Science and Practice of Resilience: Disaster Systems Applications to Aging Resilience

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Abstract  This chapter adapts the National Academies of Science systems model of resilience to natural disasters to a resilience model for aging adults. After exploring the origins and applications of the term resilience in gerontology, medicine, and public health, we incorporate the components of disaster resilience to present a framework for quantifying resilience for elderly individuals. The recent COVID-19 pandemic reinforces the importance of a system-level resilience approach. By merging transdisciplinary knowledge of resilience using a complex systems approach, we seek to develop a generalized theory for different contexts and populations. While resilience for the elderly can be quantified at the individual level, it must also be contextualized for external structural and system-level factors that influence the types and availability of resources that adults can access to recover from aging-related adversities. Understanding resilience for elderly adults can complement studies that seek to minimize risk, vulnerability, and frailty to improve quality of life and to decrease the burden of care arising from a growing elderly population.

Keywords  Resilience · Aging · Public health · Complex systems model · Disasters

Introduction

Around the world, health improvements are allowing more people to live longer. Though partially mitigated by immigration, in developed countries, declining fertility and mortality rates are causing the percent of aging populations to grow in rela-
tion to younger cohorts who traditionally contribute to their care. By 2050, there are expected to be twice as many elderly adults as children under five (World Health Organization 2018). This demographic shift will have economic, social, and political repercussions as societies negotiate how to provide health care, welfare, and other systems of social protection (United Nations 2019). At the same time, medical technological developments have improved the detection of disease, thereby increasing the need for complex care for people nearing the end of life (Wister and Speechley 2015). This burdens national health systems with the high costs of treating complex patients (Fabbri et al. 2015; Van den Bussche et al. 2011; Barnett et al. 2012; Goldman et al. 2013). Thus, increasing life expectancies must be paired with commensurate advances in illness prevention, adaptation/coping, and resilience to counterbalance the impeding stress that rapid population aging will exert on support systems.

As humans live longer, their chances of developing multiple chronic diseases such as arthritis, cardiovascular disease, cancer, diabetes, depression, and dementia increase (Barnett et al. 2012; Marengoni et al. 2011; Pefoyo et al. 2015). Neurological diseases, in particular Alzheimer’s and related dementias, are projected to affect over 100 million individuals worldwide over the next three decades, further increasing the global burden of disease (Brookmeyer et al. 2007; Takizawa et al. 2015; Lehnert et al. 2011). Although many older individuals report ‘aging-well,’ physical deterioration decreases the ability of older adults to maintain activities of daily living (ADLs) and independent lifestyles (Vermeulen et al. 2011). Worldwide, the elderly are at higher risk of socio-economic deprivation (He et al. 2016). In both urban and rural settings, social isolation and loneliness affect increasing numbers of older individuals and have been associated with depression and mortality (Nicholson 2012; Luo et al. 2012; Holt-Lunstad et al. 2015), and the elderly are affected more negatively by environmental disasters such as pandemics and hurricanes (Bell et al. 2018).

While the older individuals face numerous adversities, some recover more easily and successfully from disruptions than others. These individuals are termed “resilient.” Resilience is a theory and a methodology that can be applied to the aging process. Most aging adults face increasing vulnerabilities, meaning that their risks of negative consequences are also increasing even if actual threats and their probabilities remain static. Elderly individuals that display resilience can better maintain or optimize critical functions as they cope with the increased vulnerabilities of aging.

Recently, many scholars and health organizations have begun to discuss the importance of resilience as a factor in successful and healthy aging (Cosco et al. 2018; Pruchno and Carr 2017). Healthy aging is gaining traction as an important public health policy priority. The World Health Organization (WHO) has advocated for a more robust public-health response towards the growing older population, especially in ensuring an individual’s ability to navigate through the complex aging process. However, resilience in elderly adults is often conflated with pre-existing health status, producing inconsistencies in its definition and application. Some view resilience as a dynamic process of adaptation against adversity, while others view it as an internal personality trait. Early formulations of resilience have been primarily
psychological in nature, although recent advancements, including in the gerontological literature, have broadened its scope to include individual and environmental domains, life-course temporal dimensions, and applications to specific forms of adversity (Masten 2007; Wister et al. 2016).

Elderly individuals require access to healthcare services, safety, social support, and adequate knowledge and education to optimize their capacities throughout their lifespan. Without these resources, older individuals are less able to prepare and respond to a significant disruption in their life or health. While this broad base of needs is reflected throughout the gerontology literature, there remains considerable diversity in how to model or quantify resilience (Cosco et al. 2019; Windle 2012; Angevaare et al. 2020). There is also an absence of a generalized theory of resilience that can be applied to different contexts of aging. These gaps may be filled by employing developments in disaster resilience using complex systems theory. Here, resilience is conceptualized as a system property, but the system in question can change depending on the scale of analysis. The following sections will (a) review the full range of resilience literature; (b) examine the application of this concept within the intersecting sub-fields of medicine, public health, and gerontology; and (c) use a complex systems formulation that emerges from disaster resilience literature to propose resilience metrics and an integrated model that can be applied to older adults in future research.

**Resilience to Disasters and System Disruptions**

In disaster research, the term resilience characterizes complex systems such as environmental habitats, cyber domains, and critical infrastructure, as well as physical and psychological functions for humans and communities. This latter social category shares many features with traditional systems of resilience, most notably that a subject may demonstrate resilience only upon experiencing hardships. This distinguishes resilience from other metrics such as risk and vulnerability, which seek to understand the likelihood and potential damage of experiencing hardship. At its simplest, risk is “the possibility of loss, injury, or other adverse or unwelcome circumstance (“risk, n.” 2019).” Vulnerability is “the quality or state of being exposed to the possibility of being attacked or harmed (vulnerable, adj.” 2019 ).” Resilience characterizes the system’s response to harm after it has occurred.

