SOCIAL VULNERABILITY AND HEALTH IN OLDER ADULTS

by

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DEDICATION PAGE

This thesis is dedicated to the memory of my grandparents, who introduced me early on to the richness that comes from paying attention to what older generations have to tell us.

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ABSTRACT

Vulnerability to adverse health outcomes can be *intrinsic* (*e.g.* illnesses, disability, frailty, genetics) or *extrinsic* (*e.g.* physical and social environments). The contribution of social factors to extrinsic vulnerability in older adults is the subject of this thesis. Social vulnerability is the degree to which a person's overall social situation leaves them susceptible to further insults, either health-related or social. This thesis begins with an exploration of how various social factors are associated with health and can be considered to contribute to a holistic concept of social vulnerability. Using a social ecology perspective, seven domains of social vulnerability (engagement, contextual socio-economic status, social support, living situation, self-esteem, mastery, and relations with others) are defined. A social vulnerability index is then developed, in which social factors from all of these domains are combined into a single index, allowing the complexity of social circumstances experienced by older people to be embraced. Social vulnerability, defined using this index, is then studied in relation to health, and is found to be associated with frailty, mortality and cognitive decline. The important impact of social vulnerability on the survival of the fittest older adults (those who are not at all frail) is studied as a special case. How social vulnerability changes over time is then examined using a transitions model based on a parametric Markov chain, with the finding that older people tend to accumulate social deficits over time, but that, importantly, this relentless accumulation of social problems is not a universal experience. The thesis then turns to consideration of frontal lobe cognitive function as a possible mechanism for the association between social vulnerability and health, given the importance of the frontal lobes to social interaction in humans. It finds that the most socially vulnerable people have impaired performance on tests of frontal lobe cognition, but that performance on non-frontal tasks is not similarly associated. The findings presented in this thesis support the importance of social factors for health of older people, and suggest that the social vulnerability index shows potential as a measure which embraces the complexity of older adults' social circumstances while reducing dimensionality.

LIST OF ABBREVIATIONS USED

3MS	**Modified Mini Mental State Examination**
ADL	**Activities of Daily Living**
BL	**Baseline**
CIHR	**Canadian Institutes of Health Research**
CSHA	**Canadian Study of Health and Aging**
DSM-III-R	**Diagnostic and Statistical Manual of Mental Disorders, Third Edition, Revised**
IADL	**Instrumental Activities of Daily Living**
IQR	**Interquartile Range**
MLE	**Maximum Likelihood Estimation**
MMSE	**Mini Mental State Examination**
NPHS	**National Population Health Survey**
OARS	**Older Americans Research Survey**
SD	**Standard Deviation**
WAIS-R	**Wechsler Adult Intelligence Scale-Revised**

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CHAPTER 1 INTRODUCTION

1.1 STATEMENT OF THE PROBLEM

In my clinical work I have noticed that patients' social circumstances have a lot to do with how they fare, influencing their clinical outcomes in important ways. For example, two acutely hospitalized patients with the same level of frailty, medical illness and functional impairment will likely go on to have very different outcomes if one is socially integrated and the other is socially isolated. This has motivated my inquiry into how to conceptualize, define, measure, and model social vulnerability among older adults.

Vulnerability to adverse outcomes can arise due to *intrinsic* vulnerability (e.g., illnesses, disability, frailty, genetics), but *extrinsic* factors (e.g., one's physical environment, social supports or isolation) are also likely to play an important role. The concept of social vulnerability addresses this extrinsic vulnerability, capturing the degree to which a person's overall social situation leaves them susceptible to further insults (either health-related, or social). Considered in the inverse, social reserve is the degree of resilience that a well-connected and supportive social situation might impart.

Much work has shown that individual social factors are importantly related to health outcomes; this evidence is reviewed in section 1.3. The challenge is how to consider complex social circumstances as a whole, because the social circumstances of most older people are not well described by lists of social factors in individual boxes. For example, although living alone is a risk factor for poor outcomes, what of the older widow who compensates for this solitary living with rich social interactions and frequent social engagement in her community? As such, a holistic concept of social vulnerability would necessarily transcend the unidimensional "one thing at a time" view and attempt to capture, account for, and even embrace this complexity.

After reviewing the current state of knowledge relating to how social factors may be associated with health, this thesis then goes on to build an argument in support of a holistic concept of social vulnerability. It examines how many diverse social factors inter-relate to form what can be considered as dimensions of social vulnerability (Chapter 3), but also shows that these dimensions are inter-related in complex ways, and that a holistic measure of social vulnerability will ultimately be required in order to give this complexity its full due. The thesis will then settle into examination of social vulnerability as an index, including exploration of its properties in relation to age, sex, and frailty (Chapter 4), as well as its association with health outcomes (mortality in Chapter 4, and cognitive decline in Chapter 5).

The thesis then goes on to explore how social vulnerability changes over time (Chapter 6), before examining the special case of how social vulnerability influences the survival of the fittest older people, those who are not at all frail (Chapter 7). The thesis then moves to a consideration of a possible mechanism, beyond those usually considered in the literature (as reviewed in section 1.4.4) for how social vulnerability might exert these associations with health, and indeed, how health (in this case cognitive function) might influence social circumstances. This is done by investigating whether social vulnerability is associated with performance on tests of frontal lobe cognitive function, given the importance of the frontal lobes to social interaction in humans (Chapter 8).

The thesis concludes with a summary of the findings presented in the six constituent studies, drawing them together into a thematic discussion of what social vulnerability is, how it can be measured, and its importance to health, in terms of both clinical and policy considerations. This discussion is structured using the well-known Bradford Hill framework of criteria for evaluating evidence to support claims of causation and clinical meaningfulness.

The specific objectives of the thesis are laid out below.

1.2 OBJECTIVES

The primary objective of this thesis was to develop and explore the concept of social vulnerability in relation to health in older people. Specifically, this thesis aimed to address the following questions:

i. What is social vulnerability? What are its dimensions and how is it influenced by individual, group, and community level factors?
ii. How does social vulnerability relate to frailty and important health outcomes such as mortality and cognitive decline?
iii. How do profiles of social vulnerability change over time?
iv. Given that the frontal lobes influence social behaviour in humans, does social vulnerability relate to pre-frontal cognitive function?

1.3 STATEMENT OF KNOWLEDGE

1.3.1 PROLOGUE

Many social factors affect older people's health, and there are many different possible approaches for studying these associations. The following review, which was also published as a book chapter, defines and situates the various terms that are used in the literature to refer to social factors, discusses the current state of evidence as to how they relate to health, and outlines analytic approaches that might be useful for study in this topic area.

1.3.2 PUBLICATION DETAILS

Andrew MK. Social vulnerability in old age. In: K Rockwood, H Fillit, K Woodhouse (Eds.) Brocklehurst's Textbook of Geriatrics and Clinical Gerontology, 7th Edition. 2010. Saunders Elsevier, Philadelphia, pp.198-204.

1.4 SOCIAL VULNERABILITY IN OLD AGE

People's lives are embedded in rich social contexts; many social factors impact on each of our lives every day. This is perhaps more noticeably so for older adults as declines in health and functional status may increase reliance on social supports and diminish opportunities for social engagement, even in the face of social circles dwindling due to declining health and function among peers.

This chapter will provide an overview of how social factors affect health in old age, through a discussion of the concept of *social vulnerability*. Association with health outcomes relevant to Geriatric Medicine (including function, mobility, cognition, mental health, self-assessed health, frailty, institutionalization, and death) will be the focus, with particular emphasis on the relationship between social vulnerability and frailty. Detailed discussion of social gerontology and of standardized instruments and measurement scales used in the social assessment of older people is beyond the scope of this chapter; interested readers are referred to the two chapters on these topics in this volume.(Kane; Nazroo)

1.4.1 BACKGROUND AND DEFINITIONS

Many social factors influence health, including socioeconomic status, social support, social networks, social engagement, social capital, and social cohesion.(Schoenbach, Kaplan et al. 1986; Seeman, Kaplan et al. 1987; Marmot and Shipley 1996; Kawachi and Berkman 2000; Baum and Ziersch 2003; Mendes de Leon, Glass et al. 2003; Lindstrom, Moghaddassi et al. 2004; Marmot 2004) As such, the social context is key to a broad understanding of health and illness. Perhaps due in part to the numerous disciplines in which this line of inquiry has been investigated (including epidemiology, sociology, geography, political science, and international development among others), terminology and methods of approach have differed. In some instances, the same terminology has been used to refer to different ideas, while in others, divergent terminology obscures

underlying commonalities. There has also been debate surrounding the level, from individual to communal, at which some elements of the social context are relevant, and as such, how they can be measured.(Lochner, Kawachi et al. 1999; Baum and Ziersch 2003; Andrew 2005) In the following section, the various terms and concepts will be defined and discussed, and each will be placed in context on the continuum from individual to group influence (Figure 1).

Socioeconomic status

Socioeconomic status (SES) is a broad concept that includes such factors as educational attainment, occupation, income, wealth, and deprivation. There are three broad theories of how socioeconomic status might relate to health.(Grundy and Holt 2001) The materialist theory states that gradients in *income and wealth* are associated with varying levels of deprivation, which in turn affects health status as those with fewer means have inferior access to health care and the necessities of life. Another view is that *education* influences health through lifestyle and health-related behaviours such as diet, substance use, and smoking. A third theory sees social status (often measured by *occupation*) and personal autonomy as key influences on health, particularly through the stresses that accompany low social status and low autonomy.(Grundy and Holt 2001) Measurement of each of these elements of SES may present difficulties in the older adult population. Older persons are likely to be retired and older women may never have worked outside the home, making occupational assessments problematic. Income is associated with employment status, and many income supplements and benefits are available to those with disability and poor health raising problems of reverse causation.(Grundy and Holt 2001) Educational opportunities available to older cohorts may have been limited, creating a "floor effect" in which it is difficult to differentiate among the majority whose educational attainment is low.(Grundy and Holt 2001) Additionally, information may be missing when a proxy respondent has been used, depending on how well the proxy knows the subject. Socioeconomic status is a property of individuals; however aggregates of such measures can be used to describe the social context in which people live. For example, average income, employment rates, or educational attainment may be useful descriptors when applied to groups of people living in relevant geographical areas such as

housing facilities or neighbourhoods, and may allow for study of contextual effects on health.(Kawachi, Kennedy et al. 1997; Kawachi, Kennedy et al. 1999; Lindstrom, Merlo et al. 2002; Subramanian, Kim et al. 2002; Lochner, Kawachi et al. 2003; Lang, Llewellyn et al. 2008; Lang, Llewellyn et al. 2008)

Social support

Social support refers to the various sources of help and resources obtained through social relationships with family, friends, and other care providers. Types of social support include emotional (including the presence of a close confidante), instrumental (help with activities of daily living, provided through labour or financial support), appraisal (help with decision-making), and informational (provision of information or advice).(Berkman and Glass 2000) Various measures of social support have been studied, with some tending to be more "objective" (based on reports of actual use of services and tangible help received in the various domains) and other more "subjective", based on the individual's perception of the adequacy and richness of the supports to which they have access. Social support can also importantly be seen as a two-way transaction, with the older person receiving supports in some areas while providing support in other. For example, within spousal relationships each spouse may have complimentary strengths and weaknesses; between generations, older people may provide care for grandchildren and financial support for adult children, while receiving instrumental support.(Keefe and Fancey 2002)

Social networks

Social networks are the ties that link individuals and groups in social relationships. Various characteristics can be measured, including size, density, relationship quality, and composition.(Baum and Ziersch 2003) Both social networks and social support are generally seen as individual-level resources, and are measured at an individual level.(Berkman and Glass 2000; Kawachi and Berkman 2000; McKenzie, Whitley et al. 2002) Through social networks, individuals can access social support, material resources, and various other forms of capital (cultural, economic, and social).(Bourdieu 1985)

Social engagement

Social engagement represents an individual's participation in social, occupational, or group activities, which may include formal organized activities such as religious meetings, service groups and clubs of all sorts. More informal activities such as card groups, trips to the bingo hall, and cultural outings to see concerts or galleries can also be considered as social engagement. Volunteerism is often considered separately,(Baum and Ziersch 2003) but can also be seen as an important measure of social engagement.

Social Capital

Social capital is a broad term which has been used inconsistently in the literature, and there is ongoing debate about its nature and measurement. For example, Bourdieu defines social capital as "the aggregate of the actual or potential resources which are linked to possession of a durable network of more or less institutionalized relationships" (p.248).(Bourdieu 1985) His definition is consistent with the idea that social capital is a resource that can be accessed and measured at an individual level, stating that "the volume of social capital possessed by a given agent thus depends on the size of the network of connections he can effectively mobilize and the volume of the capital … possessed by each of those to whom he is connected" (p.249).(Bourdieu 1985) However, his definition is also consistent with the view that social capital is a *property* of the relationships within the network – if there are no connections between individuals, there would be no social capital. Coleman makes a similar argument, stating, "Unlike other forms of capital, social capital inheres in the structure of relations between actors and among actors. It is not lodged either in the actors themselves or in the physical implements of production" (p. S98).(Coleman 1988) He also sees social capital as a resource accessible by individuals, writing, "social capital constitutes a particular kind of resource available to an actor" (p. S98).(Coleman 1988)

Putnam defines social capital as "the features in our community life that make us more productive – a high level of engagement, trust, and reciprocity" (p.4),(Putnam 1996) and sees it as "simultaneously a 'private good' and a 'public good'" with both individual and collective aspects (p.20).(Putnam 2000) In order to access the "private good" benefits of social capital, an individual would need to be integrated into a network, and have direct connections with other members. But the 'public good' effects of social capital would accrue to everyone in the community, regardless of their personal connections to others. The "public good" conception of social capital is shared by others, including Kawachi and collaborators, who see social capital as an ecological level characteristic that can only properly be measured at a collective level, and state that "social capital inheres in the structure of social relationships; in other words it is an ecological characteristic," which "should be properly considered a feature of the collective (neighbourhood, community, society) to which an individual belongs" (p.176-177)(Kawachi and Berkman 2000).(McKenzie, Whitley et al. 2002; Cannuscio, Block et al. 2003; Lochner, Kawachi et al. 2003)

Measures of social capital are as varied as its definitions, and include both structural elements (such as social networks, relationships and group participation) and cognitive ones (such as trust in others, voting behaviour, newspaper subscription, feelings of obligation, reciprocity and cooperation, and perceptions of neighbourhood security).(Coleman 1988; Lochner, Kawachi et al. 1999; Baum and Ziersch 2003)

Social cohesion

The concept of social cohesion implies collectivity of definition and measurement. Again, definitions vary, but generally relate to ideas of cooperation and ties that unite communities and societies. For example, Stansfeld defines social cohesion as "the existence of mutual trust and respect between different sections of society" (p.169)(Stansfeld 1999). For Kawachi and Berkman, social cohesion relies on two key features of a society: absence of social conflict and presence of social bonds.(Kawachi and Berkman 2000)

Social isolation

Social isolation is another term that is encountered in the literature relating social circumstances and health. It is related to ideas of loneliness, reduced social and religious engagement, and reduced access to social supports. It may also incorporate properties of the older person's environment such as difficulty with transportation. As with many other social factors, social isolation can be "subjective" (as perceived by the older person themselves, *e.g.* loneliness) or "objective" (based on outside measures or assessments by others).

Social vulnerability

The concept of social vulnerability addresses the understanding that the reason we are interested in the social environment is not merely as a descriptor, but to attempt to quantify an individual's relative vulnerability (or resilience/invulnerability) to perturbations in their environment, social circumstances, health or functional status. Older people's social circumstances are complex, with multiple factors that may interact in potentially unforeseen ways. A global measure of social vulnerability would thus account for this complexity while providing descriptive and predictive value. A measure of social vulnerability should be broad enough to capture a rich description of the social deficits (or problems) that an individual has, be readily and practically measurable in population and clinical settings, be responsive to meaningful changes, and be predictive of important heath outcomes.

How can we study social influences on health?

Study of how social factors influence health requires careful consideration of analytic design in relation to the specific questions being asked (Table 1).

Possible approaches include traditional "one thing at a time" analyses in which a single social factor (for example, the social network) is related to the outcome of interest, ideally adjusting for possible confounders in a multivariable model. This approach has certain benefits, chief among them simplicity and clarity in execution and interpretation. For example, it allows for clear statements of important findings such as "An extensive

social network seems to protect against dementia."(p.1315)(Fratiglioni, Wang et al. 2000) This approach can be done using single variables considered individually, a combination of variables relating to different aspects of the same theme (*e.g.* several variables that relate to the size and quality of the social network), or set instruments that have been previously validated to measure the social factor of interest (*e.g.* the Berkman-Syme Social network Index and Lubben's Social Network Scale).(Kane and Kane 2000) The standardized psychometric properties of such scales add to the reliability and validity of studies that employ them, but their use does have drawbacks including relative rigidity and lengthier administration time. Their use may also be limited or impossible with existing datasets due to challenges encountered in their faithful reconstruction.

Deficit accumulation offers another potential approach to the study of social influences on health. Akin to the frailty index which readers will find described elsewhere in this volume,(Mitnitski and Rockwood) a *social vulnerability index,* operationalized as a count of deficits relating to many social factors, offers a means of considering an individual's broad social circumstance and the potential vulnerability of their health and functional status. The index has a number of benefits, including: 1) the potential to include many different categories of social factors (for example SES, social support, social engagement, social capital), 2) the commonly encountered difficulty of embodying social and socioeconomic characteristics using single variables in studies of older adults is alleviated by including consideration of multiple different factors, 3) related factors are not arbitrarily separated into distinct categories for separate analysis, and 4) representation of gradations in social vulnerability is improved compared with consideration of one or a few binary or ordinal social variables. This last point is particularly important given that studies using the social vulnerability index in two cohorts of older adults have found that no one was completely free of social vulnerability (*i.e.* no individual had a "zero" score on the index).(Andrew, Mitnitski et al. 2008)

In addition to these analytical considerations of how the social factor(s) of interest is/are measured, incorporating the social context into the analyses can be done in different ways. More traditional "horizontal" approaches might add a summary variable that

describes the individual's social context (*e.g.* mean neighbourhood income or educational attainment) as a variable/confounder attached to the individual in the multivariable model.(Lang, Llewellyn et al. 2008; Lang, Llewellyn et al. 2008) This approach can yield useful findings and has the advantage of simplicity, but some might argue that it does not provide a full understanding of the importance of the contextual variable(s) and it presents statistical problems in terms of independence of observations (individuals are no longer truly independent if they share these important characteristics of the groups to which they belong). Multilevel (or "vertical") modeling (*e.g.* Hierarchical Linear Modeling) is another option: here, the individual is nested within layers of group influence, with collective characteristics treated as attributes of the group rather than of the individual.(Raudenbush and Bryk 2002) This approach offers the advantage of allowing for more detailed understanding of the contextual effects, preserving the independence of observations, and not losing information as happens when data are aggregated.(Raudenbush and Bryk 2002)

The consideration of contextual or group-level variables such as neighbourhood and community characteristics is particularly relevant to the study of how social factors affect health because many social factors are properties of the groups or communities in which individuals live and may be best measured on a group level. As we have seen, there is active debate about whether social capital is a property of individuals or of groups.(Baum and Ziersch 2003; Andrew 2005) Most theories of social capital are consistent with the idea that it is a property of relationships between individuals and within societies rather than residing within individuals *per se*. The heart of the issue that continues to divide theorists is whether social capital is a resource that an individual can be said to draw upon, and thus, in practical research terms, whether or not it can legitimately be measured at an individual level. This debate has clear implications for the design and interpretation of research studies that aim to investigate how social factors influence health; valid and useful findings can rest only on sound theoretical foundations. In this regard, a second distinction may be helpful: the answer may depend on whether the question applies to *where social capital exists* (is it a property of individuals or of relationships?) or to *how it is measured and accessed*.(Andrew 2005) Practically speaking, measurement issues and

data availability may strongly influence analytical design. The issue of how social factors should be studied in relation to older adults' health is therefore ideally guided by a balance of these theoretical considerations and analytic pragmatism.

1.4.2 SUCCESSFUL AGEING

This concept has been the subject of numerous enquiries in both the academic literature and the popular press.(Rozanova, Northcott et al. 2006) Interested readers are referred to the comprehensive chapter by T. A. Glass in the 6th edition of this text.(Glass 2003) Definitions of successful aging vary, but generally fall into psychosocial and biomedical camps. Psychosocial conceptualizations emphasize compensation and contentedness, where biomedical definitions are based on absence of disease and disability.(Glass 2003) The concept of successful aging recognizes that the aging process is variable, and that how older people adapt to later life changes associated with aging influences how "successfully" they will age. Ideally, research into this area would identify potentially modifiable factors at play that help some age "better/more successfully" than others.

There is a potential downside to the idea of successful aging: if successful ageing is applied as a value judgment, it may be at the cost of blaming and further marginalizing the "unsuccessful agers," those who are not so fortunate as to have the good health and functional status that might allow them to be doing aerobics at 102 or volunteering with "the old people" at 99.(Rozanova, Northcott et al. 2006) Such stereotypes, based on both rare aging successes and on the undercurrent of ageism that is common in our society, also influence portrayal of older people in the popular media. Both positive and negative stereotypes run the risk of perpetuating the marginalization of the most vulnerable older people, whether their "unsuccessful aging" is implied or emphasized.(Rozanova, Northcott et al. 2006)

Another way to think about successful aging is those individuals who overcome their expected trajectory in the natural history of decline for a given level of frailty. Work with the frailty index has shown that trajectories of decline are established early, and that such declines are well-predicted using mathematical models.(Mitnitski, Bao et al. 2006; Mitnitski, Song et al. 2007) However, there are some individuals who improve or transition to lower levels of frailty (who are able to "jump the curve" from their own predicted course and outcomes to attain the outcomes that would be expected for people with a lower baseline level of frailty); this might be a useful subgroup in which to study predictors and correlates of this "successful aging".

1.4.3 ASSOCIATIONS WITH HEALTH

The various social factors discussed here have been associated with health outcomes that are important for the older population. Readers interested in broad-based discussions of how social circumstances relate to health (as well as to other attributes of societies) are referred to the works of Wilkinson, Marmot, and Putnam, who have each made strong and comprehensive cases that weak social cohesion and declines in social capital contribute to poor health,(Putnam 2000) and may explain associations between poor health and income inequalities(Wilkinson 1996) and social status inequalities.(Marmot 2004) As in many areas of geriatric medicine, studies pertaining specifically to older adults are limited in number. These will be discussed here along with important findings from general population studies in relation to health outcomes that are important in geriatric medicine.

