased QoL bounce back to their initial level of QoL after the normalization of environmental opportunities for their preferred activities.

This study has its limitations. One is that we cannot rule out other possible reasons, such as aging or other individual adversities, which may have contributed to changes in QoL. However, in our sample, QoL did not change during a one year follow-up observed before social distancing [49] and in the present analyses, the perceived restrictiveness of the social distancing recommendations was associated with higher decline in QoL supporting our premise that the social distancing measures constituted a natural experimental setting threatening QoL. Another limitation was that due to the social distancing recommendations, the data collection method at baseline (CAPI) differed from that used at follow-up (postal questionnaire), which may have biased the results. However, the follow-up questionnaires were carefully filled in and contained only little missing information. Selection bias may also have occurred, as our participants represented a slightly healthier section of the same-age population [11]. Nevertheless, the participants ranged widely in many background characteristics.

The major strength of this study was that we were able to operationalize resilience in a context of adversity (social distancing measures) that applied to all people at the same time. Opportunities to standardize an adversity are rare in resilience research, especially in a population-based representative and heterogeneous sample instead of a self-selected convenience sample. Our approach has most likely helped to minimize the possibility of bias. Finally, the baseline data collected two years before social distancing included a wide range of information on the participants' functioning and enabled us to study longitudinally pre-adversity resources in different life domains as predictors of adaptation. While most research has focused to investigate the psychosocial resources for resilience during the pandemic, this study extends the findings on the importance of physical resources for older adults' adaptation.

Taken together, the findings indicate that in the context of social distancing recommendations, psychosocial resources were important for maintaining good QoL regardless of how restrictive social distancing was perceived. Higher physical resources, in turn, were important among those perceiving restrictiveness, as they possibly enabled adaptive strategies to engage in alternative activities of choice and consequently, to maintain good QoL despite environmental restrictions. These findings highlight the importance of recognizing older adults' resources across multiple levels of functioning to adapt during challenging times, such as the ongoing pandemic.

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Contributions

K. Koivunen: Conception and design of the study, drafting the manuscript, data analysis and interpretation. E.P. Data collection and critical revision for important intellectual content. E.S.: Contribution to the design of the study, critical revision for important intellectual content. J.E.: Critical revision for important intellectual content. K.Kokko: Critical revision for important intellectual content. T.R.: Conception and design of the study, acquiring the funding for conducting the research, and critical revision for important intellectual content.

Ethical approval

The ethical committee of the Central Finland Hospital district provided an ethical statement about AGNES on August 23, 2017. In their positive ethical statement on May 13, 2020, the same ethical committee considered that the initially signed consent covers the AGNES-COVID-19 survey, because it is an extension of the initial study.

Conflict of Interest

The Authors declare that there is no conflict of interest

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Table 1. Participant characteristics by perceived restrictiveness of social distancing and quality of life (QoL) categories.

	QoL			Perceived restrictiveness of social distancing		
	Constant high (n=104)	Low/moderate (n=581)		Yes (n=432)	No (n=253)	
	n (%)	n (%)	p [a]	n (%)	n (%)	p [a]
Perceived restrictiveness of social distancing recommendations, high	60 (58)	372 (64)	.218	--	--	--
QoL, constant high	--	--	--	327 (86)	209 (82)	.218
Living arrangement, alone	37 (36)	226 (39)	.521	170 (39)	93 (37)	.501
Loneliness, no	86 (83)	317 (55)	**<.001**	236 (55)	167 (66)	**.004**
Age						
75 years	63 (61)	281 (48)	**.027**	226 (52)	118 (47)	.337
80 years	31 (30)	190 (33)		135 (31)	86 (34)	
85 years	10 (10)	110 (19)		71 (16)	49 (19)	
Sex, women	71 (53)	324 (59)		276 (64)	119 (47)	**<.001**
	Mean (sd)	Mean (sd)	p [b]	Mean (sd)	Mean (sd)	p [b]
Stress-coping ability	35.0 (4.1)	31.0 (4.9)	**<.001**	31.1 (4.9)	32.0 (5.1)	**.022**
Walking speed, m/s	1.9 (0.4)	1.8 (0.4)	**<.001**	1.8 (0.4)	1.8 (0.4)	.067
Chronic conditions, number	2.7 (1.8)	3.4 (2.0)	**<.001**	3.5 (2.0)	3.1 (1.9)	**.013**
MMSE	28.0 (1.8)	27.5 (2.1)	**.016**	27.8 (2.0)	27.3 (2.3)	**.009**

Note. [a] = tested with chi-square test, [b] = tested with t-test; the category *no perceived restrictiveness of social distancing recommendation* included the responses "not at all" and "little" and the category *yes perceived restrictiveness* included the responses "somewhat", "much" and "very much"; the criterion for membership of the category *constant high QoL* was a QoL score in the highest quartile at baseline (≥59 points) and maintaining it at the same level during social distancing. Participants not meeting this criterion were considered to have *low/moderate QoL*; the category *no loneliness* included the response option "very rarely/never" and the category *loneliness at least sometimes* the response options from "almost always" to "rarely".

Table 2. Odds ratios for constant high (n=104) vs. low/moderate (n=581) QoL and perceived (n=432) vs. no perceived (n=253) restrictiveness of social distancing.

	QoL [a]	Perceived restrictiveness of social distancing recommendations [a]
	Constant high (n=104)	Yes (n=432)
	OR (95% CI)	OR (95% CI)
Walking speed, per 0.1 m/s	**1.08 (1.01-1.15)**	0.98 (0.95-1.02)
Stress coping ability, per 1 point	**1.21 (1.14-1.28)**	0.98 (0.95-1.02)
Loneliness, 'no' vs. 'yes, at least sometimes'	**2.67 (1.48-4.63)**	**0.65 (0.45-0.94)**
Living arrangement, 'alone' vs. 'with someone'	1.34 (0.78-2.30)	0.79 (0.54-1.15)

Note. [a] = analyzed with logistic regression analysis, constant high vs. low/moderate QoL and yes vs. no perceived restrictiveness of social distancing, adjusted for age, sex, MMSE, education and chronic conditions. OR=odds ratio, CI=confidence interval

Table 3. Odds ratios for combinations of QoL and perceived restrictiveness of social distancing categories.

	QoL + perceived restrictiveness of social distancing recommendations [a]		
	Constant high QoL + YES perceived restrictiveness (n=60)	Constant high QoL + NO perceived restrictiveness (n=44)	Low/moderate QoL + NO perceived restrictiveness (n=204)
	OR (95% CI)	OR (95% CI)	OR (95% CI)
Walking speed, per 0.1 m/s	**1.16 (1.07-1.27)**	1.01 (0.91-1.12)	1.05 (1.00-1.10)
Stress coping ability, per 1 point	**1.22 (1.13-1.31)**	**1.22 (1.12-1.32)**	1.02 (0.98-1.06)
Loneliness, 'no' vs. 'yes, at least sometimes'	**3.03 (1.42-6.50)**	**3.36 (1.37-8.27)**	**1.57 (1.07-2.31)**
Living arrangement, 'alone' vs. 'with someone'	0.75 (0.35-1.41)	0.58 (0.26-1.29)	0.77 (0.61-1.16)

Note. [a] = analyzed with multinomial logistic regression analysis, reference group: low/moderate QoL + YES perceived restrictiveness of social distancing, adjusted for age, sex, MMSE, education and chronic conditions. OR=odds ratio, CI=confidence interval