The National Academies of Sciences (NAS) has defined disaster resilience as “the ability to plan and prepare for, absorb, recover from, and adapt to adverse events (National Research Council 2012).” The NAS definition incorporates uncertain, consequential risk events that are not easily addressed using traditional risk management approaches. Preparing for adverse events can include reducing risk and vulnerabilities, but resilience also measures the system’s response to threat, particularly its ability to absorb a hardship and recovery from it. Such an ability assumes increasing importance when certain risks and vulnerabilities cannot be wholly avoided within feasible cost margins. Limitations or shortcomings exist in
almost any designed security, and in circumstances when hardships arise despite existing protections, resilience provides another process to safeguard critical functions over time.

Resilience as a system component is independent of measures of risk. Risk incorporates the size of a potential threat, the vulnerability of the subject system, and the consequence expected should the threat occur. Together, these risk components will determine the adverse consequence on the system as it absorbs the disruption, meaning as its critical function declines under pressure. Resilience is the opposite force that pushes the critical function to return to full capacity after a decline. Resilience’s contribution to system management is not its ability to protect, but to restore (Fig. 1).

Figure 1 uses the NAS definition of disaster resilience to show the influences of risk, vulnerability, threat, and consequences that determine the magnitude of system disruption, and the system resilience that returns functionality to its original level (Linkov et al. 2014).

Systems with high resilience persevere when disruptions and hardships materialize. Though system managers prefer to avoid negative consequences wherever possible, the long-term viability of the critical function of a system must not rely on avoiding the unavoidable, but on its assured recovery that reduces downstream or long-term damages. Figure 2 shows the interactions between disruptions (realized risk) and resilience of differing intensities.

![Fig. 1 Risk, resilience, and vulnerability in the process of system disruption](image-url)
The NAS resilience model can be applied to gerontology and aging because its constituent parts (planning, absorbing, recovery, adaptation) can be applied to support elderly resilience (Linkov and Trump 2019). Planning can include healthcare provider access, transportation, social support networks, socio-economic support, access to healthy foods, opportunities for physical activity, healthcare facilities and capacities to provide care, and even safety. Many planning aspects fall under general healthy behavior, but preparations can also seek to increase individual capacity to recovery after a disruption. Following the disruption, the resilience in the absorption and recovery process can help elderly adults attain their previous levels of health or otherwise expected levels within the previous health trajectories they had been following, including decline. Figure 3 shows how the NAS model of resilience could be applied to a declining critical function for positive outcomes.

Aging is an unpredictable life process. Risks to health and well-being cannot always be anticipated and they are difficult to quantify. Successful—dubbed “resilient”—individuals recover from disruptions and learn to adapt to them for the future. In order to evaluate and improve resilience for elderly individuals, researchers and practitioners need methodologies to quantify it according to established metrics.

With the growing importance of resilience concepts to complex systems, researchers have explored resilience metrics and quantifications. Kott and Linkov (2019) differentiate between metrics-based and model-based resilience measurements, which themselves overlap (Fig. 4) (Linkov and Kott 2019).
Metrics-based approaches construct the system as a sum of the parts: they assess overall system resilience by measuring component properties using readily quantifiable measurements. However, there are no universally applicable resilience metrics or methods for formally valuing systems by individual components (Linkov and Kott 2019). Furthermore, complex systems have demonstrated that individual components can fulfill objectives while imperiling the overall system operation, as
was the case with the perverse incentives that precipitated the sub-prime mortgage crisis in 2008 (Zhang 2018). Such emergent properties of complex systems show a discontinuity between the behavior of the system’s parts and the behavior of the system as a whole (Goldstein 1999) and may jeopardize the accuracy of resilience measurements that rely on components rather than the interacting processes underlying overall system functionality.

Model-based approaches take a broader view by examining the system mission, temporal patterns, thresholds, memory, function, and adaptation. This can include simulating the physical impacts of a disruption to measure the process of recovery or examining data on system performance for statistics. Bayesian methods can combine process, statistical models, and network models to present the system as interconnected networks dependent on system functioning. Game theory and agent-based approaches examine system performance within a model using a limited set of rules defined by the modelers (Linkov and Kott 2019).

Although the complexities surrounding the understanding of risk as a concept have successfully been rendered into a universally applicable paradigm, there is currently no analogous framework for resilience. Herein we examine gerontological resilience specifically to propose an assessment tool to enable planners and managers to make better decisions to support their elderly patients and the elderly population.

Definitions of Resilience for Aging and Health

Public health, medicine, and the interdisciplinary field of gerontology each conceptualize resilience in slightly different ways. To narrow the scope of literature reviewed, this section will provide an overview of these disciplines’ definitions as applied to resilience management for older adults.

Medicine and Gerontology

Gerontology is the scientific study of old age, the aging process, and the particular problems of old people (gerontology, n.” 2019). Gerontology is not exclusive to the field of medicine; it spans multiple disciplines from nursing to sociology. Geriatrics, in contrast, is a branch of medicine that deals with the health and care of older people. We will focus on gerontology and conceptualizations of resilience within the field of medicine and public health, although further applications are possible.