Survival

Numerous studies have found associations between social factors and survival. Perceived social support and social interaction were associated with lower 30-month mortality in a cohort of 331 community-dwelling adults aged 65 and older in Durham County, North Carolina.(Blazer 1982) In the Alameda County 1965 Human Population Laboratory

study, those, including older adults, with a richer social network, more contact with friends and family, and church or other group membership (used to generate a Social Network Index) had lower mortality over 9 years of follow-up.(Berkman and Syme 1979) Using 17-year follow-up data from the same study, social connectedness predicted better survival at all ages, including those aged 70 and older.(Seeman, Kaplan et al. 1987) Older individuals with few social ties also had reduced survival in a cohort study conducted in Evans County, Georgia.(Schoenbach, Kaplan et al. 1986) In another study, increased social ties predicted five-year survival in two of three community-based cohorts.(Seeman, Berkman et al. 1993) The Whitehall studies of men employed in the British civil service identified an impressive gradient in survival across levels in the occupational hierarchy: in middle age, office workers in the lowest ranking jobs had four times the mortality of those in the highest ranking "administers" category. This gradient persisted after retirement (though it diminished to twice the risk of mortality) in the oldest age group studied, age 70-89.(Marmot and Shipley 1996; Marmot 2004) High social vulnerability, as measured using a social vulnerability index, increased the risk of mortality over five and eight years follow-up in two separate longitudinal studies of older Canadians: the Canadian Study of Health and Aging (CSHA) and the National Population Health Survey.(Andrew, Mitnitski et al. 2008) Ecological (collective-level) analyses using multilevel modeling have also linked high social capital, defined by high trust and membership in voluntary associations, with reduced mortality at state(Kawachi, Kennedy et al. 1997) and neighbourhood(Lochner, Kawachi et al. 2003) levels in the United States.

Cognitive decline and dementia

In a study of 2812 older adults living in New Haven, Connecticut, social disengagement was associated with 3, 6, and 12-year incident cognitive decline defined as a transition to a lower category of performance on the 10-item Short Portable Mental Status Questionnaire.(Bassuk, Glass et al. 1999) Greater emotional social support predicted better cognitive function measured by a battery of tests assessing language, abstraction, spatial ability, and recall over 7.5 years in the MacArthur Studies of Successful Aging.(Seeman, Lusignolo et al. 2001) Among 2468 CSHA participants aged 70 and

older, high social vulnerability was associated with a 35% increase in the odds of clinically meaningful cognitive decline (a decline of >= 5 points(Andrew and Rockwood 2008) on the Modified Mini Mental State Examination (3MS)) over five years.(Andrew and Rockwood 2010) In a cohort of 1203 older adults in Kungsholmen, Sweden, those with a limited social network (including consideration of marital status, living arrangement, and contacts with friends and relatives) had a 60% increased risk of dementia over an average of 3 years of follow-up, while the incidence of dementia decreased in a stepwise fashion with increasing social connectedness.(Fratiglioni, Wang et al. 2000) The association of strong social networks and participation in mental and physical leisure activities with reduced incidence of dementia was also supported by a systematic review.(Fratiglioni, Paillard-Borg et al. 2004) An American study of 9704 older women found that a richer social network (defined as the top two tertiles on the Lubben Social Network Scale) was associated with maintenance of optimal cognitive function (*i.e.* not experiencing age-related declines in cognition) over 15 years of follow-up.(Barnes, Cauley et al. 2007) Loneliness has also been associated with lower levels of baseline cognition in older people, more rapid cognitive decline, and double the risk of pathologically-diagnosed Alzheimer Dementia.(Wilson, Krueger et al. 2007) Social interaction and engagement reduced the probability of declines in orientation and memory in a 4-year study of community-dwelling Spanish older adults (Zunzunegui, Alvarado et al. 2003) and greater social resources (networks and engagement) were similarly associated with reductions in cognitive decline in old age.(Barnes, Mendes de Leon et al. 2004)

Socioeconomic status has also been studied in relation to cognition and cognitive declines in late life. Low SES (as measured by education, income, and assets) was associated with cognitive decline (>= 5 point decline in the 3MS over 4 years) independent of biomedical comorbidity in a cohort of 2574 older participants aged 70-79 in the Health, Aging and Body Composition study.(Koster, Penninx et al. 2005) In a study that measured performance on complex memory tasks as well as electroencephalography (EEG) recordings of event-related potentials, older women (aged 65 and older) of high socioeconomic status performed similarly to younger women in complex source memory

tasks, and appeared to make use of neural compensation strategies not used by their lower SES counterparts and not required by the younger subjects.(Czernochowski, Fabiani et al. 2008) In the Chicago Health and Aging project study of 6158 older people aged 65 and older, early life socioeconomic status (both of the individual's family and of their birth county) was associated with late life cognitive performance but not with subsequent rate of decline.(Wilson, Scherr et al. 2005) A report from the English Longitudinal Study of Ageing (ELSA) found that neighbourhood-level SES was associated with cognitive function independent of individual SES.(Lang, Llewellyn et al. 2008) Using hierarchical linear modeling, neighbourhood-level educational attainment was associated with cognitive function of Americans aged 70 and older participating in the Study of Assets and Health Dynamics Among the Oldest Old (AHEAD). This was independent of individual factors including educational attainment as well as neighbourhood measures of income, leading the authors to conclude that promoting educational attainment in the general population may help older residents to maintain cognitive function.(Wight, Aneshensel et al. 2006)

Functional decline and dependence

Low levels of social engagement among older adults have been associated with increased disability (measured as impairment in activities of daily living, mobility, and upper and lower extremity function) over 9 years of follow-up.(Mendes de Leon, Glass et al. 2003) Older adults (aged 72 and older) with dense social networks showed delayed onset of self-perceived disability over eight years of follow-up in a panel study of 1000 residents of three retirement communities in Florida.(Kelley-Moore, Schumacher et al. 2006) Social engagement through group participation, social support, and trust/reciprocity were each associated with reduced functional impairment in community-dwellers in a cross-sectional analysis of the Health Survey for England. The association between group participation and functional impairment was also statistically significant amongst residents of institutional care homes.(Andrew 2005)

Mobility

Various social factors have been associated with risk of falls and of subsequent injury. For example, one Australian population-based study found that older people with lower SES, those living alone, and those needing repairs to their home were more likely to have fallen.(Gill, Taylor et al. 2005) Another study identified protective factors for fall-related hip fractures that included being currently married, living in the same place for more than 5 years, having private health insurance, and engaging in social activities.(Peel, McClure et al. 2007) Neighbourhood-level deprivation has been associated with incident self-reported mobility difficulties and measured impairment in gait speed independent of individual SES and health status in the English Longitudinal study of Aging (ELSA).(Lang, Llewellyn et al. 2008)

Institutionalization

As most studies in this field have been done using surveys or cohorts with community-based sampling frames, there has been a paucity of research including residents of long term care facilities. However, severe lack of social support has been was associated with higher odds of care home residence,(Andrew 2005) and is a risk factor for care home placement.(Rockwood, Stolee et al. 1996; Kersting 2001) The issue of how social factors and social vulnerability affect the health of older residents of institutions requires further study. In a cross-sectional analysis of the Health Survey for England, where associations between social capital and health were found amongst care home residents, these associations were generally weaker than in the community setting, suggesting that the importance of social capital may vary according to living situation.(Andrew 2005)

Mental health

Low perceived neighbourhood social capital and high social disorganization were associated with both psychiatric and physical morbidity in a study of British adults.(McCulloch 2001) Mental health has also been found to be associated with the strength and nature of social ties, although protective effects do not appear to be uniform across all population groups.(Kawachi and Berkman 2001) For example, a study of 1714

older Cubans found that social networks (particularly those centered on children and extended family) were associated with reduced depressive symptoms in women, while being married and not living alone were more important for men.(Sicotte, Alvarado et al. 2008) Among community dwelling older adults, social support, group participation, and trust/reciprocity were each associated with better mental health as measured by the General Health Questionnaire, an instrument that has been validated to detect mild psychiatric morbidity. Social support was also associated with reduced psychiatric morbidity among older adults who resided in care homes.(Andrew 2005) Lower neighbourhood SES and higher population density were associated with depression and anxiety among people aged 75 and older in Britain, but in this study the effect of neighbourhood SES was explained by individual SES and health factors.(Walters, Breeze et al. 2004)

Self-Assessed Health

Individual-level social capital, as defined by religious participation, trust, and having a helpful friend, was associated with better self-assessed health among Swedish-speaking adults in a bilingual region of Finland.(Hyyppa and Maki 2001) High community-level social trust and membership in voluntary associations were also associated with better self-assessed health among community-dwelling adults in multi-level analyses adjusting for individual-level influences on health in two large (N=167,259 and 21,456) American studies.(Kawachi, Kennedy et al. 1999; Subramanian, Kim et al. 2002) Among 1677 community dwelling older adult participants in the Health Survey for England, higher levels of social support, group participation, and trust/reciprocity were associated with better self-assessed health.(Andrew 2005) At a neighbourhood level, low SES (including poverty, unemployment, low education, and reliance on public assistance) was associated with poor self-assessed health of Americans aged 70 and older in the AHEAD study, independent of individual-level health and SES factors. This association with self-assessed health held even though the neighbourhood-level attributes were not independently associated with cardiovascular disease and functional status.(Wight, Cummings et al. 2008)

Frailty

In two cohorts of older Canadians, social vulnerability was moderately correlated with frailty, but was distinct from it. Both frailty and social vulnerability contributed independently to the risk of mortality.(Andrew, Mitnitski et al. 2008) Several social determinants of frailty were identified in an elderly Chinese population aged 70 and older; these included low SES (occupational category and inadequate income), having few or little contact with relatives and neighbours, low participation in community/religious activities, and reporting low social support.(Woo, Goggins et al. 2005)

1.4.4 MECHANISMS

Various mechanisms have been proposed to explain how social factors might affect health. Broadly speaking, these can be broken down into four groups: biological and physiological, behavioural, material, and psychological. Study of neurophysiology and neuroanatomy may also contribute to understanding the relationship between social factors and health.

Physiological

Chronic and sustained stress responses exert powerful effects on health through complex hormonal regulatory systems, with myriad downstream effects on tissues and organs. Various animal studies have found effects on the hypothalamic-pituitary-adrenal axis. Chronically elevated levels of glucocorticoids in socially isolated rats accelerate aging processes including hippocampal cell loss and cognitive impairment.(Berkman and Glass 2000) Social support has also been linked to immune function in both humans and animals, with social isolation and loneliness compromising immunocompetence even among otherwise healthy medical students.(Berkman and Glass 2000)

Behavioural

Socioeconomic inequalities (including employment and educational opportunities) and the norms and influences exerted through social networks and communities may affect health-related behaviours such as diet, smoking, substance use, and exercise. This may partially explain social influences on health, however, many studies in which these behaviours are taken into account find that social circumstances exert additional independent effects on health.(Berkman and Syme 1979; Blazer 1982; Kawachi, Kennedy et al. 1999; Berkman and Glass 2000)

Material

Socioeconomic status and social support networks clearly affect access to goods and services. This access accrues in three broad ways: through financial resources (what you have), social status (who you are), and social contacts (who you know). Those with financial means and high social status can afford to make healthy lifestyle choices (*e.g.* balanced diet, opportunities for exercise, avoiding smoking and substance abuse) and access health care services which may be difficult to obtain without such resources. There are also strong systemic and societal factors that serve to maintain the social exclusion of marginalized individuals and groups. Those with strong social support resources can access financial and instrumental assistance in time of need.

Psychological

Self-efficacy and adaptive coping strategies are important for health, and are some of the potential psychological mechanisms through which social factors may influence health.(Berkman and Glass 2000) Low self-efficacy (having low confidence in one's abilities) is associated with fear of falling, with important functional and mobility ramifications for older people.(Tinetti and Powell 1993) Low self-efficacy has also been found to predict functional decline in older people with impaired physical performance.(Mendes de Leon, Glass et al. 2003) Social supports and engagement may bolster feelings of self-efficacy and self-confidence.

Neurophysiology and neuroanatomy

Study of patients with neurological conditions has historically been a rich source of insight into the function of the brain and nervous system. Whereas the potential mechanisms discussed in the last few paragraphs attempt to explain how social circumstances themselves might influence health, here we consider the reverse; by studying people with neurological conditions including dementia we may be able to learn more about how the brain influences social factors like engagement, participation in social networks, and perceptions of others such as trust and reciprocity that are important to the idea of social capital. For example, some individuals with dementia become socially withdrawn and apathetic, suspicious and less trusting, or have other personality changes that influence their social function. Study of the localization and function (*e.g.* with functional imaging techniques as well as more traditional neuropathology) of such problems may add to the elucidation of the links between social function and social circumstances and health. This field is in its early stages, but as an example, "agreeableness" in frontotemporal dementia (which is often characterized by personality changes and problems with social function) has been shown to be positively correlated with the volume of the right orbitofrontal cortex and negatively correlated with left-sided orbitofrontal volume.(Rankin, Rosen et al. 2004) Animal studies may also contribute to this area of inquiry. For example, study of hyenas has shown that the four distinct species of hyenas can be placed on a continuum of increasing social complexity. Interestingly, the volume of the frontal cortex (as determined by internal measurements of their skulls) is directly proportional, with the hyenas that have the most complex social relationships having the greatest frontal lobe volumes.(Holekamp, Sakai et al. 2007)

1.4.5 FRAILTY, EXCLUSION, AND "SILENCE BY PROXY"

Older adults who are frail and/or cognitively impaired present a unique challenge for research in this field for many reasons. These include exclusion from research, reliance on proxy informants, problematic assessment of social situation and socioeconomic status, and controversy regarding informed consent.

Many frail older adults may be excluded from population-based research if the sampling frame excludes nursing homes (as is commonly the case) or if persons unable to answer for themselves are not included in surveys. Even if efforts are made to include these groups by using proxy respondents, subjective reports and personal historical details may be missing or unreliable.(Andrew 2005; Andrew 2005)

This "silence by proxy" presents great challenges in research involving frail elderly people, as it is often hardest to gather information from those who are the most frail, particularly in institutions where family may be unavailable to fill in historical details. One might imagine that social support and social interactions could be more relevant to health in frail older people, as they might be most reliant on family and friends for care and encouragement, and that benefits of social engagement could be greater in terms of mobility and optimizing function appropriate to their level of ability. As such, the associations found in studies from which they are excluded could be underestimates.

1.4.6 POLICY RAMIFICATIONS AND POTENTIAL FOR INTERVENTIONS

Although there are not many intervention studies in which social vulnerability is reduced and health outcomes studied, some studies do suggest hope in this regard. For example, there is evidence that participation in some types of voluntary groups may help to buffer the negative psychological effects of functional decline.(Greenfield and Marks 2007) Intervention trials with so-called "befriending services", in which social support is offered by a volunteer visitor, have had mixed results, possibly due in part to limited uptake.(Charlesworth, Shepstone et al. 2008) There is a large literature and clinical experience with structured peer support groups, for example those provided through various disease-specific community organizations; discussion of these is beyond the scope of this chapter.

One area in which social interventions have the potential to improve health is in the design of seniors' housing. Given the mounting evidence that social engagement and interaction with neighbours improves health, these principles could be brought to bear as housing developments and facilities for older people are designed, built, and renovated. Cannuscio has described such senior housing strategies as a "promising mode of delivery of social capital to the aging population" (p.395).(Cannuscio, Block et al. 2003) Long-term care facilities could be designed to encourage interaction among residents amongst themselves and within the wider community. Resident rooms spread out along long hallways, inaccessible to those with mobility impairment, might be replaced by rooms organized into pods around shared common areas.(Stansfeld 1999) "Planned care environments" in which a continuum of living arrangements from independent apartments though to full nursing care within a single complex might foster neighbourhood cohesion and reduce residential mobility, which has been shown to negatively impact the formation of social ties.(Lindstrom, Merlo et al. 2002; Cannuscio, Block et al. 2003) Community planning on a larger scale may also help to address many of the challenges to mobility and community interaction faced by older people. Sidewalks and crosswalks wide enough and in good enough repair to allow the use of mobility aids, traffic lights with cycles long enough to allow safe crossing, accessible public transportation, and availability of services in local residential neighbourhoods are strategies that benefit the health of people of all ages. As an example of taking such policy considerations to national and international levels, these issues are at the core of the World Health Organization's Age-Friendly Cities project.(WHO)

1.4.7 CONCLUSIONS

Although further research is required to clarify and contextualize the relationships between social circumstances and health in older adults, it is becoming increasingly clear that social factors exert great influence. Here, the various social factors that have been studied in relation to health have been reviewed, along with their relationship to the concept of overall social vulnerability. Specific associations with health outcomes that are important in Geriatric Medicine, including frailty, have been discussed.

The social vulnerability index approach has numerous advantages, including theoretical grounding in an understanding of the continuum of social influences on health and in relation to work on frailty, consideration of numerous different domains of social factors at once, and great potential for clinical applicability. From the point of view of clinical services providing care in Geriatric Medicine, the issue is not only which deficits an individual has, but how they add up to contribute to that person's vulnerability perturbations in their social environment, personal health, or functional state in ways that might predispose them to adverse outcomes. As such, a composite measure of social vulnerability may be a useful and potentially clinically relevant starting point to conceptualize the social circumstance of older adults whom we encounter in the course of clinical care. This points to the need for clinical operationalization and testing of such measures of social circumstances.

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Figure 1. The continuum of social factors that influence health, acting from individual to group levels

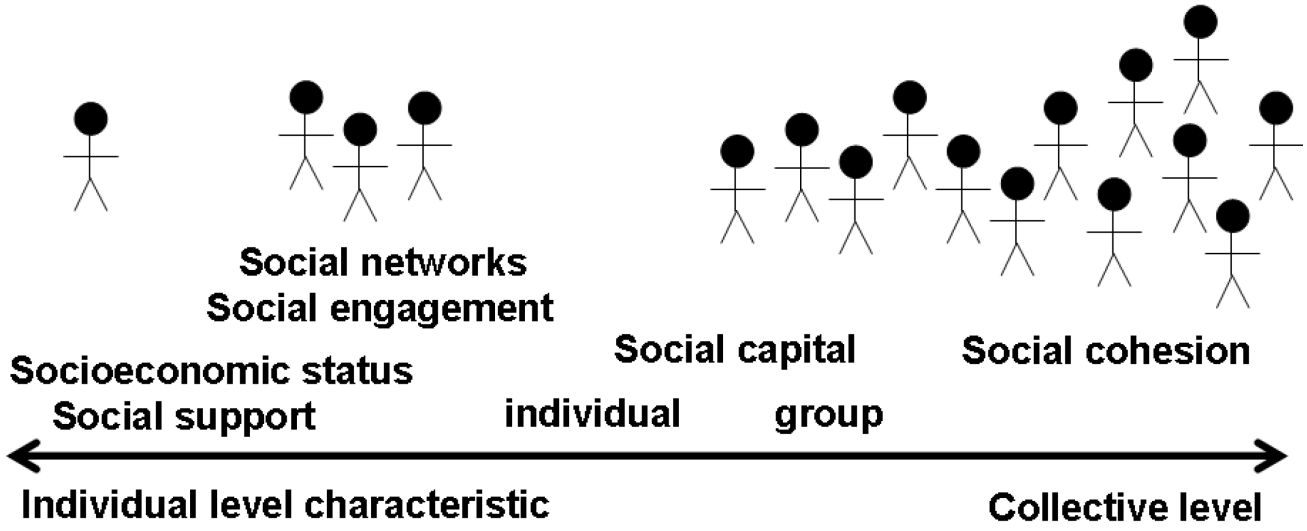

Table 1 Analytic approaches for studying social influences on health

Analytic approach	Benefits	Drawbacks
"One thing at a time"		
Single variables considered individually *e.g. size of the social network*	Simple and clear execution and interpretation	May result in overly simplistic understanding of associations
Combination of variables relating to the same theme *e.g. several variables describing social network*	Allows simultaneous investigation of several variables, adjusting for one another and for relevant confounders	- Validity considerations must be addressed - Models may become too complex with technical challenges *e.g.* collinearity
Validated measurement instrument *e.g. Lubben's Social Network Scale*	Use of standardized and validated instruments enhances reliability and validity	- Lengthy administration time - Rigidity - Use may be limited with existing datasets if difficult to reconstruct faithfully
"Many things at once"		
Index approach: deficit accumulation *e.g. social vulnerability index, frailty index*	- Takes many aspects of social circumstances into account simultaneously - Does not rely on use of single variables which may present measurement challenges in some older people - Related factors are not arbitrarily separated - Allows representation of gradations in exposure - Potential applicability to most datasets and clinical situations	- Represents risk relating to composite social circumstance rather than single identifiable factors in isolation - Complex modeling based on novel techniques
Options for studying the social context		
"Horizontal" analyses *e.g. multivariable regression modeling*	Simple and clear execution and interpretation	- May not provide a full understanding of the social context - Technical problems for models: observations not really independent
"Vertical" analyses *e.g. multilevel modeling, Hierarchical Linear Modeling*	- Yields more detailed understanding of contextual effects - Preserves independence of observations - Avoids loss of meaning due to data aggregation	- Complex models - Not all datasets lend themselves to these models; need sufficient numbers in groups with shared characteristics

CHAPTER 2 METHODS

2.1 STUDY DESIGN

This thesis is based on secondary analysis of three prospective cohort studies: the Canadian Study of Health and Aging (CSHA) (questions ii, iv), the National Population Health Survey (NPHS) (questions i, ii), and the Gothenburg H70 Study (question iii). Figure 2 provides an overview of the study questions, as well as the study cohort and methods used to address each question.

2.2 SUBJECTS AND SETTINGS

2.2.1 CANADIAN STUDY OF HEALTH AND AGING

The Canadian Study of Health and Aging (CSHA) is a representative study of dementia and related conditions in Canadians aged 65 and older. At baseline, participants (N=10,263, of whom 9,008 were community-dwelling) were sampled in a population-representative manner from English- and French-speaking older Canadians, though those living in the Yukon or Northwest Territories, residents of Aboriginal Reserves or military bases, and those with an immediately life-threatening illness were excluded. The sample was clustered within five Canadian regions and stratified by age, with over-sampling of those aged 75 and older. The baseline data collection occurred in 1991, with follow-up at 5 (CSHA-2) and 10 (CSHA-3) years.(Rockwood, McDowell et al. 2001)

Figure 3 illustrates the CSHA study design and flow of participants between various data collection points. After the initial screening interview that was conduced with community-dwellers, some were invited to have a detailed clinical assessment. This included those who had screened positive for cognitive impairment, scoring <78 on the Modified Mini Mental State Examination, as well as a random sample of participants with 3MS ≥78. All residents of institutions went directly to clinical examination. At

CSHA-2 and CSHA-3, screening interview and clinical examination groups were similarly selected, with those screening positive for cognitive impairment, a random sample of cognitively unimpaired individuals, and all who had undergone clinical assessment in the previous wave being invited to the detailed clinical assessment.

For the work on social vulnerability being reported in this thesis, the CSHA-2 screening interview was used as the baseline because it was enriched in data about social factors. The CSHA-3 provided five-year follow-up. The complete CSHA data collection was very comprehensive; in addition to the screening interviews and clinical examinations, it included data sets on risk factor identification, medication lists, caregiver interviews, decedent interviews with family members of deceased participants, and neuropsychological testing. The current analyses used the screening, clinical and neuropsychological datasets.

2.2.2 NATIONAL POPULATION HEALTH SURVEY

The National Population Health Survey (NPHS) is a panel survey administered by Statistics Canada, which samples Canadian residents of all ages. Survey waves were conducted every two years starting in 1994; the most recent follow-up wave available for analysis in this thesis was 2004 (10 year follow-up). The sample was stratified according to geographic and socio-economic characteristics and clustered by Census Enumeration Area. Residents of aboriginal Reserves, Canadian Forces Bases, and some remote areas of Northern Canada were excluded.(Singh, Tambay et al. 1994) For the analyses reported in this thesis, participants aged 65 and older at the time of the baseline data collection were selected.

NPHS datasets were accessed through an agreement with the Statistics Canada's Atlantic Regional Data Centre, which obliged the author to operate, for these purposes only, as a "deemed employee" of Statistics Canada. Statistics Canada officials reviewed the analyses to ensure that confidentiality had not been breached. The structure of the NPHS

is outlined in Figure 4. The structure of the datasets released by Statistics Canada is such that one must choose the dataset comprising participants in the baseline year of choice (in this case 1994) who were also participants or accounted for, including those who had died or moved to institutions, at the final follow-up wave (a "longitudinal square" dataset), though they did not have to have participated at all of the intervening waves. For the paper with eight year follow-up (presented here in Chapter 3), the dataset comprised 3143 individuals who were interviewed in 1994 and were accounted for eight years later in the 2002 wave. For the paper with ten year follow up (presented here in Chapter 2), the dataset comprised 2740 individuals aged 65 and older who were accounted for in the 2004 wave.

2.2.3 GOTHENBURG H70 STUDY

The Gothenburg H70 Study is a multidisciplinary study started with the aim of studying health and health-related factors in older people. Samples were systematically obtained, based on birth dates, from the Swedish Population Register, which covers names and addresses of all people living in Sweden. A representative sample (30%) of 70-year olds living in Gothenburg, Sweden (in both private households and institutions) was invited to participate in baseline data collection in 1971-72.(Steen and Djurfeldt 1993) Detailed interviews and clinical examinations were conducted thereafter at numerous time intervals; the analyses reported in this thesis are based on the 5- and 9- year follow up data at ages 75 and 79. The structure of the H70 study is outlined in Figure 5.

2.3 REFERENCES

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Singh, M. P., J. L. Tambay and S. Krawchuk (1994). The National Population Health Survey: Design and issues. Ottawa, Statistics Canada.

Steen, B. and H. Djurfeldt (1993). "The gerontological and geriatric population studies in Gothenburg, Sweden." Zeitschrift fur Gerontologie **26**(3): 163-9.

2.4 GRAPHICS

Figure 2. Overview of the research questions addressed in the current thesis, indicating datasets and methods used for each study.

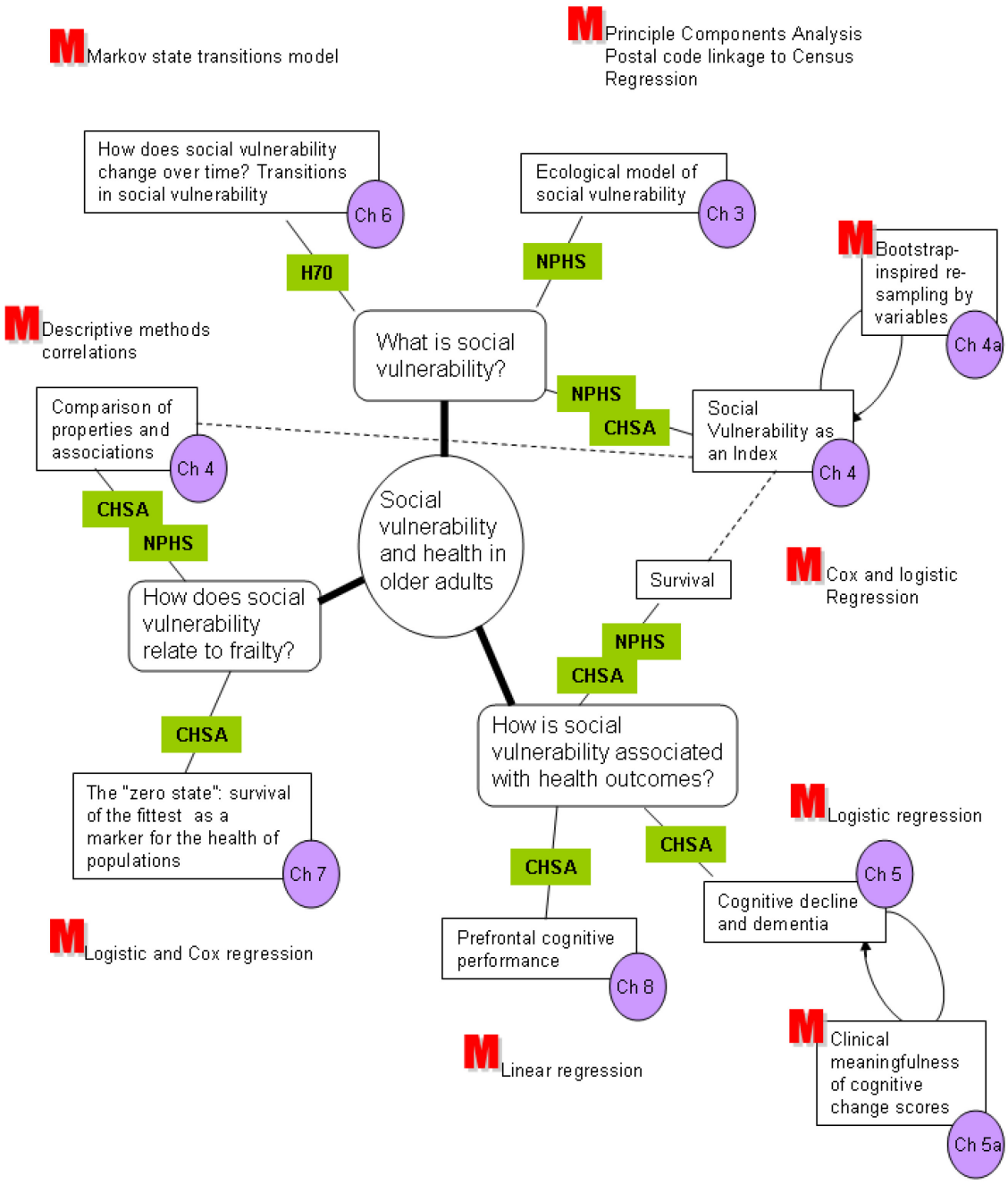


Figure 3. Flow of participants through the Canadian Study of Health and Aging (CSHA).

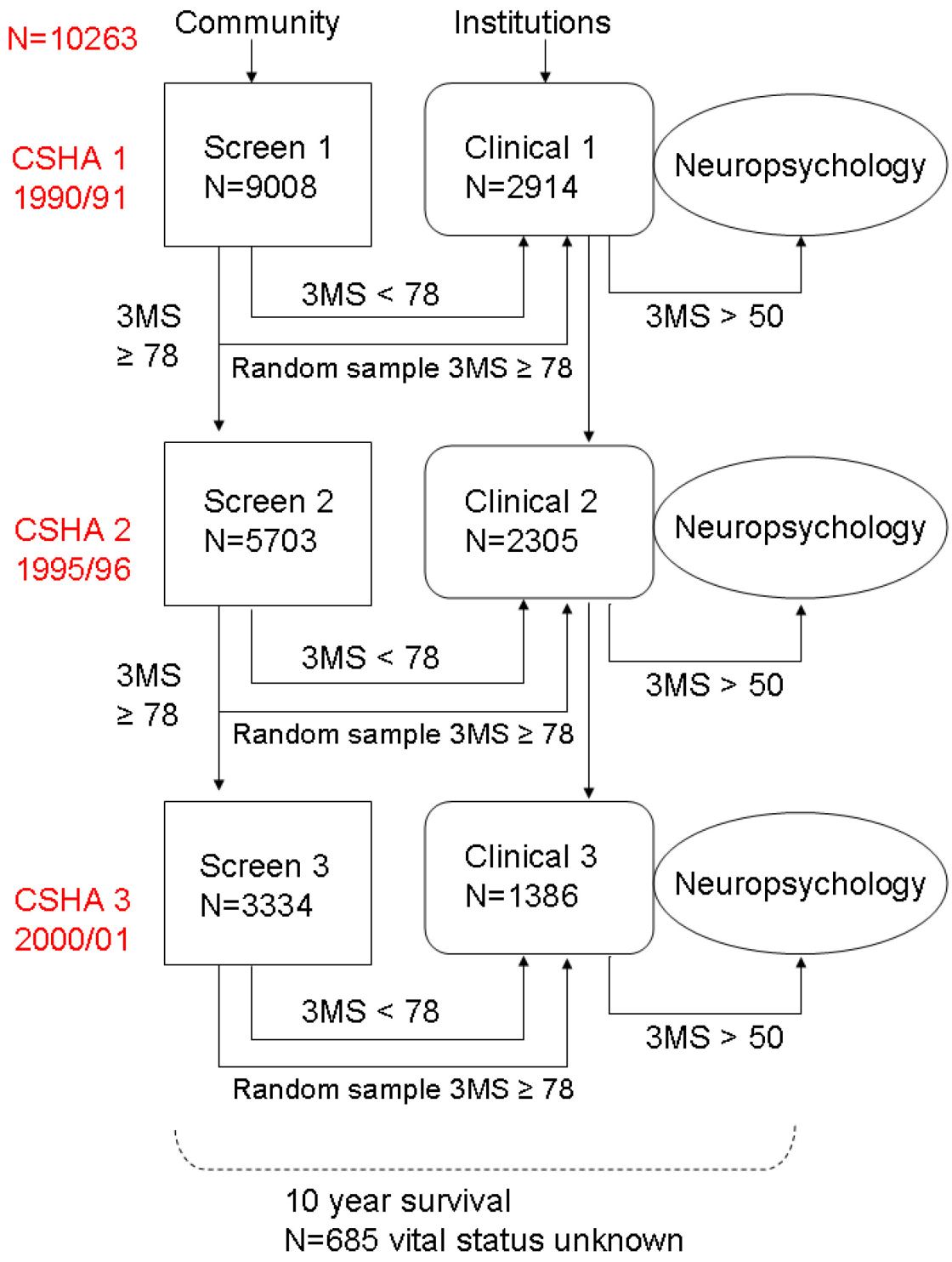


Figure 4. Design of the National Population Health Survey.

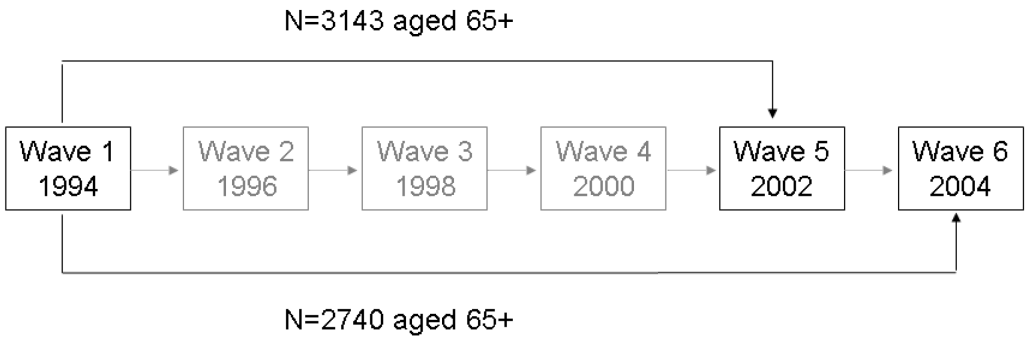
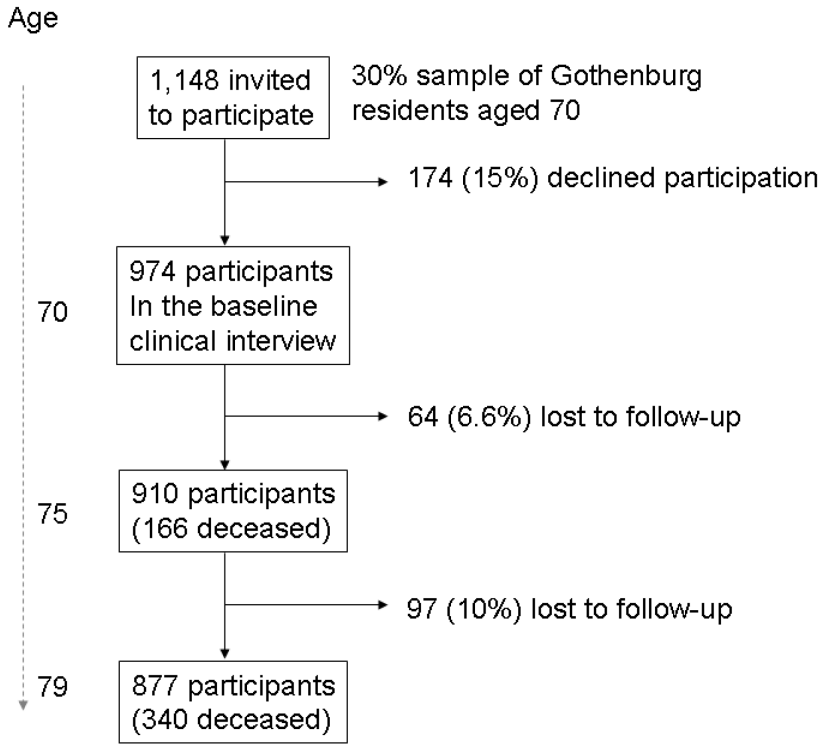


Figure 5. Participant flow in the Gothenburg H70 study.



CHAPTER 3 SOCIAL VULNERABILITY AMONG OLDER ADULTS: A SOCIAL ECOLOGY PERSPECTIVE

3.1 PROLOGUE

As reviewed in Chapter 1, associations between social factors and health have commonly been studied one at a time, often without situating them in a broader social context. The study presented in the current chapter employed a traditional Principal Component Analysis to study inter-relationships between many different social factors in the National Population Health Survey. Emergent dimensions of social vulnerability were then situated within a social ecology framework, in order to give social context its due.

As the study showed, associations between these dimensions were complex, setting the stage for the idea that a holistic construct of social vulnerability, such as the social vulnerability index presented here, provides a way forward for further study of the importance of social circumstances to older people's health.

3.2 MANUSCRIPT DETAILS

Andrew, M. and J. Keefe "Social vulnerability among older adults: a social ecology perspective from the National Population Health Survey of Canada." Ms. submitted.

3.3 SOCIAL VULNERABILITY AMONG OLDER ADULTS: A SOCIAL ECOLOGY PERSPECTIVE FROM THE NATIONAL POPULATION HEALTH SURVEY OF CANADA

3.3.1 ABSTRACT

Numerous social factors have been associated with health, though most studies have investigated single factors in isolation. We sought to investigate many social factors in relation to one another and to survival among older adults using a social ecology perspective. 2740 adults aged 65+ were followed for ten years in the Canadian National Population Health Survey (NPHS). Twenty-three individual-level social variables were taken from the 1994 NPHS and four Enumeration Area (EA)-level variables were abstracted from the 1996 Canadian Census using postal code linkage. Using Principal Component Analysis, seven dimensions emerged: engagement, contextual socio-economic status, social support, living situation, self-esteem, mastery, and relations with others. These were situated within a social ecology model with inter-connected spheres of influence from the individual through close family & friends, wider peer networks, neighbourhoods, institutions, and society at large. Vulnerability in each dimension was studied in relation to vulnerability in the others and to ten-year survival. Only vulnerability in the engagement dimension independently predicted mortality in a logistic regression model including all seven dimensions, age, sex, frailty, and education (OR 1.17; 95% CI:1.04-1.31, p=0.007). We conclude that a social ecology perspective provides a way forward for holistic study of social vulnerability among older adults.

3.3.2 INTRODUCTION

What is social vulnerability?

Many social factors, including socioeconomic status, deprivation, mastery and sense control over life circumstances, social support, social isolation or exclusion, social networks, social engagement, social capital, and social cohesion have the potential to influence health, and have been the subject of numerous investigations.(Blazer 1982; Schoenbach, Kaplan et al. 1986; Seeman, Berkman et al. 1993; Marmot and Shipley 1996; Kawachi, Kennedy et al. 1997; Bassuk, Glass et al. 1999; Putnam 2000; Mendes de Leon, Glass et al. 2003; Fratiglioni, Paillard-Borg et al. 2004; Andrew 2005; Woo, Goggins et al. 2005; Scharf, Phillipson et al. 2007; Andrew 2010) The topic is of interest to researchers and practitioners within several different disciplines (including epidemiology, sociology, geography, political science, gender studies, gerontology, social work, behavioural psychology, and medicine among others). Perhaps because of the differing approaches and literatures of these disparate disciplines, methodology and terminology have differed widely. In many senses, this breadth of approaches has the potential to enrich the field (e.g. qualitative and quantitative approaches are each well-suited to addressing different research questions, as are individual-level and ecological studies and units of analysis).

Although, and perhaps because, social factors have the potential to merge and interact in complex and possibly unforeseen ways to create the "big picture" of social environments and circumstances in which individuals and communities live and exist, individual social factors have tended to be studied in isolation. While this adds to our understanding of which factors independently influence health outcomes, the big picture may be compromised by this artificial fragmentation. Further complicating matters for those who seek to transcend disciplinary boundaries, terminology has also varied, such that in some instances the same terminology may be used to refer to different ideas, while in others, divergent terminology obscures underlying commonalities.(Andrew 2005; Andrew 2010)

The level of influence at which the various social factors act and are measured is also important. Some social factors are properties of individuals, while others are relevant at the group level, inhabiting a spectrum from the close family unit through to wider peer groups, neighbourhood influences, and the social cohesion of societies.(Andrew 2010)

A unified view of social influences on health is thus attractive for both descriptive understanding of social circumstances as they relate to heath and for planning interventions and policies to address social risk factors that may be modifiable. Such a unified view would aim to capture "social vulnerability", the degree to which a person's overall social situation leaves them susceptible to further health-related insults. Considered in the inverse, social reserve would be the degree of resilience that a well-connected and supportive social situation might impart. In this paper we aim to develop this concept of social vulnerability in old age, to situate it in the context of a human ecology theoretical framework, and to apply a theoretical model based on an ecological perspective of social vulnerability to an analysis of data from a longitudinal health survey of older Canadians.

Theoretical perspective

Social vulnerability can be considered at various levels of influence from individual to close family, wider network, and societal context framework that explicitly considers these different levels of influence is therefore desirable. The human ecology perspective, originally proposed by Bronfenbrenner, is a reasonable candidate that fulfills this requirement.(Bronfenbrenner 1979) Bronfenbrenner described a system of nested interconnected layers of influence from the individual (molar) level through the "dyad, role, setting, social network, institution, subculture, and culture" (p.8) and argued that this explicit consideration of the individual within micro- and macro-systems allows basic science and public policy to be reciprocally integrated (rather than having a one-way informing of policy by basic science).(Bronfenbrenner 1979)

The ecological perspective has been criticized as being a static and rigid descriptive model that is not seen as being responsive to change over time. If this were true, this would pose a problem for the conceptualization of social vulnerability, which is inherently dynamic and subject to changes in circumstances over both short (e.g. sudden changes in an individuals need for support that may or may not be met within their support network, death of a spouse or caregiver) and long (e.g. gradual weakening of a social network, gradual declines in ability to engage in peer social groups) time frames. We argue that the ecological framework need not be understood in this static way – in fact, we see it as a dynamic model, in which change occurs over time and which can, importantly, be modifiable through directed intervention to mitigate/reduce social vulnerability. Given our explicit focus on social factors from both individual and neighbourhood levels of analysis within this framework, we refer to it hereafter as a social ecology perspective. In doing so, we aim to acknowledge the agency of older persons themselves in the dynamic in play among the different layers of individual, family/peer group, community and society.(Keating and Phillips 2008)

In this study, we conceptualize social vulnerability within a social ecology framework and construct and populate an ecological model of social vulnerability with empirical data. We then use this theoretical framework to discuss potential interventions at the various levels of influence (from individual to societal) that may be helpful in efforts to reduce social vulnerability among older people.

3.3.3 METHODS

SAMPLE

The National Population Health Survey (NPHS) is a longitudinal panel survey of Canadian residents of all ages administered by Statistics Canada. The survey is based on self-report or proxy-respondents; there was no clinical data collection. The baseline data collection was in 1994, and the same sample was re-interviewed at two-year intervals; to date, ten-year follow-up is available. The sampling design was clustered by Census Enumeration Areas and stratified according to geographic and socioeconomic characteristics.(Singh, Tambay et al. 1994) 2740 participants were aged 65 or older in 1994 and were followed for 10 years; these individuals comprised the sample for this analysis.

MEASURES

Self-report variables pertaining to social factors with plausible health associations based on literature reviews were identified in the NPHS dataset.(Andrew, Mitnitski et al. 2008; Andrew 2010) Twenty-three social variables were indentified and included in our analyses (Table 2). Each variable was coded in terms of potential social "deficits", such that respondents were assigned a score of 0 if the deficit was absent and 1 if it was endorsed, with intermediate values applied in the case of ordered response categories.(Andrew, Mitnitski et al. 2008) For example, an individual scored 1 on the "living alone" deficit if he/she reported living alone, and 0 if he/she did not. On the "how often do you participate in group activities" item, which had five response categories, possible scores were 0 if the answer was "at least once a week", 0.25 for "at least once a month", 0.5 for "at least 3 or 4 times a year", 0.75 for "at least once a year" and 1 for "not at all". In this way, vulnerability on each item was mapped to the 0-1 interval and the scores were summed and divided by the total number of deficits considered (23) to create a summary social vulnerability index. Emergent factors from a Principal Component Analysis were identified as domains of social vulnerability. The 0-1 scores for the social variables that loaded onto each of these emergent factors were summed for each NPHS participant to generate a measure of his or her vulnerability for each domain.

Covariates considered were age (in years, with the sample being aged 65+), sex, educational attainment measured using the Statistics Canada four-level derived variable (less than secondary schooling, secondary school completed, some post-secondary education, and completed post-secondary education) and frailty.