The first explorations of resilience within psychological frameworks studied children and only slowly incorporated other stages of lifespan such as young adult, midlife, and finally the elderly (Fontes and Neri 2015; Hayslip 2012). This trajectory influenced biomedical and pharmaceutical research to include resilience in theories of elderly health and overall well-being during old age (Masten and Reed...
However, resilience is used as a metaphor, and such use has caused abstract discussions of its meaning across medical sub-disciplines (Linkov et al. 2013).

Broadly, medical literature defines aging resilience as anything from persevering in the face of life’s chronic misfortunes to a stable trajectory toward healthy functioning after a highly adverse event. Table 1, below, shows medicine and gerontology definitions of resilience and specifies where they deviate from the NAS definition. There is some consistency between the NAS definition for resilience to natural disasters and definitions within medical and public health disciplines. Herein we list common definitions as well as their distinctions from the NAS definition for the purpose of identifying conceptual gaps and synergies and potential adaptive processes. We note that many focus on maintaining stability, contrary to the NAS assumption that resilience manifests when a critical function experiences disruption and needs to recover. Recovery is not frequently mentioned, though adaptation often is.

Table 1 Selected definitions of resilience in medicine and gerontology

| Health actor or organization | Resilience definition | Distinction from NAS resilience definition |
|------------------------------|-----------------------|------------------------------------------|
| World Health Organization (Ziglio 2017) | Resilience is the ability to maintain or improve a level of functional ability in the face of adversity (either through resistance, recovery or adaptation) | NAS resilience does not denote maintenance, it assumes a decrease in critical function that will require recovery |
| American Psychological Association (2019) | The process of adapting well in the face of adversity, trauma, tragedy, threats or significant sources of stress — such as family and relationship problems, serious health problems or workplace and financial stressors. It means “bouncing back” from difficult experiences | NAS stipulates that adaptation happens after recovery (“bouncing back”) |
| Mayo Clinic (2020) | Resilience means being able to adapt to life’s misfortunes and setbacks | NAS lists adaptation is a stage of resilience after recovery |
| USAID (2013) | The ability of people, households, communities, countries and systems to mitigate, adapt to and recover from shocks and stresses in a manner that reduces chronic vulnerability and facilitates inclusive growth | Extends beyond NAS resilience definitions by seeking to reduce chronic vulnerability and facilitate inclusive growth |
| Kruk et al. (2015) | Health system resilience is the capacity of health actors, institutions, and populations to prepare for and effectively respond to crises; maintain core functions when a crisis hits; and, informed by lessons learned during the crisis, reorganize if conditions require it | NAS definitions assumes that core functions will experience some disruption |

(continued)
| Health actor or organization | Resilience definition                                                                                                                                                                                                 | Distinction from NAS resilience definition |
|------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|
| Panter-Brick and Leckman (2013) and Southwick et al. (2014) | Resilience is a process to harness resources to sustain well-being                                                                                                                                                    | NAS presumes a dip in well-being          |
| Masten (2014, 2015)         | The capacity of a dynamic system to adapt successfully to disturbances that threaten the viability, the function, or the development of that system                                                                 | NAS resilience requires that disturbances are realized, not threatened |
| Ager et al. (2013)          | Structural resilience is building robust structures in society that provide people with the wherewithal to make a living, secure housing, access good education and health care, and realize their human potential | No mention of disruptions or recovery to them |
| Southwick et al. (2014)     | Resilience is a stable trajectory of healthy functioning after a highly adverse event                                                                                                                                   | Resilience is returning to a stable position after an adverse event that caused a dip in functionality. |
| Southwick et al. (2014)     | Definitions of resilience range from a stable trajectory of healthy functioning after a highly adverse event; a conscious effort to move forward in an insightful and integrated positive manner as a result of lessons learned from an adverse experience; the capacity of a dynamic system to adapt successfully to disturbances that threaten the viability, function, and development of that system; and to a process to harness resources in order to sustain well-being | No mention of recovery, focus on adaptation |
| Kruk et al. (2017)          | Resilience emphasizes the functions health systems need to respond and adapt to health shocks, introducing a dynamic dimension into more static health system models which can help the system cope with surges in demand and adapt to changing epidemiology and population expectations of care | [compatible]                              |
| Garmezy et al. (1984)       | The concept of resilience is centered on the capacity to ‘bounce back’ from an adverse event                                                                                                                            | [compatible]                              |
| Wagnild and Collins (2009)  | Resilience is the ability to adapt or “bounce back” following adversity and challenge and connotes inner strength, competence, optimism, flexibility, and the ability to cope effectively when faced with adversity                                                                 | Compatible with NAS, but its focus on individual traits will be discussed later in this chapter |
| Wister et al. (2018)        | [resilience is] the ability and resources needed to adapt and navigate stress-inducing experiences                                                                                                                    | Adapt and navigate may not imply recovery  |
Resilience is seen as either a mediator or a moderator in exposure-outcome relationships. The only agreement between researchers using the term is that “no generally accepted definition of resilience” exists (Cosco et al. 2016). Resnick et al. (2018) find that resilience in aging is most commonly conceptualized as a “process or behavioral response that can be strengthened, improved, and called upon to establish, maintain, or regain a state of physical, psychological, or emotional equilibrium over time (Resnick et al. 2018).”