Health and functional status are clearly important to any consideration of social vulnerability; here frailty was chosen as a comprehensive construct. There are many possibly views and definitions of frailty.(Hogan, MacKnight et al. 2003; Rockwood, Song et al. 2005; Grenier 2007) For the most part, such disparate views are unified in viewing frailty as a state of increased susceptibility to health, functional, or social insults. Here, frailty is understood in this way as a state of susceptibility, and is operationalized using a deficit accumulation approach, where the number of problems that an individual has is summed to create a summary frailty index measure.(Mitnitski, Song et al. 2004; Rockwood, Andrew et al. 2007) The frailty index comprised 35 health deficits, including sensory and functional impairments, symptoms, and illnesses, with coding analogous to the social vulnerability index described above. As such, the frailty index is based on a count of health deficits, and represents the number of health-related problems that a person has, as a proportion of the total number of deficits considered in the index. The NPHS frailty index has been previously validated, and is robustly predictive of mortality.(Mitnitski, Song et al. 2005)

Neighbourhood-level variables

Individual participants were linked to their Enumeration Area (EA) of residence using postal codes. This was done using the Statistics Canada Postal Code Conversion File "plus" (PCCF+), which has been designed to rigorously assign postal codes to geographical areas units based on the best available data with built-in troubleshooting and detection of errors.(Wilkins 2002) The 1996 census was chosen to be as closely contemporaneous to the time of data collection as possible. EAs (now called Dissemination Areas since the 2001 census) are the smallest units of census geography aggregation for which data are released, and including an average of 400-700 individuals.(Gonthier, Hotton et al. 2006) Both the PCCF+ and the raw census data were

obtained through the Data Liberation Initiative.(http://www.statcan.gc.ca/dli-ild/dli-idd-eng.htm) Characteristics of the EAs were based on a 20 per cent subsample of residents who completed a more detailed "long form" questionnaire, and were downloaded using the online Census Data Analyser; each EA was assigned to a quintile of income, income inequality, education, unemployment, and caregiving for seniors based on the raw counts for each EA reported in the census.

Income quintiles were based on within-area comparisons rather than on national absolute values. This was done in order to take regional differences in income norms and cost of living into account. This variable has been previously developed and used for the Canadian Census, and was obtained from the author of the PCCF+.(Wilkins 2002) Coding was such that 1 represented the lowest income quintile and 5 the highest.

Income inequality quintiles were generated from the standard error of income within each EA. Income inequality was coded such that 1 was the most unequal and 5 the most equal. Income inequality was examined because of evidence from other studies that inequality, even within neighbourhoods, can have negative consequences for health.(Wilkinson 1996)

Educational attainment within the EA was calculated based on the proportion of adult respondents who reported having completed high school; each EA was assigned a quintile of educational attainment coded from 1 (lowest proportion of high school completers) to 5 (highest).

The proportion of unemployment among census respondents aged 25 years and over was used to divide Enumeration Areas into quintiles of unemployment from 1 (lowest unemployment) to 5 (highest).

The caregiving for seniors variable took into account both the number of adult respondents who reported having provided any regular unpaid care to an older person (as a proportion of the total adult population of the EA) and the proportion of the EA's

population that was over the age of 65. Each EA was assigned a weight in relation to the mean 65+ population for all EAs such that EAs with a larger proportion of seniors would have a weight value >1 and those with fewer seniors as a proportion of their total population would have a weight <1. This allowed the proportion of respondents who reported themselves as care-providers to be adjusted for the ambient numbers of seniors by dividing by the senior population weight. This was done in order to ensure that the caregiving variable measured altruistic caregiving behaviour rather than just providing a measure of the relative numbers of seniors "available to be cared for" in each EA.

STATISTICAL METHODS

Descriptive and regression analyses were done using Stata 10.1; SPSS 15.0 was used for factor analysis. Factor loadings were calculated using Principal Component Analysis with Varimax rotation. Seven factors were specified based on examination of the scree plot. Associations amongst the seven dimensions of social vulnerability, and of each dimension with the age, sex, frailty, and education, were studied using linear regression models. Associations between the seven dimensions of vulnerability and ten-year mortality were investigated using logistic regression and Cox regression models. All regression models were adjusted for covariates with *a priori* significance (age, sex, frailty, and education). The proportionality of hazards assumption was tested graphically and using Schoenfeld residuals. Proportional sampling weights were used to account for sample design.(Singh, Tambay et al. 1994)

3.3.4 RESULTS

The mean age was 73.4 years (95% CI: 73.0-73.7), and 57 per cent of the sample were women. Educational attainment was low, with 54 per cent of the sample having attained less than primary schooling. The mean frailty index score in this sample of community-dwelling older adults was 0.11 (95% CI: 0.10-0.11), which is not frankly frail according to the published cut-off of 0.2-0.25.(Rockwood, Andrew et al. 2007; Kulminski, Ukraintseva et al. 2008) At 10 years, 1437 (52%) of the 2740 individuals in the sample had died.

Complete data for the social vulnerability variables was available for 2058 individuals; 682 were missing data for at least one social variable. Those who had missing social data were older ($p=0.01$) and more frail ($p=0.05$).

Seven factors emerged from the Principal Component Analysis, explaining 47.0 per cent of the total variance.(Table 3) As outlined in Table 2, the seven dimensions were self-esteem, mastery, living situation, engagement, in social activities, social support, relations with others, and contextual SES. Two variables, educational attainment and language (ability to speak English or French) do not load to a single factor. Figure 6 shows the populated ecological model of social vulnerability with the seven identified dimensions of social vulnerability located across spheres of influence from the individual, to close family and friends, wider peer groups, institutions, community, and society. Of note, some dimensions span spheres, whether adjacent (in the case of living situation, which incorporates individual as well as close family spheres) or more distant (as is the case for engagement with others, which is relevant for both the family & friends as well as neighbourhoods/communities spheres).

Associations amongst the dimensions of vulnerability were studied using linear regression models, adjusting for age, sex, education and frailty. As shown in Table 4, vulnerability in several of the dimension-pairs was associated, independent of the covariates considered. Associations in vulnerability were identified between the

following pairs of dimensions: self-esteem with mastery and relations with others; mastery with self-esteem, living situation, social support, and relations with others; living situation with mastery, social support, social engagement, and contextual SES; social support with mastery, living situation, social engagement, and relations with others; social engagement with living situation, social support, social engagement, and relations with others; relations with others with all dimensions except living situation and contextual SES; and contextual SES with living situation. All associations had positive regression coefficients, indicating that vulnerabilities generally trended together across dimensions.

Vulnerability in each dimension was explored in relation to the four covariates considered: age, sex, education, and frailty. (Table 5) Women reported lower vulnerability in social engagement and social support, but were more vulnerable in terms of their living situation (living alone and being single or widowed) ($p<0.001$). Vulnerability in living situation and mastery increased with increasing age (both $p<0.001$). Higher levels of frailty were associated with more vulnerability in the engagement, mastery, and self-esteem dimensions (all $p<0.001$). Older adults with lower education reported more vulnerability in four of the domains: engagement, mastery, contextual SES (all $p<0.001$) and self-esteem ($p=0.01$).

When vulnerability in each dimension was studied in relation to mortality, low engagement, low self-esteem, and low mastery each predicted mortality independent of age and sex. Only low engagement remained statistically significantly associated with mortality when the logistic regression models were further adjusted for frailty and education.(Table 6)

Vulnerability in engagement (OR 1.21, 95% CI:1.09-1.36, $p=0.001$) and self-esteem (OR 1.69, 95% CI:1.07-2.67, $p=0.025$) both predicted 10-year mortality in a logistic regression model that included all seven dimensions as well as age and sex, but again only vulnerability in the engagement dimension independently predicted mortality in a model that also included frailty and education (OR 1.17; 95% CI:1.04-1.31, $p=0.007$).

Cox regression modeling yielded the same result, with vulnerability in the engagement dimension independently predicting mortality (HR 1.15, 95% CI: 1.07-1.23, $p<0.001$). Testing of the proportional hazards assumption revealed no problems with the assumption of proportionality of hazards in this model.

All of the 23 social variables (including all of the seven dimensions of vulnerability plus language ability and education, which had not loaded onto any dimension) were summed to generate a social vulnerability index. Adjusting for age, sex, and frailty, increasing social vulnerability was associated with increased odds of mortality over ten years in a logistic regression model (OR 1.05, 95% CI: 1.00-1.10, $p=0.04$). These results mean that for every additional social deficit, an individual's odds of mortality increased by 5 per cent. Similar results were obtained using Cox regression (HR 1.04, 95% CI:1.01-1.07, $p=0.01$).

3.3.5 DISCUSSION

We identified seven dimensions of social vulnerability (self-esteem, mastery, living situation, social support, engagement, relations with others, and neighbourhood SES) in a sample of 2740 older Canadians and situated them within a social ecology framework of social vulnerability. Vulnerability in several pairs of dimensions was associated; not all of these were within single or adjacent spheres of influence in the ecological framework. In a regression model that included all dimensions and adjusted for age, sex, education, and frailty, only vulnerability in the engagement dimension was independently predictive of mortality.

We found that many of the dimensions of social vulnerability were inter-related, and in all cases increased vulnerability in one of the pair was associated with increased vulnerability in the other (i.e. regression coefficients were positive). Interestingly, these associations were not limited to adjacent spheres in the ecological model. This suggests that the spheres of influence are likely intertwined rather than clearly distinct from one

another. For example, vulnerability in mastery (an attribute of the individual) was strongly associated with vulnerability in living situation (living alone and being widowed), lack of social support, and weak relations with others (few visits with friends and relatives and living in a neighbourhood with low caregiving for seniors). Notably, living alone and without a partner (being single or widowed) was associated with *increased vulnerability* in mastery and social support. This may run counter to the commonly held view that older people who live alone are self-reliant and independent; under such a view we might have expected those who live independently to have better mastery and greater social supports and would thus have lower vulnerability in these other dimensions. Our finding that living alone and without a marital partner is associated with lower mastery, social support, and social engagement is all the more interesting when viewed in this light. That older people who are widowed or single and live alone live in lower socioeconomic neighbourhoods is unfortunate but not surprising, given their over-representation amongst the lowest income earners in society. (National Advisory Council on Aging (2005))

Exactly which factors should contribute to the construct of social vulnerability is debatable. Since our aim was to be as holistic as possible, we included self-esteem and mastery, though it could be argued that these are psychological traits and not social factors. There is considerable evidence that one's sense of control over life circumstances is an important contributor to both social status and health.(Marmot 2004) The individual's view of themselves is also relevant to their interactions with others; leaving this out would contribute to the continued fragmentation of investigation into how social factors are related to health. Our finding that vulnerability in the self-esteem and mastery domains was associated with vulnerability in other domains supports their inclusion in the comprehensive conceptual model that we propose.

Associations between the seven dimensions of vulnerability and the covariates age, sex, frailty, and education yielded some results that may help to clarify differences in social vulnerability as faced by members of different groups of older adults (i.e. the oldest old, women, those with low education, and those who are frail). Those with lower education

reported lower engagement, self-esteem, mastery, and had lower contextual SES (the measure of which included neighbourhood educational attainment). This is consistent with existing literature concerning the importance of education across many social measures.(Dalgard, Mykletun et al. 2007; Browning, Sims et al. 2009) The more frail reported lower self-esteem and mastery, which support assertions of the global importance of frailty and function on peoples' self-conceptualization.(Hogan, MacKnight et al. 2003) This finding is also consistent with existing literature reporting a link between functional disability, comorbidity, and low mastery.(Jang, Chiriboga et al. 2009) That the more frail had lower levels of engagement in social activities is not surprising: given the functional and illness elements within the definition of frailty, those who are ill and functionally impaired would likely have a more difficult time travelling to and participating in such activities. This being the case, it is all the more remarkable that we have identified an association between social engagement and improved survival that is independent of frailty. The oldest old reported more vulnerability in mastery and were more likely to be vulnerable in their living situation (widowed and living alone). Here, women had higher reported engagement and social support but were more vulnerable in their living situation (*i.e.* living alone and being single or widowed). Previous analyses using the social vulnerability index have found that women are more socially vulnerable then men, and that in both sexes, higher social vulnerability predicts mortality independent of age and frailty.(Andrew, Mitnitski et al. 2008) The present analysis of the individual domains of social vulnerability helps to clarify this point; although women may have higher social support and engagement, the added impact of widowhood and living alone seems to drive their higher levels of overall social vulnerability. This finding suggests that sex differences in social vulnerability profiles warrant further study.

Social engagement was the only dimension that was independently predictive of mortality at 10 years. The engagement measures included participation in social groups, volunteer activities, religious services, and physical leisure activities. Exercise is known to have survival benefit, and it is possible that the impact of exercise may drive this association. This possibility was investigated using a sensitivity analysis, in which vulnerability in the engagement domain was re-calculated excluding the physical activity

item. Engagement defined in this way remained statistically significantly associated with mortality, independent of age, sex, frailty, and education (OR 1.18, 95% CI:1.06-1.31, p=0.003). The association was somewhat attenuated with the exclusion of exercise, which suggests that exercise, particularly exercise with a potential for socialization (as was considered in this item) is important. Notably though, the association was independent of frailty, which makes the possibility of "reverse causation" less likely – i.e. the association between not participating in socially engaging activities and mortality is not simply because frail individuals are less able to participate and more likely to die. Interestingly, lower mastery was associated with mortality independent of age and sex, but this association was confounded by frailty and education. This suggests that frailty and education may be importantly related to mastery.

Our findings should be interpreted with caution. All measures were based on self-report in a large social survey. It is possible that this subjective perception of social vulnerability may differ from an assessment that is based on more objective measures. However, it is also conceivable that a person's self-perception of their social circumstance may contribute to their social vulnerability in important ways that are independent of the objective set of circumstances. Additionally, although the ecological model of social vulnerability considers spheres of influence at group (family, peer) and community (institutions, neighbourhoods, and society) levels, all measures were based on individual-level data. Even the census measures (relative educational attainment, income, income inequality, and community caregiving for seniors), while not originating directly from the individual NPHS participants, were aggregated at the Enumeration Area level from individual responses to the 1996 census. Although there is debate surrounding the level, from individual to communal, at which some elements of the social context are relevant, and as such, how they can be measured.(Lochner, Kawachi et al. 1999; Baum and Ziersch 2003; Andrew 2005). Ideally some group-level measures would have usefully expanded the model, though these are difficult to obtain. Some suggestions in the literature include assessments of neighbourhood orderliness (e.g. lack of graffiti and litter, few abandoned buildings), civic engagement (e.g. rates of voting and newspaper subscriptions) and trust (e.g. gas stations not requiring payment prior to gasoline

pumping) but these measures were not available here.(Putnam 2000) The paucity of true ecological measures represents an identified challenge for study of social environments and health.(Lochner, Kawachi et al. 1999; Baum and Ziersch 2003) In a related issue, the true societal level was not well represented in our data. Ideally, including an analysis of regional policies might strengthen discussion in regard to the societal sphere of influence.

Individuals missing the social vulnerability variables were more likely to be older and more frail. Self-report data of this nature in older adults is commonly missing for those in whom proxy respondent is used. This "silence by proxy" is therefore a limitation of studying self-reported issues in frail older people, as the frailest (and arguably those for whom assessment and intervention for social vulnerability may be of greatest import) may be unable to answer for themselves.(Andrew 2005; Andrew 2005) Given this, our estimates of the importance of social vulnerability may be conservative. In particular, associations with mortality may well be conservative given that social vulnerability tends to increase with age and frailty.(Andrew, Mitnitski et al. 2008)

The low percentage of variance explained by seven identified dimensions of social vulnerability supports the idea that social vulnerability is a global construct that does not lend itself well to being parsed into bits for separate analysis. The holistic importance of social vulnerability is also supported by our finding that the full social vulnerability index, which combined all of the social variables, was predictive of mortality. This is consistent with previously published findings using the social vulnerability index.(Andrew 2008) It also highlights a challenge for policy making, in that it may be difficult to appropriately design and target interventions to address overall social vulnerability. Few strategies have been proven to enhance social capital, or to reduce social vulnerability, though few such interventions have been rigorously studied in relation to health outcomes to date, and further research is warranted. The ecological perspective presented here provides a framework for considering potential policy interventions.

At the individual level, potential interventions might include educational opportunities (throughout the life course), pension support with a guaranteed "living wage", empowerment strategies (which may be generalized or targeted to specific contexts), sensible medical care and supportive care to address frailty, interventions to address disability (e.g. Occupational Therapy, mobility aids, and help where needed for Activities of Daily Living). At the level of close family and friends, policies to support caregivers might help to enhance social support, as might facilitation of opportunities to interact with friends, for example though provisions of common space in living facilities. Policy-backed support for community groups, and provision of common space for formal and informal socializing could help to strengthen peer group engagement, as would transportation initiatives to help facilitate the participation of older people in community groups.

At the institutional level, design of seniors' housing is important, with common spaces for socializing, and facilities containing the spectrum of care so individuals can remain within the same complex if they want to.(Cannuscio, Block et al. 2003) Neighbourhood initiatives that enable residents to take pride in their community and initiatives to enhance social cohesion in the neighbourhood would be potentially helpful on the community level. Age-friendliness of communities is also important, for example walkable sidewalks that are navigable for mobility aids, crosswalks with enough time to safely cross the street, senior-friendly public transportation, and benches to sit and take rests. Societal initiatives that may be helpful to reduce social vulnerability could include sustainable pension policies that do not disadvantage women and part-time workers, policies to support caregivers, and enhancing age-friendliness of infrastructure and transportation options. For example, the age-friendliness of cities is being investigated and evaluated as part of a World Health Initiative.(WHO 2007) Furthermore, as part of the same project, age-friendly initiatives for rural and remote areas are being tested in four Canadian provinces (British Columbia, Manitoba, Nova Scotia, and Quebec).

Of note, there is considerable overlap in the spheres of influence within the ecological model that many of these interventions could influence, which again highlights the inter-relationship and inter-connectedness of the different levels from individual to society. For example, caregiving and support within a family or peer group relies on the individual's willingness to receive support, and also relates to norms of caregiving behaviour within the broader community. Policies that seek to support caregivers could thus be facilitatory or encounter barriers at numerous levels of the ecological model. From a policy perspective, our findings also raise the question of whether it is better to implement a number of narrowly focused policies, each aimed at a different issue in a different part of the ecological model, or a single "omnipolicy" which is comprehensive and complex.

FUTURE DIRECTIONS

Additional study in other samples and settings, ideally with different types of methodologies and measures, stands to further understanding of social vulnerability among older people. We have proposed a social ecology model of social vulnerability which may serve as a useful framework for future studies and interventions addressing this important issue.

3.3.6 ACKNOWLEDGEMENTS

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3.3.8 GRAPHICS

Table 2. Variables included in the social vulnerability model, and the domains to which they loaded in the Principal Component Analysis. EA = Enumeration Area.

Self-esteem
- Feel that you are a person of worth at least equal to others
- You take a positive attitude towards yourself

Mastery
- Too much is expected of you by others
- You would like to move but cannot (control/empowerment)
- Neighbourhood or community is too noisy or polluted
- You have little control over the things that happen to you
- How often have people you counted on let you down?
- Not enough money to buy the things you need (income)

Living situation
- Marital status
- Lives alone

Social support
- Someone to count on for help in crisis
- Someone to confide in
- Someone to count on for advice in personal decisions
- Someone to make you feel loved and cared for
- Frequency of contact with relatives

Engagement
- How often participate in groups
- How often attend religious services
- Member of voluntary organisations
- Participation in physical leisure activities (list of 20)

Relations with others
- Frequency of contact with friends
- Frequency of contact with neighbours
- EA caregiving for seniors

Contextual Variables (Enumeration Area)
- EA income quintiles
- EA educational attainment
- EA income inequality
- EA unemployment

Not loading onto any one factor
- Can speak English or French
- Educational attainment

Figure 6. Populated ecological model of social vulnerability. The seven emergent dimensions of social vulnerability (in italics) are situated within the ecological framework, which includes spheres of influence from the individual, to close family and friends, wider peer groups, institutions, community, and society.

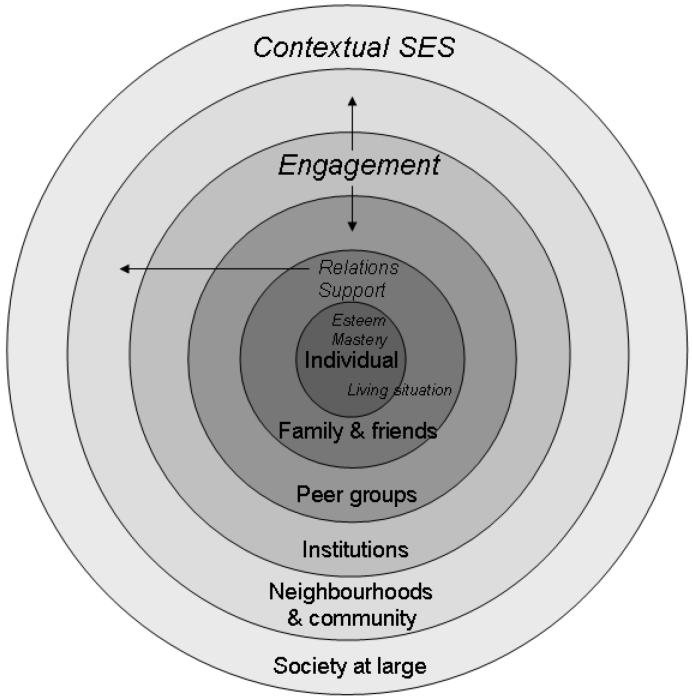

Table 3. Principal Component Analysis with seven emergent factors.

7 factors **Rotated Component Matrix(a)**

	Component						
	1	2	3	4	5	6	7
Frequency of group engagement	.927	-.037	-.022	-.032	.021	.006	.063
No group engagement	.917	-.029	-.018	-.003	-.006	.013	.050
Attending religious services	.471	.065	.141	.056	-.035	-.018	.138
Physical leisure activities	.311	-.223	.043	.151	.246	.032	-.056
EA income	.004	.783	-.010	-.106	.014	-.021	-.195
EA education	.000	.735	-.022	.002	-.076	-.010	.264
EA inequality	.034	-.704	.054	.001	-.046	-.029	-6.15E-005
EA unemployment	.015	.582	.049	.007	.010	-.059	-.147
Support: advice	.055	-.012	.736	.039	-.065	.109	.011
Support: help in a crisis	.019	-.019	.713	-.061	.008	.025	-.014
Support: someone to confide in	.061	-.027	.680	-.107	.001	.136	.006
Support: someone to make you feel loved	.033	-.006	.583	.196	.119	.020	.002
Frequency of contact with relatives	-.017	.030	.372	.151	.039	-.121	.216
Lives alone	.018	-.035	.076	.940	-.008	.046	-.036
Marital status	.054	-.051	.057	.937	.013	.053	-.016
Worth equal to others	-.012	-.018	.022	.025	.846	-.016	.032
Positive attitude towards self	.014	.027	.046	-.032	.841	.086	.082
Too much expected of you by others	-.122	.007	.016	-.030	-.059	.566	.026
Want to move but cannot	.050	-.001	.036	-.008	.074	.560	.150
Not enough money	.067	-.083	.039	.004	.006	.524	-.101

	Component						
	1	2	3	4	5	6	7
How often have people let you down	-.011	.045	.115	.127	-.003	.462	.176
Noisy/polluted neighbourhood	-.004	-.064	-.106	.044	-.087	.392	.360
Frequency of contact with neighbours	.092	.029	.147	-.053	.120	.067	.555
EA caregiving for seniors	.001	.149	.025	-.065	.128	.006	-.500
Frequency of contact with friends	.274	-.012	.241	-.195	.091	.049	.405
Education	.262	-.344	.017	-.069	.166	.148	-.386
Ability to speak English or French	.070	.003	-.012	-.026	.084	.047	.178

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 6 iterations.