The theories of resilience for aging adults stemmed from development psychology and have enriched existing models of Successful Aging (SA) (Cosco et al. 2018). SA is a concept, approach, model, experience, and outcome heavily debated among medical researchers (Katz and Calasanti 2015; Rowe and Kahn 1987; Smith et al. 2018). It states that while aging, people move along a continuum from robustness and autonomy to frailty and dependence. SA examines the characteristics that influence or help determine an older adult’s functional performance in relation to younger adults. Elderly adults who exhibit high SA have shown effective adaptation to challenges throughout their older adult life. Recent scientific literature examines the operationalization of SA, revealing over a hundred different definitions (Cosco et al. 2014, 2017). The lack of a consistent SA definition is a fundamental weakness that has produced a similar weakness in existing research on aging and resilience (Cosco et al. 2014). Many of the models of SA include the following five characteristics: (1) successful aging happens across the lifespan; (2) successful aging occurs in response to challenges; (3) successful aging is defined uniquely for each individual to the degree that individual goals and preferences differ; (4) capacity for successful aging is partially under individual control and partially predetermined; and (5) successful aging incorporates many domains (i.e. health, social, biological, psychological) (Smith et al. 2018).

A primary criticism of the successful aging model is that it assumes that only persons who are free of negative elements in all domains are aging in a positive manner (Cosco et al. 2018; Smith et al. 2018). It focuses on the prevention of age-related function declines instead of a strength-based optimization of individual, social, and environmental resources (Cosco et al. 2017). Yet, many older people face aging-related challenges. Resilience models of aging offer improvements over SA in their ability to incorporate adversity (Cosco et al. 2018). Resilient aging has been recently conceptualized as the “minimization of negative outcomes and maximization of positive physical and psychological health outcomes in late life (Smith et al. 2018).” Resilience applied to gerontology thus does not stem from resilience theory applications in other fields, but from reactions to existing aging paradigms.

Scholars across gerontology sub-disciplines conceptualize resilience into one of the following categories (1) a trait, (2) a phenotype or observable manifestation of underlying characteristics, (3) a capacity (i.e. outcome derived from such characteristic or capacity), or (4) a trajectory or process (Whitson et al. 2016). In reviewing the definitions of Table 2, we add the category of ability. Resilience as a personality trait is typically defined as a constant and stable resource that enables an individual to respond to stress in a flexible manner (i.e. psychological hardiness) (Fontes and Neri 2015). Within the greater theory of lifespan development, resilience is also
Table 2  Types of resilience in medical literature and their limitations

| Domain                        | Definition                                                                 | Distinction from NAS definition                                                                 |
|-------------------------------|---------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| Physical (or physiological) Resilience (Resnick et al. 2011) | The ability to recover or optimize function in the face of age-related losses or disease | Age-related losses may denote slow decline rather than punctuated disruptions and recovery.     |
| Psychological Resilience (Resnick 2014; Resnick et al. 2011) | An individual’s capacity to overcome challenges and avoid decompensation, depression, apathy, and other types of negative psychological outcomes | Stresses avoidance of negative outcomes, rather than the act of recovery.                        |
| Emotional Resilience (Resnick 2014; Resnick et al. 2011) | The ability to maintain the separation between positive and negative emotions in times of stress | It is not clear how separating emotions relates to recovery from challenges. “Times of stress” may not be the same as a challenge that negatively impacts function. |
| Cognitive Resilience (Resnick 2014; Resnick et al. 2011) | An older adult’s ability to overcome noted changes in his or her cognitive ability, negative comments he or she may hear from others, and associated stress related to cognitive performance and embarrassment | Nothing about restoring lost abilities, only coping with people observing the loss.                |
| Health Resilience (Resnick 2014; Resnick et al. 2011) | The capacity to maintain good health in the face of significant adversity | Maintaining health is not the same as losing some function and recovering. “Robustness” rather than resilience. |
| Community Resilience (Chandra et al. 2011) | …entails the ongoing and developing capacity of the community to account for its vulnerabilities and develop capabilities that aid that community in: (1) Preventing, withstanding, and mitigating the stress of a health incident (2) Recovering in a way that restores the community to a state of self-sufficiency and at least the same level of health and social functioning after a health incident (3) Using knowledge from a past response to strengthen the community’s ability to withstand the next health incident | (1) includes prevention, which is risk management, not resilience.                                |

(continued)
conceived as a trajectory that maintains normal development through individual plasticity and the potential for personal change through flexibility and capacity, stemming from prior experiences of risk, trauma, limitations, and losses suffered throughout life (Fontes and Neri 2015). A resilient life trajectory can emerge when an individual experiences adversity, has or develops protective factors, and ultimately attains a positive health outcome (Hayslip 2012). Lastly, gerontology associates resilience with key characteristics or capacities of adaptation such as psychological coping, social coping, social learning, and emotional regulation. Often, theories of reserve view resilience as a capacity or characteristic that is accrued over time to be used in moments of hardship (i.e. common in the case of cognitive reserve and Alzheimer’s prevention) (Cosco et al. 2017; Stern 2007). For example, individual, social, and environmental resources are seen as areas in which individuals can build reserves to foster resilience against adversity, though this may equate resilience with reduced vulnerability, which are distinct according to the NAS definition.

| Domain                        | Definition                                                                                                                                  | Distinction from NAS definition                                                                 |
|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| Creative resilience           | The human ability to think in a less linear, more elastic fashion that helps them overcome adversity                                       | Unclear if creativity is the methodology behind this resilience, or the function being protected by resilience |
| Spiritual resilience          | The ability to sustain an individual’s sense of self and purpose through a set of beliefs, principles or values                              | No mention of adversity Sustainability of sense of self and purposes is not recovery after a loss |
| Motivational resilience       | The ability to sustain an individual’s characteristics that drives the individual to learn, grow and adapt to their environment             | No mention of adversity Sustaining individual’s drive to learn, grow, and adapt, is not the same as restoring drive after a loss |