Table 4. Vulnerability in each of the seven dimensions in relation to vulnerability in the others. All associations were in a positive direction (i.e. of increasing vulnerability in both associated domains) and were tested using linear regression adjusting for age, sex, frailty, and education.

	Esteem	Mastery	Living situation	Support	Engage-ment	Relations	Context
Esteem		+++	NS	NS	NS	+	NS
Mastery	+++		+++	+++	NS	+++	NS
Living situation	NS	+++		+++	+	NS	++
Support	NS	+++	+++		++	+++	NS
Engagement	NS	NS	+	++		+++	NS
Relations	+	+++	NS	+++	+++		NS
Context	NS	NS	++	NS	NS	NS	

Legend: + $p<0.05$, ++ $p<0.01$, +++ $p<0.001$.

Table 5. Associations of the social vulnerability dimensions with covariates (gender, age, frailty, and education; multivariable linear regression coefficients are presented with 95% confidence intervals). Statistically significant associations are shaded.

	Engagement	Contextual SES	Support	Alone	Esteem	Mastery	Relations
Female Gender	-0.13 (-0.25, -0.01) p=0.03 Women less vulnerable	-0.05 (-0.13, 0.03) p=0.23	-0.14 (-0.23, -0.05) p=0.003 Women less vulnerable	0.52 (0.44, 0.60) p<0.001 Women more vulnerable	-0.00 (-0.03, 0.03) p=0.87	-0.06 (-0.16, 0.03) p=0.2	-0.03 (-0.10, 0.05) p=0.49
Age (increasing)	0.01 (-0.01, 0.02) p=0.28	-0.00 (-0.01, 0.00) p=0.50	-0.01 (-0.01, 0.00) p=0.10	0.03 (0.02, 0.03) p<0.001	-0.00 (-0.00, 0.00) p=0.41	-0.02 (-0.03, -0.01) p<0.001	0.00 (-0.00, 0.01) p=0.73
Frailty (increasing)	1.37 (0.77, 1.96) p<0.001	0.35 (-0.03, 0.73) p=0.07	0.05 (-0.29, 0.58) p=0.51	-0.11 (-0.50,0.27) p=0.57	0.39 (0.22, 0.55) p<0.001	2.22 (1.74, 2.71) p<0.001	0.22 (-0.18, 0.61) p=0.28
Education (lower)	0.42 (0.26, 0.58) p<0.001	0.34 (0.25, 0.44) p<0.001	0.05 (-0.06, 0.15) p=0.39	0.03 (-0.07, 0.13) p=0.54	0.04 (0.01, 0.08) p=0.01	0.02 (0.09, 0.32) p<0.001	0.06 (-0.03, 0.14) p=0.19

Table 6. Results of the logistic regression analysis: association of vulnerability in each dimension with 10-year mortality. Statistically significant associations are shaded.

Dimension	Covariates considered	OR 10-year mortality	95% CI	p value
Self-esteem	Age, sex	1.79	1.19-2.70	p=0.005
	Age, sex, frailty, education	1.37	0.90-2.11	p=0.15
Mastery	Age, sex	1.14	1.01-1.29	p=0.04
	Age, sex, frailty, education	1.00	0.88-1.14	p=0.96
Living situation	Age, sex	1.08	0.96-1.21	p=0.22
	Age, sex, frailty, education	1.09	0.97-1.24	p=0.15
Social support	Age, sex	1.04	0.90-1.21	p=0.59
	Age, sex, frailty, education	1.03	0.89-1.20	p=0.65
Social engagement	Age, sex	1.28	1.16-1.41	p<0.001
	Age, sex, frailty, education	1.22	1.10-1.35	p<0.001
Relations with others	Age, sex	0.99	0.82-1.20	p=0.93
	Age, sex, frailty, education	0.96	0.78-1.18	p=0.71
Contextual SES	Age, sex	1.14	0.96-1.35	p=0.14
	Age, sex, frailty, education	1.07	0.90-1.28	p=0.43

CHAPTER 4 SOCIAL VULNERABILITY, FRAILTY, AND MORTALITY

4.1 PROLOGUE

The previous study laid the groundwork for the social vulnerability index, which is now studied further in the current Chapter. In the second study presented here in Chapter 4, the social vulnerability index is constructed in both the Canadian Study of Health and Aging and the National Population Health Survey. The properties of the index are examined, as are associations with age, sex, frailty, and mortality.

Combining many different social factors into a single index leads to questions about the relative importance of the variables used in its construction. For example, how do we know if the associations being identified are due to the influence of the entire index, or could one or a few of the constituent variables be so strongly driving the association that the importance of the other variables is dwarfed? This question also has important ramifications for the selection of variables to be included in the index. The first study presented in this Chapter is a methodological exploration addressing these very questions. It describes a novel bootstrap-inspired technique of re-sampling among the variables in an index in order to assess the index's robustness.

4.2 MANUSCRIPT DETAILS:

Andrew, M. and A. Mitnitski "Re-sampling among variables within an index: a bootstrap-inspired method of assessing robustness."

4.3 RE-SAMPLING AMONG VARIABLES WITHIN AN INDEX: A BOOTSTRAP-INSPIRED METHOD OF ASSESSING ROBUSTNESS

4.3.1 ABSTRACT (METHODOLOGICAL EXPLORATION)

BACKGROUND: We describe a technique of bootstrap-inspired re-sampling of individual variables within an index. Multiple replicates of the index, each consisting of randomly-selected subsamples of variables from the full index, are generated and analyzed in relation to dependent variables of choice.

METHODS: The case study sample comprised community-dwelling adults aged 70+ years in the Canadian Study of Health and Aging. A social vulnerability index was created using 40 social variables. Using bootstrap-inspired re-sampling from among the constituent variables, multiple distinct indices were created by re-sampling 80% of the variables on each occasion so that each re-sampled index included 32 randomly selected variables. The replicate indices were used in a Kaplan-Meier survival analysis, stratified by quartile of social vulnerability.

RESULTS: Survival plots of the re-sampled indices showed remarkable uniformity for men and for the most vulnerable women, with little overlap between the strata, suggesting that the index is generally robust to the specification of individual variables for both men and the most socially vulnerable women.

CONCLUSION: Re-sampling by variables is a technique which informs the development of index variables, allowing assessment of their robustness to inclusion/exclusion of individual variables.

4.3.2 BACKGROUND

Bootstrapping

Bootstrapping as a broad idea is applied in many fields, including computing, law, business, biology, physics, linguistics, and statistics. Each use differs in details of application and methodology. For example, in computer science, computers are "booted" to start up, while in finance, to bootstrap a business is to start up with no external capital.(Bhide 1992) In linguistics, it is a theory of language acquisition, in which knowledge of form (syntax) is used to help understand the (semantic) meaning of new words (p.452).(Fromkin 2000) The common meaning is a process that is self-sustaining and without reliance on outside help and the reference is said to have originated in a German folk tale by Rudolf Erich Raspe, in which Baron Münchhausen pulls himself from a swamp using either his bootstraps or his hair.(Raspe 1795) Its use in statistical analysis was originally described by Efron in the late 1970s and early 1980s,(Efron 1979; Efron and Tibshirani 1993) drawing on earlier work on the jackknife technique by Quenouille.(Quenouille 1949)

In statistics, bootstrapping is a method currently used for variance estimation, bias reduction, confidence interval calculation, and estimating probabilities of events.(Efron and Tibshirani 1993) It is based upon repeated random sampling from a pool of individual observation sets (*e.g.* of individual respondents in a survey or database), which allows generation of many samples from the original. The variability among these "replicate samples" is then used to estimate the variance of the original sample.

Use of indices in health research

Indices are constructed using many individual variables which are combined together. This combination can be done in different ways. In some indices, all of the constituent variables are added together with equal weight (as in the Thrombosis in Myocardial Infarction (TIMI) risk score for unstable angina),(Antman, Cohen et al. 2000) while in others, the index's items can be assigned different weights or point values based on some assessment of their relative importance. For example, the Mortality Risk Index Score for

predicting prognosis in institutionalized older adults is comprised of twelve items, with the contribution of each having a weight corresponding to its individual strength (Hazard Ratio in a multivariable Cox proportional hazards model in a derivation cohort) as a risk factor.(Mitchell, Kiely et al. 2004)

Indices are important, and their use provides certain benefits. Use of an index allows for dimensionality reduction and avoids technical difficulties with multiple co-linearity that can be encountered when many variables are individually and separately included in a model. An index also allows for graded distribution of risk, rather than the binary assignments or few categories generally seen with individual variables. Indices, such as the previously published frailty index,(Mitnitski, Song et al. 2004; Mitnitski, Song et al. 2005) also allow for the idea of state transitions (study of how individuals progress from having a certain number of deficits to having a different number at follow-up examinations, for example)(Mitnitski, Song et al. 2007) and estimation of limits to the number of deficits that individuals can accumulate.(Rockwood and Mitnitski 2006) Indices are also useful as tools for guiding decision-making, as is the case for the TIMI risk score (Antman, Cohen et al. 2000) and the Glasgow Coma Scale.(Teasdale and Jennett 1974)

When associations between an index and some outcome of interest (*e.g.* mortality, disease diagnosis, etc.) are tested, a reasonable question arises: how do we know if the associations being identified are due to the influence of the entire index, or could one or a few of the constituent variables be so strongly driving the association that the importance of the other variables is dwarfed? For example, imagine an aging index with the following constituent variables: chronological age group, grey hair (Yes/No), eye colour (Brown vs other), likes “I love Lucy” reruns (Yes/No), and favourite ice cream flavour is vanilla (Yes/No). This index is highly likely to be predictive of mortality, but the relative importance of the constituent variables is also likely to be very unequal, as “chronological age group” would be expected to drive the association.
Another way would be to re-construct the index multiple times (creating “subtraction” indices), each time leaving out one variable. For the example above, one imagines that

the index that excludes chronological age group would not be strongly predictive of mortality, while indices leaving out each of the other variables (but including chronological age group) would retain their predictive power. This is not unlike a "jackknife" procedure that is traditionally used for variance estimation and to examine a dataset for outliers, though in the case of the traditional jackknife, the procedure involves reconstructing multiple datasets, each consisting of *n*-1 *observation*s (*e.g.* individuals within a dataset, where there are *n observations* in the full dataset), such that one observation (individual) is left out of each replicate sample.(Efron and Tibshirani 1993)

Bootstrapping can be understood as building upon this simple jackknife example. In a traditional bootstrap procedure, a number of randomly-selected observations are left out of the replicate datasets, again providing a means of assessing variance within a sample.(Efron and Tibshirani 1993)

Here, we describe a technique of bootstrap-inspired re-sampling amongst the individual constituent *variables* (rather than *observations*) used in the construction of an index variable.(Rockwood, Mitnitski et al. 2006; Andrew, Mitnitski et al. 2008) Using re-sampling within the index, for example selecting 80% of the constituent variables at random from the full list of variables many times over, multiple versions of the index are generated, each consisting of subsamples of variables from the original complete index. Each replicate index can then be analyzed in relation to the dependent variables of choice, allowing for an assessment of the robustness of the index, and of the index's sensitivity to inclusion or exclusion of specific variables or groups of variables.

4.3.3 CASE STUDY

The aim of this paper is to describe the re-sampling by variables technique and its application to creating and describing the properties of an index. In this methodological report, a case study using a social vulnerability index is presented for illustrative purposes. These results have been described in more detail elsewhere, and interested

readers are referred there for detailed interpretation.(Andrew, Mitnitski et al. 2008) The aim of this methodological report is to describe a new method that we have found to be useful in work with indices.(Rockwood, Mitnitski et al. 2006; Andrew, Mitnitski et al. 2008)

4.3.4 METHODS

DATA FOR THE CASE STUDY

The Canadian Study of Health and Aging (CSHA) is a representative study of dementia and related conditions in older Canadians. Sampling was population-based with clustering within five geographic regions and over-sampling of those aged 75 and older.(Rockwood, McDowell et al. 2001) The CSHA started in 1991 with follow-up waves at five (CSHA-2) and ten (CSHA-3) years. In the present example, baseline data were drawn from CSHA-2, as more detailed social data had been collected during the second wave of CSHA. This sample thus included older people aged 70+ at baseline (N=3776 with complete social data), with five-year survival as the outcome.(Andrew, Mitnitski et al. 2008) At five years, 930 (25%) individuals had died and 69 (2%) were lost to follow-up.

A social vulnerability index was created by identifying 40 self-report social variables or potential social “deficits” and coding each one as 0 (deficit not endorsed) to 1 (deficit reported), with intermediate values for ordinal response categories. The index thus had a possible score 0-40 (Table 7).(Andrew, Mitnitski et al. 2008)

RE-SAMPLING BY VARIABLES METHOD: BUILDING ON THE "JACKKNIFE"

In a simple "jackknife by variables" procedure, the index is re-created *n* times, each time leaving out a single one if its *n* variables. For this example of the social vulnerability index, here this results in 40 *n*-1 "subtraction indices", each including 39 of the 40 variables. Each of these *n*-1 indices can then be used in its own survival analysis to test the influence of leaving out single variables on the index's overall association with the dependent variable or outcome of interest.

The re-sampling by variables technique is an extension of the "jackknife by variables", in which several randomly selected variables are left out of each replicate index, and this re-sampling procedure is repeated many times over. This was done using the Matlab mathematical software application (version 7.1, The MathWorks Inc., Natick, MA). An (x,y) matrix was constructed with the observations (individual survey participants) on the x axis and the constituent variables of the social vulnerability index on the y axis. The social vulnerability index is a sum of 40 deficits coded 0 (deficit absent) or 1 (deficit endorsed by the participant). Using Matlab, many (*e.g.* hundreds to thousands) distinct indices were created by re-sampling 80% of the variables on each occasion (and leaving the remaining 20% out of each replicate index), such that each re-sampled index included 32 randomly selected variables. Here, 100 replications are shown in order to preserve clarity in Figure 7. Each of the re-sampled indices was then used in a Kaplan-Meier survival analysis that included all of the survey participants (unlike traditional bootstrapping methods, which would leave out a portion of the participants with each replication), and the curves were superimposed and re-traced to create a single plot which has the appearance of a "horse tail" (Figure 7). The survival analysis was stratified by quartile of social vulnerability, such that a traditional Kaplan-Meier curve would have 4 survival lines, one for each quartile of social vulnerability. Men and women were analyzed separately.

4.3.5 CASE STUDY RESULTS AND INTERPRETATION

Results of the "jackknife by variables" procedure are shown in Table 8 (reprinted from the original report of this study's findings)(Andrew, Mitnitski et al. 2008). 40 subtraction indices were created, each leaving out a single variable from the full index. In each case, the association with mortality remained unchanged (OR 1.06-1.07, p = 0.001-0.003), suggesting that there was no individual variable driving the association much more strongly than the others (Table 8).

Results of the re-sampling by variables technique are shown for both women (Figure 7a) and men (Figure 7b). Each of these figures shows the results of 100 distinct survival analyses using the 100 replicates of the social vulnerability index, with the curves superimposed on the same axis.

For men (panel B), there is little overlap between the curves for different quartiles, suggesting that the results of the survival analysis are robust to changes within the index. There is some variability to the exact trajectory of the curve for each quartile of social vulnerability (each different colour in the graph), but there is minimal overlap between the curves for one quartile with those of another quartile. This suggests that for men, the exact choice of variables to be included in the social vulnerability index has little impact on the association of the index with mortality, and that the overall number of deficits and impression of vulnerability is more important than the specifics of the included variables.

For women, there is overlap between curve iterations in the least socially vulnerability quartiles (shown in red and turquoise), but the curves are well-defined for the most vulnerable (blue and green). This suggests that for women, the specific choice of variables to be included in the index is less important for those who are most vulnerable, while for the less socially vulnerable, responses to specific variables (and the inclusion of specific variables in the index) may have more of an influence. (Andrew, Mitnitski et al. 2008)

4.3.6 DISCUSSION (METHODOLOGICAL EXPLORATION)

We have described a technique for informing the construction of indices and testing their properties. In particular, the re-sampling by variables technique allows for testing of the index's robustness to the specific choice of constituent variables. Indices that are robust to specific choices made in their construction are likely to be more stable and reliable, while those which are sensitive to the inclusion or exclusion of specific individual variables may be less useful. Additionally, as this case study illustrates, the procedure may highlight important differences in the behaviour of the index between sample subgroups (*e.g.* men *vs.* women), which may be useful in generating further hypotheses and research directions. In summary, our aim was not to provide a method of selecting the most important constituent variables, but rather to investigate the extent to which the inclusion or exclusion of available variables affects the stratification of individuals into distinct risk groups.

Statistical datasets are matrices with observations (often, as in the present example, representing distinct individuals) on the *x* axis and a list of variables along the *y* axis. While in traditional bootstrapping, the re-sampling is done among the observations, there in no *a-priori* contraindication to using a similar approach to re-sample among the variables making up the y axis of the matrix. This *bootstrap-inspired* re-sampling technique, which is different from true bootstrapping in that it re-samples among variables rather than observations, is the approach we describe here in relation to index variables.

There are different reasons to use index variables, and characteristics that may be desirable for some applications may be less so for others. Parsimony is one such characteristic. For some indices, parsimony (*i.e.* including as few variables as possible in an index) may be desired for various reasons including ease of interpretation, avoidance of interrelationships and complex patterns of dependencies among the variables, and ease of clinical use. In these cases, distilling the index down to a small number of essential components is sensible. Many indices in common clinical use are of this type: for

example the TIMI risk scores and the Glasgow Coma Scale.(Teasdale and Jennett 1974; Antman, Cohen et al. 2000) In such indices with small numbers of variables, the re-sampling by variables procedure may be less applicable, though one can still imagine a place for examining the properties of the index using a "jackknife by variables" approach, in which the influence of including or excluding single specific variables is studied with the aim of furthering understanding of the index's properties.

On the other hand, over-simplification of complex constructs has drawbacks. Including larger numbers of variables in an index can allow for graded distribution of risk, rather than the few categories that would be captured by a more parsimonious classification index. As an example, a frailty or cumulative deficit index comprising many variables shows benefits in the ability to discriminate differences in risk of death compared with a simpler phenotypic operationalization of frailty that includes only five variables.(Rockwood, Andrew et al. 2007; Kulminski, Ukraintseva et al. 2008) With ever-increasing computation capabilities of desktop, laptop, and hand-held computers and the continued expansion of available data (*e.g.* new biomarkers, functional measures, and social indicators), complexity is becoming less of an obstacle, and may in fact be increasingly embraced in both research and clinical settings.

Indices which include large numbers of variables can also be used to enhance generalizability between different datasets. For example, both the cumulative deficit frailty index and the social vulnerability index have preserved characteristics and robust prediction of health outcomes even when their constituent variables differ between datasets.(Mitnitski, Song et al. 2005; Andrew, Mitnitski et al. 2008) For this type of index, where the exact list of constituent variables is not fixed between applications to different settings or data sets, the re-sampling by variables procedure is particularly well-suited. Alternative methods of constructing indices and studying their characteristics (*e.g.* weighting of factors included within an index, or use of statistical methods like Principal Components Analysis) compromise generalizability because of their reliance on characteristics of the particular data set in which they are applied.

There are existing traditional approaches for investigating the properties of indices. For example, techniques such as factor analysis and principal component analysis allow relationships between variables in the index to be studied and used to separate the index's constituent variables into related domains. These respected techniques have their place, but they also have drawbacks and as such there is room for additional methods in the development, assessment, and use of indices. These procedures are not without arbitrariness. For example, in principal component analysis, the operator specifies the number of dimensions to be "discovered". Such measures are also more fixed and instrument-dependent, and may thus be less generalizable. One benefit of the social vulnerability and frailty indices, and of other similar indices, is the potential to derive them differently (though using precisely defined methodology and criteria for variable selection, coding, and index construction) using data available in different datasets.(Searle, Mitnitski et al. 2008) With this potential for flexibility comes a scientific imperative to ensure that the properties of a proposed index are rigorously tested, an application for which the re-sampling by variables procedure is well suited.

In the re-sampling by variables procedure, the percentage of variables to be re-sampled with each iteration of the bootstrap by variables procedure is not fixed. In this example, 80% re-sampling was used, but investigators could choose to set different re-sampling fractions/percentages. The key is that each re-sampled index leaves out one (in the case of the simple "jackknife by variables" example) or more variables. Likewise, the number of replicate indices created through repeated re-sampling is not fixed. In this example, we show results of 100 replicates in the interest of clarity of the figure, though any reasonable number (*e.g.* hundreds to thousands) could have been specified.

We have proposed the re-sampling by variables method based on random re-sampling from the pool of variables included in the index. A possible alternative would be an extended "jackknife" technique, in which purposefully defined groups of variables would be excluded, one group at a time. This might allow testing of the impact of including or excluding related groups of variables from the index. While we agree that this might provide additional specific information (about which particular groups of variables,

perhaps all relating to a shared topic, act together in important ways for example), and might be well-suited to certain applications, the random resampling is more broadly applicable, covers the many possible combinations of variable selection in its randomness, and thus has the potential to more thoroughly assess and test properties such as the robustness of indices.

4.3.7 CONCLUSIONS (METHODOLOGICAL EXPLORATION)

Indices have many potential applications in health research, and are increasingly used to predict outcomes and aid decision-making. Bootstrap-inspired re-sampling can be used to generate multiple replicate indices by randomly re-sampling from the variables within an index, and allows testing of the robustness of the index. This is a new technique that can be added to the methodological repertoire used to inform development and use of indices.

4.3.8 AUTHORS' CONTRIBUTIONS (METHODOLOGICAL EXPLORATION)

MA and AM conceived the paper. AM did the initial development of the bootstrap by variables technique, and contributed to the technical planning of the analyses. MA did the analyses and wrote the initial draft of the manuscript. Both authors revised the manuscript.