Three components are common to almost all conceptualizations of resilience when using a life span perspective. The first is that an individual faces some form of adversity. The second is that the individual has a positive response, sometimes referred to as adaptation, to adversity (Cosco et al. 2016). The third is that most of these definitions perceive the goal of resilience to be adaptation against the increasing adversity that comes with normal aging (Cosco et al. 2018). This adaptation may refer to establishing a new optimal operation of a critical function, or to resisting the same pathway of downward degradation experienced by others in similar positions. Ultimately, degradation to a state of death remains inevitable, so resilience cannot be permanent, but is measured relative to others such that an individual can be deemed more or less resilient than someone else (Fig. 5).
While not all studies on aging incorporate resilience, most highlight the importance of mental health and cognitive function towards the process of adaptation after an adverse event. Elderly individuals face many risks, and practitioners and scholars agree that protections against these risks are important to ensure positive health outcomes. However, scholars disagree on what constitutes a risk, whether an individual needs to experience risks or adversity to develop resilience, and how positive outcomes are defined for aging resilience (Hayslip 2012). For example, a lack of disease or disorder, or above normal outcomes despite difficult circumstances, are limited approaches to understanding resilience, but there is little consensus on what it means to be a “healthy” older adult. Positive outcomes do not always easily generalize across time or domains because outcomes are dependent upon the measures used to determine them. Furthermore, resilience is often viewed separately from recovery in the medical field (Hayslip 2012).

Resilience is a multi-dimensional concept with an unlimited number of interacting variables. Thus, resilience in the medical field is divided into specific domains such as physical, psychological, emotional, cognitive, health, motivational, community, spiritual, and creative resilience (see Table 2). However, these divisions can continue indefinitely, leading to a dilution of resilience meaning and theory-making and more fragmentation across health fields. Breadth and specificity must be balanced because the current lack of consensus on how to operationalize resilience has led to weak linkages between concepts and methods that is further confused by discipline-specific technical language. Therefore, resilience across health fields has encountered the same two obstacles that have inhibited resilience measurement in other complex systems: (1) resilience is often conflated with risk analysis and quantitative risk assessment, and (2) resilience knowledge is fragmented across separate disciplines that do not typically communicate with one another (Hayslip 2012).
While consensus over a common definition for resilience may never be reached across all health fields, researchers and practitioners agree on its importance to gerontology. Therefore, a standard model or framework may be useful in order to better understand and measure resilience for aging older adults.

Table 2 provides definitions of resilience for specific domains in medical literature and their distinctions from the NAS definition for disaster resilience.

**Public Health and Aging**

Resilience is salient for the public health domain as more of the population lives longer and the role of public health in ensuring well-being among older individuals continues to grow. The WHO has observed the mounting burden of aging on health systems around the world (World Health Organization 2002, 2015, 2017). Many supranational and national public health roadmaps focus on the prevention of frailty among the elderly, especially as it pertains to physical and cognitive decline (Road Map for State and Local Public Health 2020; Galea and Huber 2012). Frailty in public health is not a disease, but a syndrome of extreme vulnerability to life stressors and adversities, typically involving impairments and imbalances to physiological functional systems, such as lung capacity, leg strength, and diminished energy reserve (Cesari et al. 2016). The pace of population aging, coupled with increasing rates of some aging-related adversities, such as multimorbidity, means that the population health burden is growing at unprecedented rates. To ensure successful and active aging processes, many public health organizations and policies focus on preventing frailty among the elderly to avoid the cascading negative consequences of disease and disability at old age.

Policy responses to aging are often developed in siloes and thus disjointed, reflecting broader public polarization of perceptions of old age. At one extreme, old age is viewed as an apocalyptic crisis of immense vulnerability, disengagement, and dependency, leading to a “care of the elderly” perspective. At the other extreme, old age is conceived as an important period of social engagement in which the elderly contribute to all levels of society (e.g. capital generation, volunteerism, and intergenerational support), outweighing social costs with the benefits that they contribute. Neither perspective is wrong, but neither is entirely correct. Effective public health policy for aging requires a compromise between the two views.

Medical conceptualizations of resilience primarily emerged from the SA model, whereas public health often references “active aging” in its frameworks and policies. Active aging hypothesizes that staying active in later life can help maintain overall health and well-being (Havighurst 1961; Rantanen et al. 2018). Active aging is considered a distinct process from SA because an individual strives to reach or maintain elements of well-being through activities relating to that person’s goals, functional capacities, and opportunities (Rantanen et al. 2019). Active aging also includes compensating for functional limitations with environmental and social support (Foster and Walker 2015). Typically, the active versus successful aging
divide is seen in European and United States policy discourse, respectively (Rowe and Kahn 1987; Foster and Walker 2015).

In 2002, the World Health Organization (WHO) adopted active aging as its underlying policy goal for elderly health, defining the concept as the process of optimizing opportunities for health, participation, and security in order to enhance quality of life into old age (World Health Organization 2002). The WHO acts as a public health authority, but its influence transcends into the clinical and medical spheres. However, in 2015, in its World Report on Ageing and Health, the WHO pivoted towards a more inclusive approach towards active aging policy called healthy aging (see Fig. 6). Healthy aging is defined as “the process of developing and maintaining the functional ability that enables well-being in older age (World Health Organization 2015).” The WHO concept of healthy aging considers an individual as a product of their intrinsic capacity (i.e. personal characteristics, genetic inheritance, and health characteristics), extrinsic environmental characteristics, and functional ability (i.e. intrinsic capacity, extrinsic environmental characteristics and their interactions). Stemming from theories of reserve, the model of healthy aging

![Fig. 6 Various trajectories of physical capacity over time. (a) is the optimal trajectory where the individual has a high intrinsic capacity until the end of life. (b) shows an individual that experiences different disruptions. They have different options as to how they can recover. (c) is a declining trajectory where capacity continuously declines until death. From the World Health Organization. World report on ageing and health. World Health Organization, 2015](image-url)
assumes that an individual accumulates reserves of functional ability throughout life that contribute to fostering resilience at older ages (World Health Organization 2015). Here, resilience is "the ability to maintain or improve a level of functional ability in the face of adversity" (either through resistance, recovery or adaptation). While the definition used by the WHO stems from medical and gerontological literature, it still applies to the broader public health sphere. The WHO must balance both systems-level public health policies and individual level healthcare outcomes. Resilience comprises both intrinsic capacity (i.e. psychological traits) and environmental attributes (i.e. social networks and access to healthcare). Unlike traditional medical literature, the WHO applies this definition to population health.

In the public health framework, aging is positioned on a trajectory where physical capacity slowly declines, as one grows older. Healthy aging divides this trajectory into three periods (see Fig. 6) that are not defined by age and are not monotonic (World Health Organization 2015). The first is a period of high and stable physical capacity. The second is a period of declining physical capacity. The third is a period of significant loss of physical capacity (World Health Organization 2015).

This life course perspective reinforces the preventative nature of active aging. System shocks can precipitate regime changes (Connelly et al. 2017) and thresholds determine a system’s ability to absorb a shock (Connelly et al. 2017). Defining threshold values that reflect transitions from one state to another (i.e. robustness, frailty, etc.) can help better inform decision-making as to which interventions in gerontology and geriatrics should be implemented and at what point in the trajectory for maximum efficacy and effectiveness.

Resilience occurs when an individual is able to maintain high and stable functional ability and intrinsic capacity over their lifetime for as long as possible (Smith et al. 2018; Foster and Walker 2015; Walker and Foster 2013). This differs from the NAS definition because it is not event-based, but views the entire process of aging as a continuous and relentless adversity to be managed.

The public health system can help provide resources and services during each of these three phases, which further ensures individual and health system resilience. For example, during a period of high and stable capacity, health services should focus on preventing chronic conditions and prioritizing early detection and control of such diseases. The environment (i.e. built environment, social support networks, food system, etc.) should promote capacity-enhancing behaviors. During a period of declining capacity, the health system should transition towards a focus on reversing or slowing an older person’s decline in individual capacity, such as through improved formal and self-care/maintenance. Policies focusing on the environment should begin to remove barriers to participation that come with loss of function ability (i.e. age-friendly approaches), while concurrently providing avenues for compensating for such loss (i.e. wheelchair accessibility, aging in place, affordable housing, public transportation), some of which cross domains. Once there is a significant loss of capacity, long-term care services should be available, accessible, and usable. These services can support capacity-enhancing behaviors and begin the process of ensuring a dignified later life and ultimately a “good” death (Smith et al. 2018; Foster and Walker 2015; Walker and Foster 2013).
Quantifying Resilience for the Elderly

Resilience Quantification in Medicine and Public Health

The WHO emphasizes that new knowledge on aging and health is critical to useful and impactful clinical practice, population health intervention, and social policies (World Health Organization 2015). Using a resilience framework to understand healthy and successful aging among older adults may help identify protective factors associated with resilience and provide generalizable solutions to the elderly seeking to overcome adversity across their life. Currently, the metrics which are used by researchers do not always align with what individual patients prioritize when adapting to a disruption in health (i.e. biomarkers and objective measures versus psychosocial factors and subjective measures) (Cosco et al. 2013, 2017). There is a need to better understand the specific health needs of older adults as a population and what a healthy trajectory looks like in the face of inevitable disease and physiological or mental decline (Cosco et al. 2013).

Many researchers in health fields conceptualize aging as a linear process (i.e. latent variable modeling and GMM) (Cosco et al. 2016, 2017a, b, 2019; Wister et al. 2018). While linear trends are useful for statistical analyses, aging is a complex, non-linear process. Likewise, the majority of resilience research on aging is conducted in cross-sectional studies (Cosco et al. 2017). Very few longitudinal studies of resilience among the elderly exist despite providing greater insights into resilience across the lifespan. Moreover, benchmarks and thresholds are not consistent across studies. Better metrics are needed in order to use new methodological approaches that can assess and model a complex system.

There is no gold standard to measure or quantify resilience in aging, and studies are highly variable in definitions, measures, and designs. Clinical scholars have examined biomarkers, such as musculoskeletal changes (adiposity, muscle mass, grip strength, bone mineral density, body weight, gait velocity), stem cell changes (% COP, COP lamin A), serum markers (hemoglobin, albumin, oxidation products, antioxidants), metabolic markers (HbA1C), hormonal changes (DHEA, testosterone, Vitamin D, PTH, IGF1), and new inflammatory markers (CRP, IL6, TNFa) (Al Saedi et al. 2019), where high levels denote individual health and latitude to temporarily decrease without immediate negative consequences. Other studies have inferred resilience through examining behaviors and subjective measurements such as emergency department visits, overnight hospital stats, and perceived pain (Wister et al. 2018), which also measure general health rather than ability to absorb and recover from emerging disruptions.