4.3.9 ACKNOWLEDGEMENTS (METHODOLOGICAL EXPLORATION)

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4.3.10 REFERENCES (METHODOLOGICAL EXPLORATION)

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4.3.11 GRAPHICS (METHODOLOGICAL EXPLORATION)

Figure 7. . 'Re-sampling by variables' analyses. Survival curves showing 100 replicates with 80% re-sampling within the social vulnerability index. Panel A – women, Panel B – men.(Andrew, Mitnitski et al. 2008)

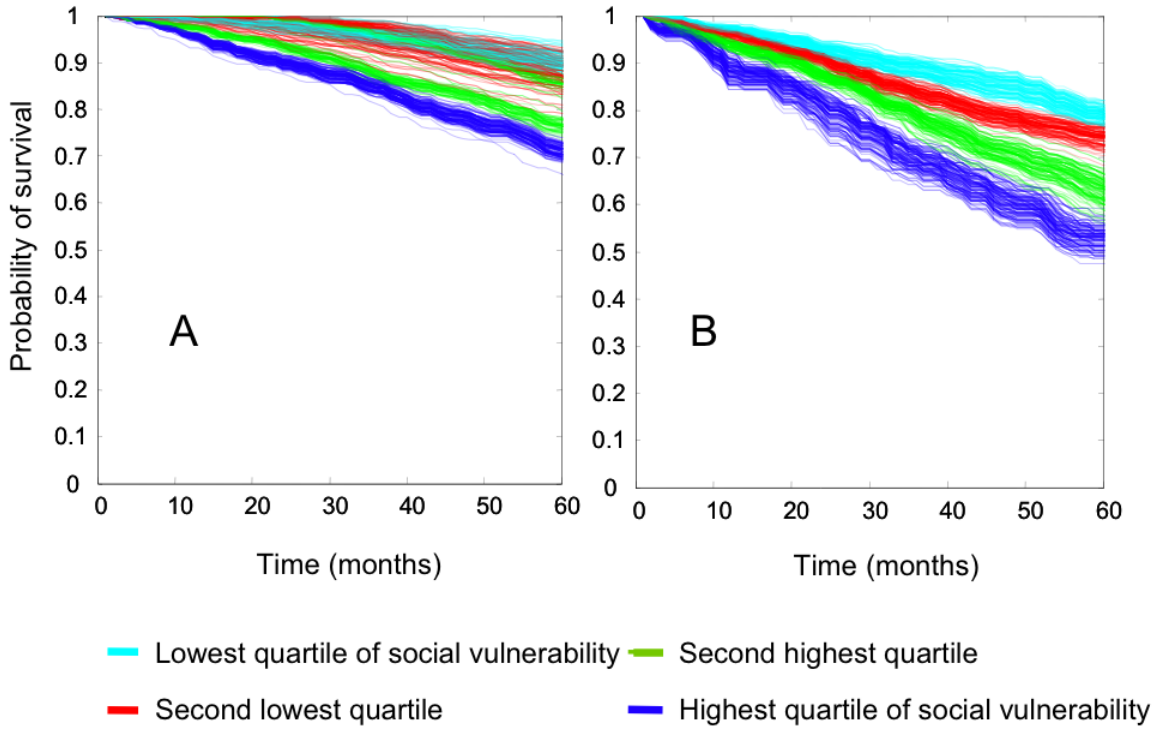

Table 7. Social variables included in the social vulnerability index. This table was originally published in Andrew MK *et al*, PLoS One, 2008.

Communication to engage in wider community	
1	Read English or French
2	Write English or French
Living situation	
3	Marital status
4	Lives alone
Social support	
5	Someone to count on for help or support
6	Feel need more help or support
7	Someone to count on for transportation
8	Feel need more help with transportation
9	Someone to count on for help around the house
10	Feel need more help around the house
11	Someone to count on to listen
12	Feel need more people to talk with
13	Number of people spend time with regularly
14	Feel need to spend more time with friends/family
15	Someone to turn to for advice
16	Feel need more advice about important matters
Socially oriented Activities of Daily Living	
17	Telephone use
18	Get to places out of walking distance
Leisure activities	
19	How often visit friend or relatives
20	How often work in garden
21	How often golf of play other sports
22	How often go for a walk
23	How often go to clubs, church, community centre
24	How often play cards or other games
Ryff scales	
25	Feel empowered, in control of life situation
26	Maintaining close relationships is difficult and frustrating
27	Experience of warm and trusting relationships
28	People would describe me as a giving person
How do you feel about your life in terms of …	
29	Family relationships
30	Friendships
31	Housing
32	Finances
33	Neighbourhood
34	Activities
35	Religion
36	Transportation
37	Life generally
Socio-economic status	
38	Does income currently satisfy needs
39	Home ownership
40	Education

Table 8. Case study "jackknife by variables" analysis results. Each row displays results from a logistic regression model demonstrating associations between each reconstructed *n*-1 index and mortality. Excluding individual variables from the index does not affect associations with mortality. This figure was originally published in Andrew MK *et al*, PLoS One, 2008.

Social vulnerability index excluding listed item	Odds Ratio: odds of death for each additional deficit in the index	95% Confidence Interval	P>|z|
full index	1.06	1.02 - 1.10	0.002
Education	1.06	1.02 - 1.09	0.003
Read	1.06	1.02 - 1.10	0.001
Write	1.06	1.02 - 1.10	0.001
Marital status	1.06	1.03 - 1.10	0.001
Lives alone	1.07	1.03 - 1.10	0.001
Support - help	1.06	1.02 - 1.10	0.002
Feel need more help	1.06	1.02 - 1.10	0.001
Support -transportation	1.06	1.02 - 1.10	0.002
Feel need more help with transportation	1.06	1.02 - 1.10	0.002
Support -chores	1.07	1.03 - 1.11	0.001
Feel need more help with chores	1.06	1.02 - 1.10	0.002
Support - listen	1.06	1.02 - 1.10	0.002
Feel need more people to talk with	1.06	1.02 - 1.10	0.002
Support –number of visits	1.06	1.02 - 1.10	0.003
Feel need more visits	1.06	1.02 - 1.10	0.002
Support - advice	1.06	1.02 - 1.10	0.001
Feel need more advice	1.06	1.02 - 1.10	0.001
Telephone use	1.06	1.02 - 1.10	0.002
Get out of walking distance	1.06	1.02 - 1.09	0.003
Visit friends & relatives	1.06	1.02 - 1.10	0.002
Gardening	1.06	1.02 - 1.10	0.003
Participate in sports	1.06	1.02 - 1.10	0.002
Go for a walk	1.06	1.02 - 1.10	0.002
Clubs, church	1.06	1.02 - 1.10	0.003
Play cards, games	1.06	1.02 - 1.09	0.003
Control, empowerment	1.06	1.02 - 1.10	0.002
Close relationships	1.06	1.02 - 1.10	0.001
Trusting relationships	1.06	1.02 - 1.10	0.002
Giving person	1.06	1.02 - 1.10	0.002
Relationships	1.06	1.02 - 1.10	0.001
Friends	1.06	1.02 - 1.10	0.002
Housing situation	1.06	1.02 - 1.10	0.001
Finances	1.06	1.02 - 1.10	0.001
Neighbourhood	1.06	1.02 - 1.10	0.001

Social vulnerability index excluding listed item	Odds Ratio: odds of death for each additional deficit in the index	95% Confidence Interval	P>|z|
Income sufficient	1.06	1.02 - 1.10	0.001
Home ownership	1.06	1.02 - 1.10	0.001

4.4 PUBLICATION DETAILS:

Andrew, M. K., A. Mitnitski and K. Rockwood (2008). "Social vulnerability, frailty, and mortality in elderly people." PLoS One 3(*5*): e2232

4.5 SOCIAL VULNERABILITY, FRAILTY, AND MORTALITY IN ELDERLY PEOPLE.

4.5.1 ABSTRACT

BACKGROUND: Social vulnerability is related to the health of elderly people, but its measurement and relationship to frailty are controversial. The aims of the present study were to operationalize social vulnerability according to a deficit accumulation approach, to compare social vulnerability and frailty, and to study social vulnerability in relation to mortality.

METHODS AND FINDINGS: This is a secondary analysis of community-dwelling elderly people in two cohort studies, the Canadian Study of Health and Aging (CSHA, 1996/7-2001/2; N=3707) and the National Population Health Survey (NPHS, 1994-2002; N=2648). Social vulnerability index measures that used self-reported items (23 in NPHS, 40 in CSHA) were constructed. Each measure ranges from 0 (no vulnerability) to 1 (maximum vulnerability). The primary outcome measure was mortality over five (CHSA) or eight (NPHS) years. Associations with age, sex, and frailty (as measured by an analogously constructed frailty index) were also studied. All individuals had some degree of social vulnerability. Women had higher social vulnerability than men, and vulnerability increased with age. Frailty and social vulnerability were moderately correlated. Adjusting for age, sex, and frailty, each additional social 'deficit' was associated with an increased odds of mortality (5 years in CSHA, odds ratio = 1.05, 95%

confidence interval:1.02-1.07; 8 years in the NPHS, odds ratio = 1.08, 95% confidence interval:1.03-1.14). We identified a meaningful survival gradient across quartiles of social vulnerability, and although women had better survival than men, survival for women with high social vulnerability was equivalent to that of men with low vulnerability.

CONCLUSIONS: Social vulnerability is reproducibly related to individual frailty/fitness, but distinct from it. Greater social vulnerability is associated with mortality in older adults. Further study on the measurement and operationalization of social vulnerability, and of its relationships to other important health outcomes, is warranted.

4.5.2 INTRODUCTION

As people age and become more vulnerable, their social circumstances particularly impact their health.(Blazer 1982; Schoenbach, Kaplan et al. 1986; Seeman, Kaplan et al. 1987; Seeman, Berkman et al. 1993; Bassuk, Glass et al. 1999; Fratiglioni, Wang et al. 2000; Mendes de Leon, Glass et al. 2003; Andrew 2005) Even so, the many descriptions of how social factors, aging and health relate to each other employ various terms. Social inequalities, social environments, sense of life control and coherence, social support, social networks, social engagement, social capital, social cohesion, and socioeconomic status each have been associated with health status.(Kawachi, Kennedy et al. 1997; Kawachi and Berkman 2000; McCulloch 2001) While the varying terminology reflects different traditions and fields of study, a useful discipline is imposed by aiming for an approach that is feasible, valid, rooted in clinical practice and summarizable for policy-making.

Recent work on the quantification of fitness and frailty might provide a guide to quantifying social vulnerability.(Ahmed, Mandel et al. 2007; Andrew and Mitnitski 2008) A series of studies has shown that health status can be summarized by a deficit accumulation approach, *i.e.* counting the deficits present in an individual.(Mitnitski,

Mogilner et al. 2001; Kulminski, Yashin et al. 2006; Woo, Goggins et al. 2006) The underlying idea is that the more deficits (or problems) an individual has (or accumulates), the more vulnerable she or he will be to insults that an individual with fewer deficits might be able to keep at bay. This has proved to be a robust enough approach to yield comparable estimates of the rate of deficit accumulation of health-related deficits – adding about 3 percent of a list of deficits with each increasing year of age – across several surveys,(Mitnitski, Song et al. 2005) and to demonstrate replicable limits to frailty.(Rockwood and Mitnitski 2006)

If a series of individual deficits could be combined to estimate not just relative fitness/frailty, but also social vulnerability, the resulting social vulnerability index variable would offer insights into understanding the complex health and social care needs of older adults. Especially as people become very old, "social" and "medical" factors have a complex inter-play that affects important health outcomes and is important for both clinical care and policy-making, but how to consider so many factors has been a challenge. The aims of the present study were to operationalize social vulnerability according to a deficit accumulation approach, to compare social vulnerability and frailty, and to study social vulnerability in relation to mortality.

4.5.3 MATERIALS AND METHODS

Study samples

The Canadian Study of Health and Aging (CSHA) is a representative study of dementia and related conditions in older Canadians (age ≥65 years). Details of the methods are described elsewhere.(Rockwood, McDowell et al. 2001) Briefly, sampling was population-based and representative of English- and French-speaking older Canadians (age ≥65). The sample of 10,263 individuals was clustered within five Canadian regions and stratified by age, with over-sampling of those aged 75 and older. In CSHA-1 (1991-92), a screening interview was conducted with 9,008 community-dwelling participants.

Follow-up at 5 years (CSHA-2) and 10 years (CSHA-3) included repeat screening assessments. Of the 10,263 initial CSHA study participants, 9,998 individuals were accounted for at CSHA-2 (of whom 2,982 had died) and 9,578 were accounted for at CSHA-3 (of whom 5,150 had died). Here, baseline data were drawn from the CSHA-2 screening interview, which had included additional information about social factors. As such the study sample comprised community dwelling adults aged 70+ at baseline (Figure 8).

The National Population Health Survey (NPHS) is a panel survey sampling Canadian residents of all ages and administered by Statistics Canada. Survey waves were completed every two years starting in 1994; the most recent available follow-up wave was done in 2002, yielding eight year follow-up. The sampling design included multistage stratification by geographic and socio-economic characteristics and clustering by Census Enumeration Areas.(Singh, Tambay et al. 1994) Eight-year follow-up was available for 2468 individuals aged 65+ at baseline who had completed all items in the social vulnerability measure (Figure 8).

Measures

Social vulnerability

Self-report variables relating to social factors that could be considered as deficits were identified separately in the CSHA and the NPHS (Table 9). Deficit selection was guided by two imperatives. First, we aimed to include a broad representation of factors that influence and describe an individual's social circumstance. These factors were based on previous studies which have suggested that they are relevant (*e.g.* social support, social engagement, sense of mastery/control over one's life circumstances).(Blazer 1982; Schoenbach, Kaplan et al. 1986; Seeman, Kaplan et al. 1987; Seeman, Berkman et al. 1993; Mendes de Leon, Glass et al. 2003; Marmot 2004) As part of a holistic description of social vulnerability, socioeconomic status (*e.g.* income adequacy, home ownership – addressing both wealth and housing security – and educational attainment) was also

included,(Grundy and Holt 2001; Grundy and Sloggett 2003) as these factors also influence vulnerability to insults with the potential to impact their health status. The two instrumental activities of daily living items included (ability to use the telephone and to get to places outside of walking distance) explicitly relate to an individual's ability to maintain social ties and participate in their community, and were therefore included in the social index. Second, working within the constraints of secondary data analysis, we aimed to make the measure of social vulnerability as sensible and as broadly applicable and comparable between datasets as possible.

Each respondent was assigned a score of 0 if a binary social deficit was absent and 1 if it was present; intermediate values were applied in cases of ordered response categories. For example, an individual scored 1 on the "lives alone" deficit if he/she reported living alone, and 0 if he/she did not. On the "do you ever feel you need more help" deficit, which had three response categories, possible scores were 0 if the answer was "never", 0.5 for "sometimes" and 1 for "often". As such, vulnerability on each deficit was mapped to the 0-1 interval. For each individual, a social vulnerability index was constructed using the sum of the deficit scores, yielding a theoretical range of 0-40 in the CSHA and 0-23 in the NPHS. To allow better comparison between the datasets, each with a different number of social deficits, the social vulnerability index was also calculated as a proportion of the total number of deficit items by dividing the sum of deficit scores by the number of deficits considered (40 in the CSHA and 23 in the NPHS), yielding an index with a theoretical range of 0-1.

Frailty

Frailty was operationalized analogously to the social vulnerability index, in both the CSHA and NPHS, as described elsewhere.(Mitnitski, Song et al. 2004; Mitnitski, Song et al. 2005) In brief, deficits representing self-reported symptoms, health attitudes, illnesses, and impaired functions (Table 10) were identified and given scores mapping to the 0-1 interval as described above, with a greater score corresponding to worse health status. The social vulnerability and frailty indices were mutually exclusive; no deficits overlapped.

Statistical analysis

Distributions and properties of both the social vulnerability index and the frailty index were explored using descriptive techniques, including graphs (histograms and scatter/ correlation plots), and descriptive statistics (mean and variance values). ANOVA was used for differences in means, and Chi-square testing for proportions. The characteristics (distributions, means, and ranges) of the frailty and social vulnerability indices were compared and correlations calculated.

Logistic regression modeling was used to determine the association between social vulnerability (explanatory variable) and the primary study outcome of survival at follow-up (five years in CSHA, eight years in NPHS). Survival time was determined by vital status at follow-up and date of death, if the respondent died during the follow-up period, Survival analyses were done using Kaplan Meier curves and Cox proportional hazards regression. All models exploring associations between social vulnerability and survival were adjusted for age, sex, and frailty. Statistical significance of survival differences was assessed using log-rank testing. Proportional sampling weights were used where possible to account for sample design.

To investigate the robustness of the composition of the social vulnerability index in respect to individual items, and whether mortality was driven by one or a few of the index's constituent variables, we employed a multi-stage approach. At the design level, we investigated the social vulnerability index in two separate samples, as described. At the instrumental level, we employed two different social vulnerability measures, as also detailed above. At the analytical level, we employed two techniques, each based on repeated re-sampling within the index. Established repeated re-sampling techniques such as "jackknifing" and "bootstrapping" are used to estimate variance and confidence intervals.(Armitage, Berry et al. 2002) In most applications, the re-sampling is based on observations, or individuals within the sample. Here, as we have done elsewhere with respect to the frailty index,(Rockwood, Mitnitski et al. 2006; Rockwood, Abeysundera et

al. 2007; Rockwood, Andrew et al. 2007) we have employed these techniques by applying the re-sampling procedure to a group of variables rather than to a group of observations. The earlier analyses with the frailty index have suggested that a greater number of variables is required to ensure stability in the modeling,(Rockwood, Mitnitski et al. 2006) so these techniques were applied to the CSHA data, which had a high enough number of variables to yield stable estimates. In the first, a "jackknife by variables" procedure, the social vulnerability index was reconstructed *n* times (where *n* is the number of variables in the index), each time leaving out a different variable, such that the total number of included variables in each reconstruction was *n*-1. In the second, a "bootstrap by variables" procedure, the index was reconstructed 100 times, each time randomly sampling 80 percent of the variables such that on each iteration 20 percent of the constituent variables were randomly left out of the index.(Rockwood, Mitnitski et al. 2006) For both the "jackknife" and "bootstrap by variables" techniques, associations with survival were tested with each resampled and reconstructed version of the social vulnerability index to assess the impact of leaving out single variables or randomly selected groups of variables from the index.

Statistical analyses were done using STATA 8 and Matlab 7.1 software packages.

4.5.4 RESULTS

Descriptive analyses

Mean age was 77.9 (95% CI: 77.8-78.1) in the CSHA and 73.4 years (95% CI: 73.0-73.7) in the NPHS. The samples comprised 60% women in the CSHA and 58% women in the NPHS. 41% of CSHA participants lived alone, compared with 35% in the NPHS. 66% of CSHA participants had less than secondary school education (<12 years of formal schooling); this was true of 52% in the NPHS. While a few items were strongly correlated (*e.g.* in the CSHA, reading correlated strongly with writing (r=0.60), and marital status correlated with living alone (r=0.77)), correlation among the items in the social vulnerability indices was generally weak: CSHA median correlation 0.085, IQR =

0.04-0.14. (Statistics Canada confidentiality agreement for data release does not allow the NPHS correlations to be released or published). The distributions of the social vulnerability and frailty indices were similar in the CSHA and NPHS (Figure 9a-d). Median social vulnerability was 0.25 (0.20, 0.31) in the CSHA and 0.28 (IQR 0.21,0.35) in the NPHS. While some people showed no degree of frailty, no individual was completely free of social vulnerability in either dataset. In both samples, social vulnerability increased weakly but significantly with age; women had higher index scores than men at all ages in the CSHA and this trend was present in the NPHS (Figure 10). The social vulnerability and frailty indices were weakly to moderately correlated with each other. The correlations were higher for women than for men (CSHA r=0.37 for men and 0.47 for women; NPHS r=0.13 for men and r=0.24 for women).

Mortality

Adjusting for age, sex, and frailty, each additional social deficit in the index was associated with an increased odds of death over five years in the CSHA (OR=1.05, 95% CI: 1.02, 1.07) and eight years in the NPHS (OR=1.08, 95% CI: 1.03, 1.14). Cox regression modeling yielded similar results: adjusting for age, sex, and frailty, each additional social deficit increased the risk of death by 3% in the CSHA (HR 1.03, 95% CI: 1.01-1.05) and 4% in the NPHS (HR 1.04, 95% CI: 1.01-1.07). Using the index operationalization that scales each index to values between 0 and 1, thereby adjusting for the different number of deficits included in the two indices and allowing direct comparison between the two datasets, the strength of association was similar in the CSHA and NPHS. For this hypothetical comparison of no social vulnerability (index=0) *vs.* maximal vulnerability (index=1), adjusting for age, sex, and frailty, maximal vulnerability would confer six times the odds of mortality: OR=6.22 (95% CI: 2.30, 16.83) in the CSHA and OR=6.22 (95% CI: 1.82, 21.21) in the NPHS.

Survival decreased progressively in each quartile of increasing social vulnerability (Figure 11a&b). This survival gradient remained statistically significant when adjusted for age and sex (stratified log-rank test $p<0.001$ in both the CSHA the NPHS). Further

adjusting for frailty, the survival gradient remained statistically significant in the NPHS (stratified log-rank test p=0.04) but not in the CSHA (p=0.15). Although women had better survival than men, survival for women with high social vulnerability was equivalent to that of men with low vulnerability (Figure 11c&d).

Re-sampling techniques

Associations with mortality, adjusted for age, sex, and frailty, remained unchanged as each individual social deficit was left out of the CSHA social vulnerability index in the "jackknife by variables" procedure (Table 11). Survival analysis results using the "bootstrap by variables" technique are shown in Figures 12a&b. The separation between quartiles of social vulnerability remains clear for men despite random omission of 20% of the index variables in each iteration. For women, the separation was clear for the two quartiles indicating the highest social vulnerability, but less so for those with lower vulnerability according to the index.

4.5.5 DISCUSSION

We used a social vulnerability index to evaluate social factors as they relate to older adults' health. The distribution of social vulnerability was such that no individual was free of social deficits. Social vulnerability increased with age, and women had higher index values than men. Social vulnerability was weakly to moderately correlated with frailty; while the two may be related, they are clearly distinct, particularly since each contributes independently to mortality. Increasing social vulnerability was associated with reduced medium-term survival (5- 8 years).

Our findings must be interpreted with caution. Our operationalization of social vulnerability was based on self-report data rather than on objectively defined social factors. Thus it is possible that some individuals over-report and others under-report vulnerability. Further study of distinctions between subjective and objective aspects of social vulnerability is warranted. It is, however, conceivable that older adults' self-

perceived vulnerability may be more relevant to their health and quality of life than more objective measures. While we found that social vulnerability increases with age, it was not possible to distinguish between accumulation of deficits with age and the possibility of cohort differences in vulnerability. This would require a different study design (follow-up of different age-based cohorts over time) but warrants further study. In addition, each study had important non-response, and we found that people who did not respond, or who did not have information on social factors were frailer and older. They had higher mortality rates and were more likely to be institutionalized. As both increasing age and increasing frailty are associated with increased social vulnerability, exclusion of these individuals may have led to underestimates of the levels of social vulnerability in the populations of older Canadians represented by the samples, and may have resulted in conservative estimates of associations between social vulnerability and mortality. Little is known about social vulnerability in institutional settings, but given that institutional living would affect social vulnerability in important ways (*e.g.* not living alone, access to social support, networks, and activities), further research is warranted.

We devised tests to address another potential critique of our approach: whether some individual items included in the index drive the identified associations with mortality. If this were the case for one or more variables, an argument might be made that it/they should not be combined in the index. For example, items such as income and education could be treated as separate confounders rather than being included in the index. For this reason, we investigated whether inclusion or exclusion of individual variables (using the "jackknife by variables" technique), and groups of variables (using the "bootstrap by variables technique") materially affect the analysis results. We have demonstrated that inclusion or exclusion of single variables in the index does not affect the results, and that the same may be true for randomly selected groups of variables (particularly for men), when a sufficient number of variables are included in the index. Of course, the unit of observation is important: for individuals, knowing exactly which deficits are present is likely to be important, but at a population level we find that the number of deficits (rather than the content of these deficits) is more predictive of mortality.

Our findings are consistent with previous research associating various social factors, generally studied one at a time, with health and survival. For example, increased social ties, participation in groups, contact with friends and family, and perceived social support have been associated with survival.(Blazer 1982; Schoenbach, Kaplan et al. 1986; Seeman, Kaplan et al. 1987; Seeman, Berkman et al. 1993) Social disengagement, low participation in leisure activities, and limited social networks have been associated with cognitive decline and dementia(Bassuk, Glass et al. 1999; Fratiglioni, Wang et al. 2000; Wang, Karp et al. 2002; Fratiglioni, Paillard-Borg et al. 2004) and disability.(Mendes de Leon, Glass et al. 2003) Trust and voluntary sector participation are associated with survival at state and neighbourhood levels.(Kawachi, Kennedy et al. 1997; Lochner, Kawachi et al. 2003) Weak social cohesion has been proposed as an explanation for observed links between poor health and income inequalities(Wilkinson 1996) and social status inequalities.(Marmot 2004)

The social vulnerability index is a new measure which allows pragmatic quantification of important health information. It appears to be a valid measure, as it predicts mortality and has preserved properties in two independent samples, though further study is warranted to strengthen understanding of its validity and properties. Validation in further independent samples is warranted. *Content and construct validity* are addressed by embedding the index in a theoretical framework(Hepburn 2003; Andrew 2005) and including social factors that have been found to be relevant in characterizing individuals' social situations and to health outcomes. The weak to moderate correlation seen with frailty is evidence for *criterion and convergent validity*, as some relationship between social vulnerability and frailty is reasonable, though the two are distinct measures. The remarkable conservation of the properties of the social vulnerability index approach and associations (albeit of two indices differing in the details of their construction but sharing a common approach and theoretical basis) with health in two different cohorts of older Canadians suggests *generalizability and reproducibility*, though replication in other populations and settings is needed. As the social vulnerability index is a new measure, its reliability (within and between raters, and over time) has yet to be quantified, but is of interest, particularly in considering potential applicability to clinical settings.

The social vulnerability index is an aggregate of items that each have been put forward as reflecting particular aspects of how social factors interact with health. They were not proposed to be combined in the way that we have done, so it is reasonable to ask whether it is fair to combine these many factors into a single index. Two considerations motivated our combining individual factors, even though we recognize that the factors come from different theoretical backgrounds and not all were intended to be combined as we have done. The first is entirely pragmatic. Large numbers of factors are difficult to handle in multivariable models, and require impracticably large sample sizes, especially if interactions are to be modeled. The second motivation for combining factors was so that we could study the properties of the social vulnerability index. In working with the frailty index, we have been struck by the insights that it allows regarding the complexity of frailty. Analyzing the properties of the frailty index has allowed us to employ tools from mathematics which allow us to consider complexity more formally, and not just as a synonym for 'complicated'. For example, the frailty index appears to accumulate at a characteristic rate across studies (at about 0.03/year on a log scale).(Mitnitski, Song et al. 2005) Here, accumulation of social vulnerability with age was seen chiefly with women. The frailty index has a characteristic sub maximal limit (about 0.67), *i.e.* people generally do not have more than two thirds of the deficits included in a frailty index – in other words, when the limit has been achieved, no further deficit accumulation is possible, as further deficits would result in death.(Rockwood and Mitnitski 2006) This is an intriguing observation and we aim to investigate whether there is a maximal limit to how socially vulnerable an individual can become and still survive. Additionally, the frailty index shows reproducible transitions between health states,(Mitnitski, Bao et al. 2006) pointing to additional studies of how individuals transition between levels of social vulnerability – *i.e.* how they accumulate deficits as they move from lower to higher vulnerability.(Mitnitski, Bao et al. 2006)

It is possible that, for example, a principal components analysis might suggest separable domains of social vulnerability. Though such analyses are traditional, they are not without arbitrariness (for example, allowing the operator to specify the number of dimensions to be 'discovered'), and there are reasons to be skeptical about the approach.

It is more instrument-dependent, and thus less generalizable. Many single items that are readily measured in younger people – socioeconomic status in relation to occupation, income and address, for example, are less well measured in people post-retirement, or in neighborhoods in transition.(Grundy and Holt 2001) In general, psychometric reductionist techniques consider fewer variables, but lose information. Here we achieved analytical parsimony with just one variable, without losing items that were individually informative. What is more, the index also allows an essentially continuous distribution of risk rather than the artificially small number of risk groups possible with ordinal variables.

Our approach has certain strengths. Several estimates were closely replicable, despite the social vulnerability indexes being constructed differently in the two samples. This suggests that the social vulnerability index has potentially wide applicability: the constituent variables can differ in different settings as long as the basic tenant of including multiple social factors relating to important broad domains is met. The holistic quantification and measurement of social vulnerability has great potential relevance for health and social policy. Being able to identify individuals and groups who are socially vulnerable could be useful for prediction of health outcomes as well as for targeting of interventions and design of specialized programs. While it is certainly possible to study the health influence of individual social factors, this "one thing at once" approach is limited, especially for older adults in whom complex sets of social circumstances may exist and interact in different (possibly unpredictable) ways to contribute to vulnerability in an aggregate sense. Even older adults who have a particular deficit (*e.g.* who live alone) would still be differentially susceptible to insults of circumstance (*i.e.* those insults that perturb the delicate balance of assets and deficits, strengths and weaknesses, which has thus allowed them to maintain their heath), depending on their profile of other deficits and strengths.

Several of our findings point to interesting sex differences in social vulnerability. In both the CSHA and the NPHS, women had higher social vulnerability index values than men. One might wonder whether this is due to older age among women, but the finding was

independent of age. Correlations with frailty also differed, and were higher for women than for men. Additionally, although women had better survival than men (consistent with many other epidemiological studies), high social vulnerability in women seems to negate this sex benefit, reducing their survival to equal that of less vulnerable men (Figure 11). The index's composition also seems to matter differently between the sexes. For men, survival analyses using re-sampling techniques maintained clear separation into quartiles of social vulnerability, suggesting that for men the specific variables included in the index are not as important as the overall impression of vulnerability. For women, separation was quite clear for the two highest quartiles of social vulnerability, although there was overlap in the survival curves of those less vulnerable. This suggests that for the most socially vulnerable women, the specific individual variables included in the index are less important than they are for those less vulnerable. The reasons for sex differences in the characterization of social vulnerability and in associations with survival are unclear, suggesting a need for further research. Possible contributing factors include sex differences in self-reporting behaviour or coping strategies.

4.5.6 CONCLUSIONS

In two separate samples, we have found that social vulnerability is higher amongst people who are frailer, and that social vulnerability is associated with higher mortality, independent of frailty. Although much work needs to be done in characterizing social vulnerability, clinical and public health services for older people need to recognize that attention to social factors is integral to the provision of care.

4.5.7 ACKNOWLEDGMENTS

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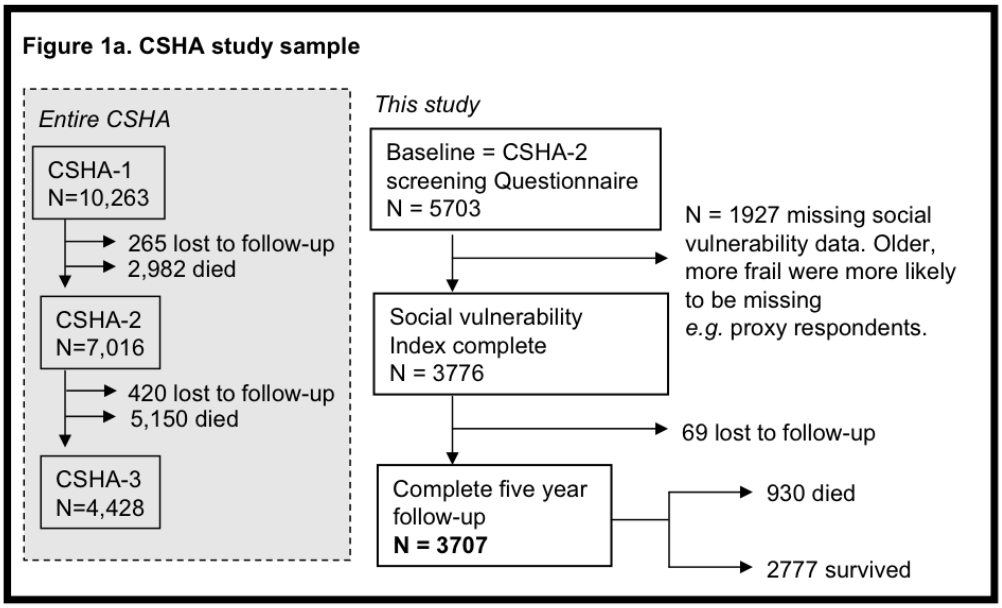
4.5.9 GRAPHICS

Figure 8. Composition of the Canadian Study of Health and Aging sample (Panel a) And the National Population Health Survey (Panel b).



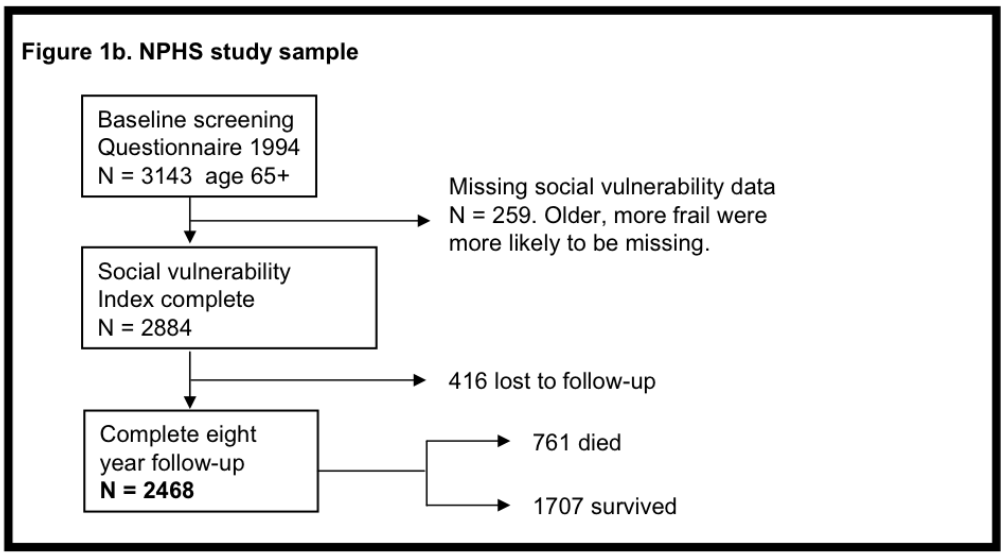


Figure 9. Distributions of social vulnerability: A) Canadian Study of Health and Aging (CSHA), B) National Population Health Survey (NPHS) and frailty: C) CSHA, D) NPHS. While some individuals scored "zero" on the frailty index, no individual was completely free of social vulnerability.

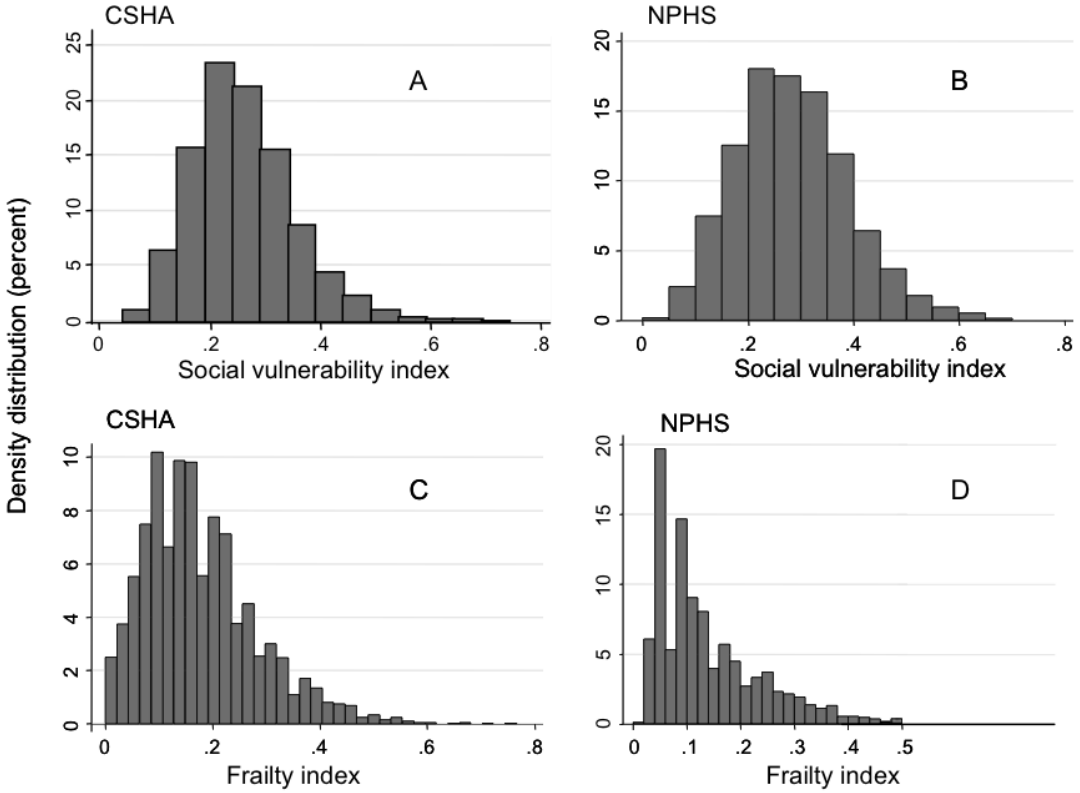


Figure 10. Mean (95% Confidence Interval) social vulnerability in relation to age and sex. Panel A) In the Canadian Study of Health and Aging, social vulnerability increased with age and women had higher index scores than men at all ages. Panel B) In the National Population Health Survey, women showed a trend towards higher scores at older ages.

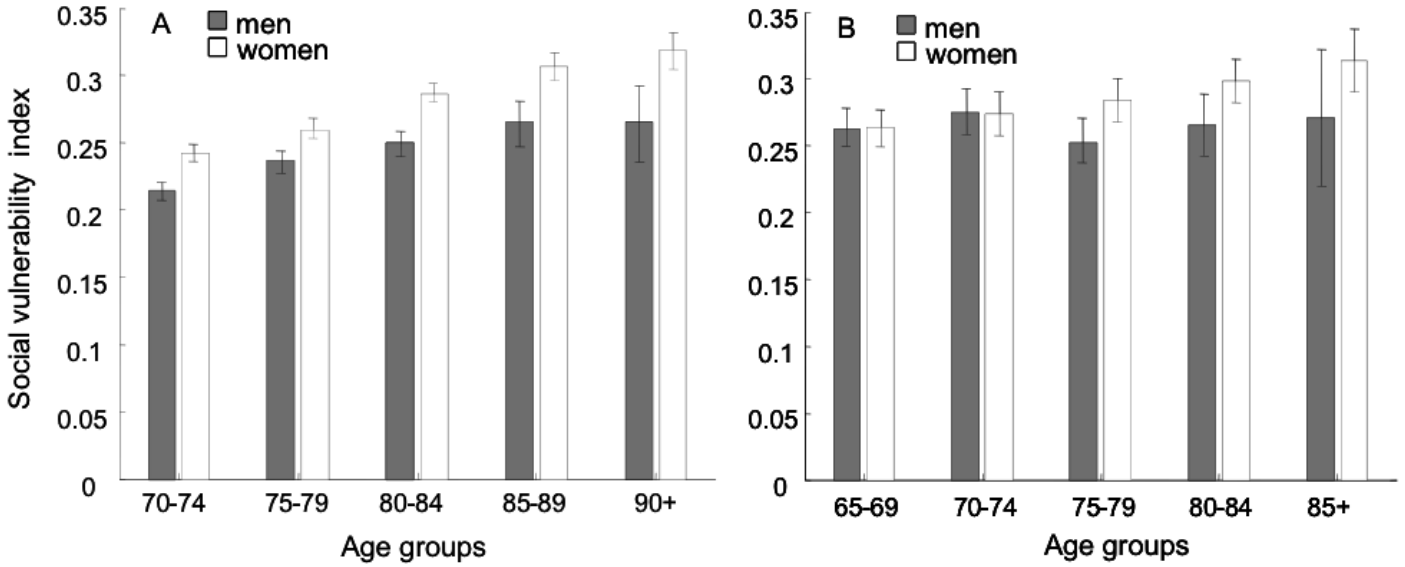


Figure 11. Survival by level of social vulnerability. Panels A (Canadian Study of Health and Aging) and B (National Population Health Survey) show decreasing survival by increasing quartile of social vulnerability. Panels C (CHSA) and D (NPHS) show that although women had better survival than men, survival for women with high social vulnerability was equivalent to that of men with low vulnerability.

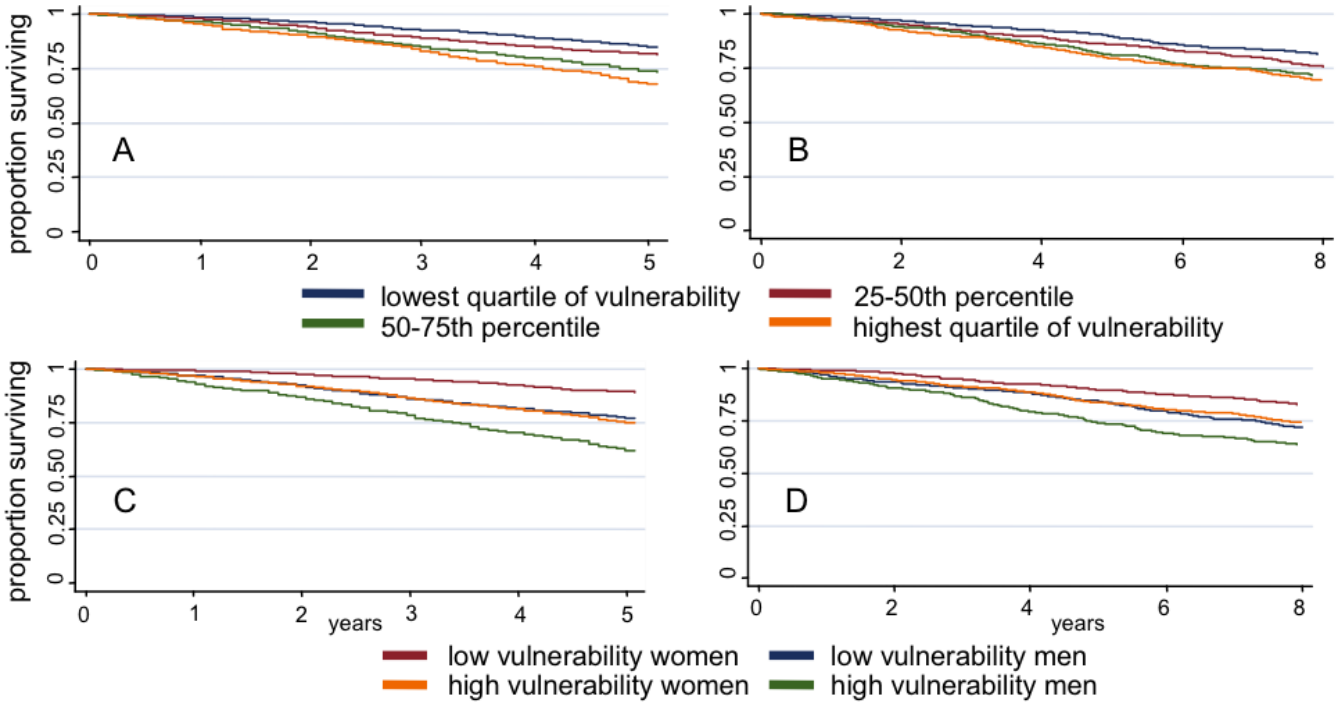


Figure 12. 'Bootstrap by variables' analyses. Survival curves show 100 replications of 80% re-sampling within the Canadian Study of Health and Aging social vulnerability index. Panel A – women, Panel B – men.

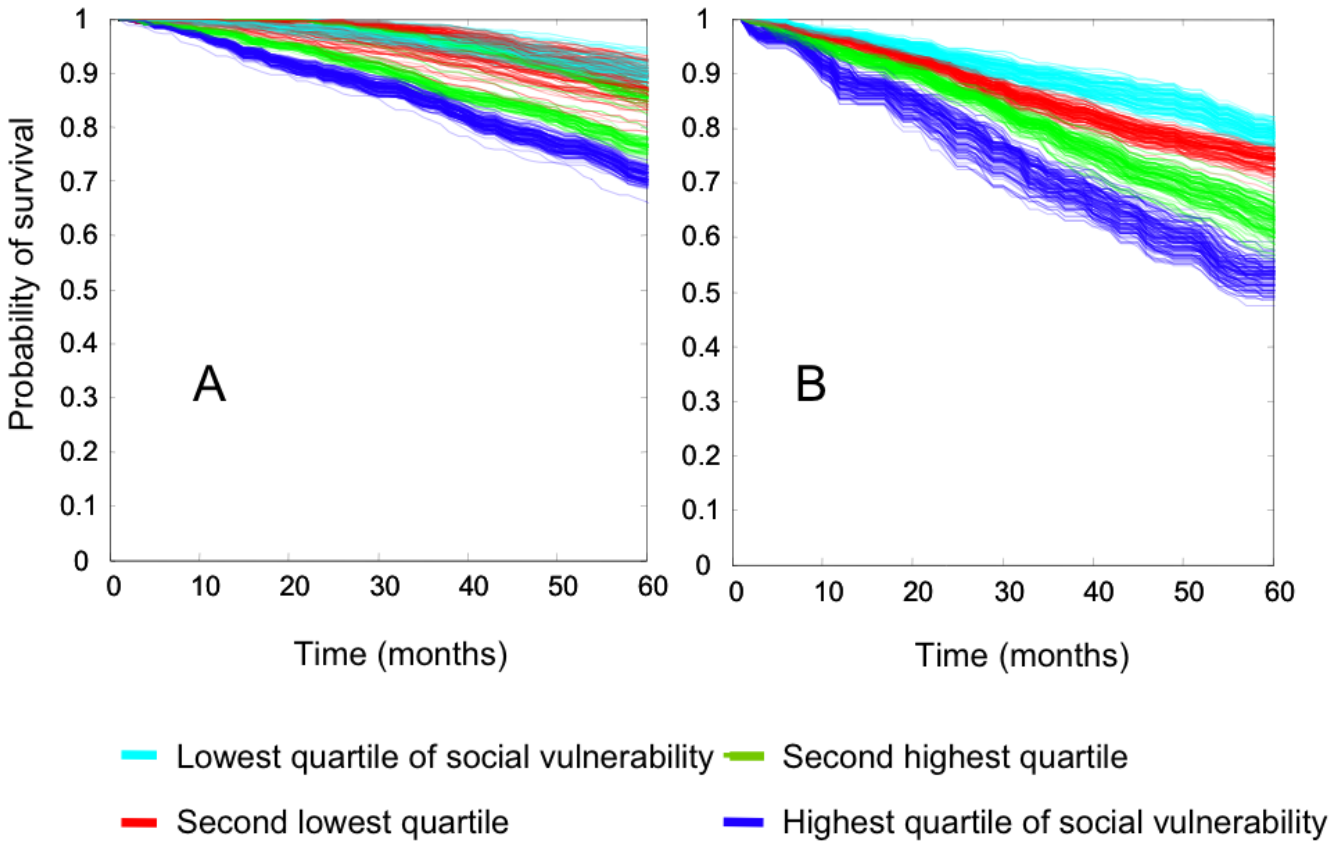


Table 9 Items aggregated in the social vulnerability index used in each survey.