Different contexts produce inequities between the recovery capabilities of different populations of aged adults. Quantifying resilience for the elderly will indicate which sub-populations have a better ability to recover from disruptions, and which populations merit either strengthened protection against disruptions or stronger support should disruptions occur. It can also help planners manage disruptions as they occur in ways productive for long-term recovery, as well as make informed resilience-focused investment decisions during times without disruptions.
Social scientists incorporate social determinants of health by using socio-economic data, social support, and other domains. Self-reported data and surveys are common tools used to collect resilience-specific data. However, the sample sizes in such studies tend to be small and the surveys are not always the same, varying in questions asked and outcomes assessed. More recently, epigenetics and genetic research has provided novel and objective indicators of resilience in health across an individual’s lifespan and past generational experiences. External factors, such as poverty, societal perceptions of race, education, and the physical environment, can influence the health outcomes of a single individual. These external factors play a larger role as time passes, meaning that they are of critical importance to the elderly.

Public health suggests that understanding the resilience necessary for different individuals to function at the same level may require first understanding the distinct context in which they live. While health promotion and medicine are often criticized for ignoring these contextual forces, a recent shift has started to view health within the larger framework of the socio-ecological model (Fig. 7), which recognizes that individuals are nested within larger ecosystems that are largely beyond their control.

![Socio-ecological model in health.](image)

Fig. 7 Socio-ecological model in health. Adapted from McLeroy, K. R., Steckler, A. and Bibeau, D. (Eds.) (1988). The social ecology of health promotion interventions. Health Education Quarterly, 15(4):351–377
Within the socio-ecological framework, five spheres influence an individual’s well-being, starting with characteristics of an individual, then expanding outwards to the larger environment. Applied to older adults, the first sphere embodies individual healthy behaviors like social engagement and cognitive load. Next, the second sphere includes individual determinants include factors that may be outside the individual’s direct control, such as genetics, past education, and socio-economic status that can affect how people experience stressful events (Wister et al. 2016). In the social realm, social cohesion and belonging benefit aging adults (Cramm and Nieboer 2015). Overlaid on the individual and community is the built environment that aging adults live in, including aspects that support the nested systems, like electricity and walkability to grocery stores with fresh produce for healthy meals. Finally, the built environment is subjected to the changes in circumstances or resources of the natural world.

These spheres directly impact numerous factors that determine health behaviors and outcomes, such as institutional factors, community factors, public policy (i.e. governance and law making), intrapersonal factors, and interpersonal processes (Cramm and Nieboer 2015; McLeroy et al. 1988), and can be used to frame quantifications of individual resilience. For example, recent public health “aging-in-place” efforts have attempted to use a broader systems perspective to support the long term resilience of the elderly by using a socio-ecological perspective (Acosta et al. 2018). The socio-ecological model uses a complex systems perspective and provides a framework for organizing common features of health applicable to aging.

Importantly, the nesting of the spheres provides a helpful framework for understanding risks and their disruptions to various spheres and their relationship to individuals. Aggregating these factors together could provide a risk quantification for a specific profile of an aging person (i.e. a Hispanic parishioner living in a flood zone), but the manifestation of the risk and subsequent resilience capabilities needed may depend on which sphere it strikes. A disruption of the social environment, such as the closing of a café that serves as a gathering place for retired adults, will impact only the nested health determinants and will not be mitigated by disaster insurance. Meanwhile, the impact of a disruption to the natural environment, like a tornado or a pandemic such as COVID-19, could disrupt all systems. Resilience measures for individuals may benefit by incorporating these different contexts.

**Resilience Matrix for the Elderly**

We can begin to quantify different aspects of elderly resilience through the resilience matrix (Linkov et al. 2013). The resilience matrix (Fig. 8) combines the National Academies of Sciences system functions (plan/prepare, absorb, recover, adapt) and Network-Centric Warfare domains, an established paradigm that collects data in the physical realm, and translates it to information to be used for cognitive decision making (Alberts et al. 2001). These three domains are confined to the first two spheres of the socio-ecological framework. A fourth domain, social, is overlaid
on them, correlating to the social sphere which incorporates some outside influences, such as reciprocity in social relationships. Thus, the Network-Centric Warfare domains almost entirely concern the individual’s agency in his or her resilience.

Metrics are constructed using existing gerontology research and by assessing their implications throughout the different stages and domains as they apply to a geriatric population. Each cell in the matrix addresses the question: “How is the system’s ability to [plan/prepare for, absorb, recover from, adapt to] a health disruption among older individuals implemented in the [physical, information, cognitive, social] domain?” Since many metrics are difficult to measure through direct means, they must be estimated using a system-by-system basis that incorporates both quantitative and qualitative measures.

The physical responses characterize the circumstances of an individual’s body. Informational responses encompass the information and resources available to individuals to help them cope during disruptions, and cognitive responses reflect the individual’s engagement with the changes needed during disruptions. The social responses encompass the existing structure of the individual’s social network and specifically its ability or willingness to support an individual, including when the individual might not be actively engaged in seeking support. The four domains all contribute to an individual’s ability to prepare for, absorb, recover from, and adapt to disruptions (Table 3).

Fig. 8 Resilience matrix for natural disasters
The resilience matrix can characterize an individual within diverse contexts. However, as seen in the socio-ecological framework, many factors influencing well-being are beyond individual control. The outmost spheres of the socio-economic framework can contribute to individual recovery by reducing the burden of the individual resilience. A neighborhood with walkable streets is more conducive to elderly socializing. Although resilience may be measured using an individual scale, the externalities of the socio-ecological model reveal opportunities to further enhance and anchor individual resilience.
From Metrics to Model

Quantifying the individual metrics may not characterize how they will interact for individuals who rate high in some metrics but low in others. Herein we explore some of the complexities of the socio-ecological model of nested spheres as applied to individual resilience.

The medical establishment is concerned with the choices of individuals, and can play a role devising methods to measure such metrics and develop recommendations for improving them among aging adults who score poorly. But informational preparation supposes that resources are available to provide recovery support, something that is largely outside an older adult’s control. While access to relevant information is increasingly open in the age of the Internet, it still presents ample barriers for many, especially when a professional is needed to apply the information, such as a doctor or a psychologist. Of more concern, however, is the availability of resources. As risk and vulnerability factors increase, the ability to rely on individual resources decreases, and social or environmental support becomes more important (Ungar 2011). Many elderly adults may know exactly what they need, but may not be able to afford or access services or programs. The role of economic wealth in individual resilience must not be overstated, nor should the political support of health and social service provisions targeting aging populations. Thus, public health inquiries into gerontological resilience are rightly focused on broad-scale interventions. The different managers of individual and public health (health care providers, family caretakers, public health policy writers) all oversee aspects of resilience, which together complement a resilient model.

There is also an important temporal aspect to resilience manifestation. The flexibility that enables rapid responses through social support arises because those supports are not structural, and hence maintaining them long-term may be beyond the social network capacity (Cohen and Syme 1985). In studies of resilience to multimorbidity in the elderly, the time during which support is available matters, given more and less treatable points in illness trajectories. The spheres of the socio-ecological model show varying amounts of temporal volatility. Some individual determinants, such as the role of genetics in affecting illness outcomes, will not change, except in the more extreme cases of epigenetics. Social and physical spheres will be particularly dynamic as individuals age, but the environmental infrastructure, including public policy, will change much more slowly. This creates a structural lag (Riley et al. 1994). Thus, the timing of an individual’s resilient response may depend partially on the balance of metrics within his or her specific context, and for this reason a model of interacting metrics may constitute the next step in quantifying resilience.
Conclusion

This chapter retrofits and applies the NAS definition and complex systems model of resilience developed to understand the effects of natural disasters to the quantification of resilience in the elderly, with particular focus on ability to recover from age-related disruptions. This contrasts with existing notions of resilience in gerontology literature, which emerged as a response to the inability of the successful aging paradigm to incorporate adverse events and crucial adaptive processes. Though called resilience in the gerontology literature, the current paradigm focuses strongly on adaptation and coping rather than recovery, particularly given the chronic nature of multimorbidity in older age (Wister et al. 2018).

Resilience in older adults should not be conflated with their pre-existing health status except in quantifying their ability to fully absorb a threat without system failure. There are distinct metrics of resilience for medicine and public health as they relate to gerontology, but models of resilience, specifically applied to aging population or sub-population, should include both because they are irrevocably intertwined. To optimize their capacities over their lifespan, an older individual needs to prepare and respond according to the resilience matrix, but they also require access to, and the ability to harness an umbrella of resources, such as healthcare services, safety, social support, and adequate education (Hayslip 2012). This broad base of needs, reflected in the gerontology literature, corresponds to the various types of disruptions that can influence the spheres of the socio-ecological model, as well as the categorical responses of the resilience matrix. Resilience requires the participation of the individual as well as his or her broader community; thus, it is useful to begin to view resilience as a property of an overall system (Linkov et al. 2014). Resilience is not solely an individual attribute, but inherently tied to the broader context, including economic circumstances, positive social networks, and relationships that may or may relate to individual behavior, as well as the political supports and context made available to people lacking either economic security or long term social support. To lay the responsibility of resilience on an individual alone would remove the larger institutional contexts that also shape an individual’s health, as well as their access to resources necessary during recovery.

The emergence of the SARS-CoV-2 novel coronavirus (COVID-19) in the U.S. in early 2020 has revealed an unprepared system with respect to many areas, including testing, ventilators, and other specialized equipment for respiratory diseases: designated intensive care units, etc. This emphasized the importance of the integration of systems as a primary component of response to disasters such as the COVID-19 pandemic that placed older adults and other vulnerable groups at increased risk of morbidity and mortality, especially in the long-term care system. In addition, a resilience approach to the support of seniors may be instrumental in preventing older adults from flooding into hospitals and overburdening the overall healthcare system.

While resilience analysis cannot replace risk assessment, it can provide a systems approach to complex processes that have multiple nested domains, emergent properties, and potential underlying processes. A resilience management framework
includes risk analysis as a key component of its approach, providing a way to plan, prepare, absorb, recover, and adapt from a threat that has a high incidence of uncertainty. Rapid and efficient recovery is critical to the resilience of a system. Early integration of resilience into the design of systems such as health, community, and long-term care can help lay the groundwork for resilience thinking.

Aging is an unpredictable process and the human body is a complex system. Establishing a framework for resilience in aging will require specific methods to define and measure resilience. New modeling and simulation techniques for complex systems could be tested and evaluated for their usefulness. Researchers should continue to develop the field of gerontology resilience through collaboration with other disciplines, including systems engineering, public health, computer science, and the bio-sciences. Lastly, there needs to be clear strategies for communication of the importance of resilience approaches to key stakeholders and actors. Resilience management needs to be prioritized in patient health behavior, provider decision-making, clinical guidelines, public health policies, and healthcare infrastructure, not just in scientific research and theory.

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