Communication to engage in wider community	
1	Read English or French
2	Write English or French
Living situation	
3	Marital status
4	Lives alone
Social support	
5	Someone to count on for help or support
6	Feel need more help or support
7	Someone to count on for transportation
8	Feel need more help with transportation
9	Someone to count on for help around the house
10	Feel need more help around the house
11	Someone to count on to listen
12	Feel need more people to talk with
13	Number of people spend time with regularly
14	Feel need to spend more time with friends/family
15	Someone to turn to for advice
16	Feel need more advice about important matters
Socially oriented Activities of Daily Living	
17	Telephone use
18	Get to places out of walking distance
Leisure activities	
19	How often visit friend or relatives
20	How often work in garden
21	How often golf of play other sports
22	How often go for a walk
23	How often go to clubs, church, community centre
24	How often play cards or other games
Ryff scales	
25	Feel empowered, in control of life situation
26	Maintaining close relationships is difficult and frustrating
27	Experience of warm and trusting relationships
28	People would describe me as a giving person
How do you feel about your life in terms of …	
29	Family relationships
30	Friendships
31	Housing
32	Finances
33	Neighbourhood
34	Activities
35	Religion
36	Transportation
37	Life generally
Socio-economic status	
38	Does income currently satisfy needs
39	Home ownership
40	Education

A) Canadian Study of Health and Aging

Table 9 Items aggregated in the social vulnerability index used in each survey.

Communication to engage in wider community	
1	Can speak English or French
	Living situation
2	Marital status
3	Lives alone
Social support	
4	Someone to count on for help in crisis
5	Someone to confide in
6	Someone to count on for advice in personal decisions
7	Someone to make you feel loved and cared for
8	Frequency of contact with friends
9	Frequency of contact with relatives
10	Frequency of contact with neighbours
Social engagement and leisure	
11	How often participate in groups
12	How often attend religious services
13	Member of voluntary organisations
14	Participation in physical leisure activities (list of 20)
Empowerment, life control	
15	Too much is expected of you by others
16	You would like to move but cannot (control/empowerment)
17	Neighbourhood or community is too noisy or polluted
18	You have little control over the things that happen to you
19	Feel that you are a person of worth at least equal to others
20	You take a positive attitude towards yourself
21	How often have people you counted on let you down?
Socio-economic status	
22	Not enough money to buy the things you need (income)
23	Educational attainment

B) National Population Health Survey

Table 10. Frailty index constituent variables in a) the Canadian Study of Health and Aging (CSHA) and b) the National Population Health Survey (NPHS).

a) CSHA frailty index

	Variable
1	Eyesight
2	Hearing
3	Help to eat
4	Help to dress and undress
5	Help to take care of appearance
6	Help to walk
7	Help to get in and out of bed
8	Help to take a bath or shower
9	Help to go to the toilet
10	Help in shopping
11	Help to prepare own meals
12	Help to do housework
13	Ability to take medications
14	Ability to handle own finances
15	Poor self-assessed health
16	Hypertension
17	Heart and circulation problems
18	Stroke or effects of a stroke
19	Arthritis or rheumatism
20	Parkinson's Disease
21	Eye trouble
22	Ear trouble
23	Dental problems
24	Chest problems
25	Stomach problems
26	Bladder control problems
27	Bowel control problems
28	Trouble with feet or ankles
29	Trouble with skin
30	Fractures
31	Frequent trouble with pain

As previously published(Mitnitski, Song et al. 2004) but done using a different wave of the CHSA, leaving out items in the social vulnerability index (living alone, telephone use, and ability to get places out of walking distance).

b) NPHS frailty index

	Variable
1	Activities around home restricted due to health problems
2	Difficulty with meal preparation
3	Difficulty with shopping
4	Difficulty with everyday housework
5	Difficulty with chores
6	Difficulty with self care
7	Difficulty with moving about inside home
8	Food allergy
9	Other allergies
10	Asthma
11	Arthritis
12	Back problems excluding arthritis
13	Hypertension
14	Migraines
15	Chronic bronchitis, emphysema
16	Sinusitis
17	Diabetes
18	Epilepsy
19	Heart disease
20	Cancer
21	Stomach trouble or ulcers
22	Stroke
23	Urinary incontinence
24	Alzheimer's disease, dementia
25	Cataracts
26	Glaucoma
27	Other diseases
28	Vision problems
29	Hearing problems
30	Speech problems
31	Trouble getting around the neighbourhood
32	Dexterity
33	Trouble with thinking to solve everyday problems
34	Trouble with Pain
35	Pain severity
36	Feelings – happiness

As previously published(Mitnitski, Song et al. 2005) leaving out items in the social vulnerability index.

Table 11. Jackknife by variables results using CSHA data. Excluding individual variables from the index does not affect associations with mortality.

Index excludes	Odds Ratio	95% Confidence Interval	P>|z|
full index	1.06	1.02 - 1.10	0.002
Education	1.06	1.02 - 1.09	0.003
Read	1.06	1.02 - 1.10	0.001
Write	1.06	1.02 - 1.10	0.001
Marital status	1.06	1.03 - 1.10	0.001
Lives alone	1.07	1.03 - 1.10	0.001
Support - help	1.06	1.02 - 1.10	0.002
Feel need more help	1.06	1.02 - 1.10	0.001
Support -transportation	1.06	1.02 - 1.10	0.002
Feel need more help with transportation	1.06	1.02 - 1.10	0.002
Support -chores	1.07	1.03 - 1.11	0.001
Feel need more help with chores	1.06	1.02 - 1.10	0.002
Support - listen	1.06	1.02 - 1.10	0.002
Feel need more people to talk with	1.06	1.02 - 1.10	0.002
Support –number of visits	1.06	1.02 - 1.10	0.003
Feel need more visits	1.06	1.02 - 1.10	0.002
Support - advice	1.06	1.02 - 1.10	0.001
Feel need more advice	1.06	1.02 - 1.10	0.001
Telephone use	1.06	1.02 - 1.10	0.002
Get out of walking distance	1.06	1.02 - 1.09	0.003
Visit friends & relatives	1.06	1.02 - 1.10	0.002
Gardening	1.06	1.02 - 1.10	0.003
Participate in sports	1.06	1.02 - 1.10	0.002
Go for a walk	1.06	1.02 - 1.10	0.002
Clubs, church	1.06	1.02 - 1.10	0.003
Play cards, games	1.06	1.02 - 1.09	0.003
Control, empowerment	1.06	1.02 - 1.10	0.002
Close relationships	1.06	1.02 - 1.10	0.001
Trusting relationships	1.06	1.02 - 1.10	0.002
Giving person	1.06	1.02 - 1.10	0.002
Relationships	1.06	1.02 - 1.10	0.001
Friends	1.06	1.02 - 1.10	0.002
Housing situation	1.06	1.02 - 1.10	0.001
Finances	1.06	1.02 - 1.10	0.001
Neighbourhood	1.06	1.02 - 1.10	0.001
Active	1.06	1.02 - 1.10	0.002
Religion	1.06	1.02 - 1.10	0.001
Transport	1.06	1.02 - 1.10	0.002
Life generally	1.06	1.02 - 1.10	0.002
Income sufficient	1.06	1.02 - 1.10	0.001
Home ownership	1.06	1.02 - 1.10	0.001

CHAPTER 5 SOCIAL VULNERABILITY AND COGNITIVE DECLINE

5.1 PROLOGUE

In the previous Chapter, social vulnerability was examined in relation to frailty and mortality. Here, the social vulnerability index is studied in relation to another important health outcome for older people: cognitive decline. The main study presented in this Chapter was done using the Canadian Study of Health and Aging, in which participants completed the Modified Mini Mental State Examination (3MS) cognitive screening test at each wave.

When we consider cognitive decline over time, it is important to take a step back and think about what constitutes a clinically meaningful (and not just statistically detectable) change in performance on a given measure. This had not been previously established for the 3MS; the first study in this chapter was therefore done in order to establish what would represent a clinically meaningful magnitude of change in 3MS test scores over time.

5.2 PUBLICATION DETAILS (3MS)

Andrew, M. K. and K. Rockwood (2008). "A 5 point change in Modified Mini Mental State Examination was clinically meaningful in community-dwelling elderly people." J Clin Epidemiol **61**(8): 827-831.

5.3 A 5 POINT CHANGE IN MODIFIED MINI MENTAL STATE EXAMINATION WAS CLINICALLY MEANINGFUL IN COMMUNITY-DWELLING ELDERLY PEOPLE

5.3.1 ABSTRACT (3MS)

OBJECTIVE: To determine what change in the Modified Mini Mental State Examination (3MS), a validated and widely used cognitive screening tool for which meaningful change scores have not been clearly characterized, should be considered meaningful.

STUDY DESIGN AND SETTING: The 3MS was administered at baseline after five and ten years, as part of the population-based Canadian Study of Health and Aging. We calculated Cohen's effect sizes to estimate detectable changes in 3MS screening scores over five and ten years in this large and representative study sample.

RESULTS: 3255 older adults who were community-dwelling at baseline completed the 3MS as part of a screening interview at all three interviews. Mean 3MS score was 90.4 (SD 6.9) at t_1, 89.1 (SD 8.2) at five years, and 85.8 (SD 13.0) at ten years. A change of just over one point, over five and ten years, represented a clinically detectable change with a medium effect size (Cohen's d=0.5).

CONCLUSION: While a change of ≥1 point was clinically detectable, consideration of additional criteria for clinical meaningfulness suggested that a change of ≥5 points likely represents a clinically meaningful difference for groups, and is a reasonable choice of cutoff in studies using the 3MS to define cognitive change in individuals.

5.3.2 WHAT IS NEW

- What level of change on the Modified Mini Mental State Examination (3MS) is clinically important is disputed
- "Importance" varies by context: both clinical detectability and clinical meaningfulness can be considered when interpreting change scores on instruments like the 3MS
- While a change of ≥1 point in 3MS score was clinically detectable, a change of ≥5 points is more likely to be clinically meaningful
- A change of ≥5 points on the 3MS is a reasonable choice of cutoff in studies using the 3MS to define cognitive change

5.3.3 INTRODUCTION (3MS)

The Modified Mini Mental State Examination (3MS) is a validated cognitive screening tool.(Teng and Chui 1987) Although widely used in studies of change in cognitive status, the test difference that represents a meaningful change over specific time intervals has not been well characterized. For example, claims about meaningfulness have been made for differences of as small as about 1 point per year (or 5 points over 4-6 years) change the 3MS score,(Yaffe, Lindquist et al. 2003; Koster, Penninx et al. 2005; Shadlen, Siscovick et al. 2006; Wengreen, Munger et al. 2007; Yaffe, Haan et al. 2007) to a 10 point decline over 5 years,(Maxwell, Hogan et al. 1999; Maxwell, Hicks et al. 2005) and to a minimal 17 point change.(Correa, Perrault et al. 2001) Other reports make mention of statistically significant differences in 3MS scores between groups or over time, without explicitly addressing their clinical meaningfulness.(Bernick, Katz et al. 2005; Elkins, Longstreth et al. 2006) In an earlier analysis from the Canadian Study of Health and Aging (CSHA), Tombaugh studied the reliability of changes in 3MS scores in a small sub-sample (n=160) over short (3 months) and long (5 years) time intervals, and found that a change of 5-10 points over five years might signal a relevant change in cognition.(Tombaugh 2005) As there is no widely accepted definition of meaningful

cognitive decline on the 3MS, we sought to determine what change in the 3MS score should be considered relevant in studies of cognitive change over time using a large prospective sample of older adults.

No universally accepted standard exists for the quantification of clinical meaningfulness. However, considerable recognition is afforded to the proposal by Cohen that the estimation of effect sizes at least allows clinical detectability to be estimated across a wide range of conditions.(Cohen 1988; Rockwood and MacKnight 2001) The effect size expresses a signal to noise ratio by allowing calculation of change or difference between two sample means taking variance into account. Other attributes of clinical meaningfulness have been proposed to include valid design of both the study and the analysis, presence of a biological gradient, reproducibility between studies, and convergence between different assessment measures.(Rockwood and MacKnight 2001) Here we report the clinical detectability of changes in the 3MS, which we then evaluate in relation to the clinical meaningfulness of detectable change.

5.3.4 METHODS (3MS)

Sample

The Canadian Study of Health and Aging (CSHA) is a representative study of dementia and related conditions in older Canadians (age ≥65). The sample of 10,263 individuals was clustered within 5 regions and stratified by age, with over-sampling of those aged 75 and older. A baseline (CSHA-1) screening interview was conducted with 9,008 community-dwelling participants in 1991. Clinical examinations were conducted on all 1,255 individuals in long term care facilities, as well as community-dwellers who screened positive for cognitive impairment (defined as a Modified Mini-Mental State Examination score of <78), and a random sample without impaired cognition. As such, the CSHA clinical sample (n=2,914) is enriched for cognitive impairment and frailty while the screening sample consists of less frail individuals. Follow-up at 5 (CSHA-2) and 10 (CSHA-3) years included repeat clinical assessments for these 2,914 individuals,

and repeat screening assessments for community-dwellers who were not in the clinical sub-sample. Clinical examinations were also undertaken on people with incident cognitive impairment between study waves and on a second random sample without cognitive impairment.(Rockwood, McDowell et al. 2001)

For this analysis we included only the 3,255 CSHA participants who had complete 3MS data from the screening interview at all three time points. All were community-dwelling and aged ≥65 years at baseline.

Measures

The 3MS is a cognitive screening tool with a possible score of 0-100. It includes items testing immediate and remote memory, orientation, attention and concentration, language and naming, verbal fluency, and executive function.(Teng and Chui 1987) The 3MS was administered to all participants as part of a screening interview at baseline. At five and ten years it was re-administered in a screening interview to surviving participants who remained community-dwelling, and as part of a complete clinical examination in those who were institutionalized.

Function was measured using a modified version of the Older Americans Research Survey (OARS) Activities of Daily Living (ADL) and Instrumental ADL (IADL) items combined.(Thomas, Rockwood et al. 1998) This self-reported assessment has been extensively validated and is widely used.(McDowell 2006)

Statistical analysis

The effect size is a useful means of assessing the meaningfulness of change in test scores taken at two time points. In general terms, Cohen's *d* is calculated as shown in equation 1.1, where M_1 and M_2 are the sample means at times 1 and 2. Effect sizes are interpreted as being either small *(d* = 0.2), medium (*d* = 0.5) or large (*d* = 0.8).(Cohen 1988) The pooled standard deviation is calculated using equation 1.2.

Equation 1.1

$$\text{Cohen's } d = \frac{M_1 - M_2}{\sigma_{pooled}}$$

We calculated the mean and standard deviation of 3MS scores at each examination using the STATA 8.0 statistical software package. In a further analysis, to account for the negatively skewed distribution of 3MS scores, the values were reflected by subtracting each from 101 and applying a log transformation. We also used a modified equation as suggested by Cohen to take the extra power (and stronger effect size) gained through the use of matched (*i.e.* before-after) test scores, dividing the initially calculated *d* by $\sqrt{(1-r)}$, where r represents the correlation between the two sets of test scores (equation 1.3).(Cohen 1988)

Equation 1.2

$$\sigma_{pooled} = \sqrt{\frac{SD_1^{\,2} + SD_2^{\,2}}{2}}$$

To evaluate clinical meaningfulness, we evaluated change scores in relation to age (to assess a biological gradient) by comparing the odds of a 1-point and a 5-point 3MS decline across 5-year age strata. To evaluate the convergence of measures, we correlated the change in the 3MS with change in function as measured by independence in ADL and IADL. Reproducibility was assessed by comparing the detectable difference in 3MS scores between CSHA-1 and CSHA-2 with that between CSHA-2 and CSHA-3.

Equation 1.3 $$\text{Modified Cohen's } d = \frac{\left(\frac{M_1 - M_2}{\sigma_{pooled}} \right)}{\sqrt{(1-r)}}$$

5.3.5 RESULTS (3MS)

The mean baseline age of the 3,255 people with complete 3MS test data at all three time points was 72.1 (SD 5.5) years. Sixty-three percent were women. The 3MS scores had a negatively skewed distribution at all three time points (Figure 13). The mean (SD) 3MS scores were 90.4 (6.9) at baseline, 89.1 (8.2) at five years, and 85.8 (13.0) at ten years.

The pooled SD was 7.6 for the five year follow-up from CSHA-1 to CSHA-2, and 10.4 for the ten year follow-up from CSHA-1 to CSHA-3. Solving for the difference in means, a decline of $\geq$4 points over 5 years or $\geq$5 points over 10 years on the 3MS represented a medium effect size (Cohen's $d = 0.5$).

When 3MS scores were reflected and log transformed to account for the skewed distributions of test scores, the effect size calculations showed even smaller changes to fall in the meaningful range. The pooled SD was 2.06 at 5 years and 2.16 at 10 years, suggesting that a decline of 1.1 points represents a meaningful effect size. The test scores were moderately correlated at the three time points: r=0.67 for 5 year follow-up and r=0.48 for 10 year follow-up. Applying the correction in equation 1.3 suggested by Cohen to account for the extra power (and hence the strengthened effect size) gained by

using matched values (*i.e.* before-after 3MS scores), a difference of 1 point remained detectable in terms of effect size. Given that the test scores were matched in the before-and-after design, this is the most appropriate calculation upon which to base the discussion of clinical detectability and clinical meaningfulness, and is used hereafter in this paper.

Figure 14 shows the odds of a 1-point change (Panel A) and a 5-point change (Panel B) across the 5-year age strata. In evaluating the convergence of measures, the correlation between change in 3MS scores and change in ADL/IADL function was 0.51. In assessing reproducibility, detectable declines in 3MS score calculated using equation 1.3 were the same over the five year periods from CSHA-1 to CSHA-2 and from CSHA-2 to CSHA-3 (≥1 point).

5.3.6 DISCUSSION (3MS)

In a large longitudinal sample of older Canadians, we found that a decline of ≥1 point on the 3MS was clinically detectable, with a medium effect size (Cohen's $d = 0.5$). However, applying further criteria for clinical meaningfulness, a change of 5 points seemed relevant. Our findings also suggest that: 1) at least between 5 and 10 years, the length of the of follow-up period does not seem to affect the difference in 3MS scores that should be considered detectable, and that; 2) small changes, on the order of 5 points or even less, may well be important.

How well does clinical detectability translate into clinical meaningfulness? While a 5-point difference might be meaningful for groups, many clinicians would doubt that of a 1-2 point change. It appears therefore that we should distinguish between clinical *detectability* and clinical *meaningfulness*.(Rockwood and MacKnight 2001; Rockwood, Fay et al. 2006) Clinical *detectability* refers to the ability of an instrument to detect changes over time, without attaching value judgments about whether such a change represents pathological change or normal fluctuation. Cohen's effect size

approach,(Cohen 1988) in its focus on the properties of the instrument, should be seen as addressing the question of detectability. This is consistent with our finding that the length of observation time does not materially affect the effect size. Attributions of clinical *meaningfulness*, however, would seem to imply an additional judgment about whether the detected change is within the range expected with normal aging or test-retest fluctuation, in which case we might expect that length of follow-up time would be an important consideration, given that some degree of decline in cognition might be expected with normal aging. Here, as with any epidemiological study, inferences are made at the group rather than the individual level. As such, even though a 1-point change represents a detectable effect at a group level, it does not necessarily hold that a 1-point change in a given individual's score would be clinically meaningful.

Various criteria may be considered in assessing clinical meaningfulness, including presence of a biological gradient, reproducibility between studies, and convergence between different assessment measures.(Rockwood and MacKnight 2001) We noted considerable overlap in the confidence intervals for the different age groups' odds of suffering a 1-point decline, but not a 5-point decline in 3MS score (Figure 14). That the odds of a 5- point decline increase with age suggests a biological gradient. This supports the clinical meaningfulness of a 5-point change, but not a 1-point change. Correlation between 3MS decline and functional decline illustrates appropriate convergence of measures. Our finding of very similar detectable 3MS declines from CSHA-1 to 2 and CSHA-2 to 3 demonstrates reproducibility. In short, many criteria for clinical meaningfulness are met by a 5-point change in the 3MS.(Rockwood and MacKnight 2001)

Our findings must be interpreted with caution. Although the CSHA sample size is large and follow-up data are available over 10 years, we excluded individuals who died during the 10 year follow-up period, and due to study design, also those who had been institutionalized. To investigate the possible influence of bias introduced by excluding institutionalized individuals, who would have been more likely to have suffered cognitive decline, we performed a separate calculation using individuals who had complete 3MS

data at baseline and five year follow-up, which because of study design, also allows inclusion of institutionalized individuals (the 3MS was performed with institutionalized individuals as part of the complete clinical examination at CSHA2 but not CSHA3). This resulted in N=5,887, a mean 3MS score of 88.1 (SD 8.7) at t_1, and a mean score of 83.5 (SD 15.0) at five years. A change of 6.2 points would thus be considered clinically relevant based on a medium effect size (Cohen's $d = 0.5$). This suggests that the definition of what represents meaningful cognitive decline depends to some extent on the study sample or population to which the definition is applied. Samples that include frailer individuals who are more likely to suffer greater cognitive decline will have greater variance and thus clinical meaningfulness may require a bigger change in test scores. That said, we found the effect to be relatively small (≥4 *vs.* ≥6 point decline on the 3MS). Using the transformation to account for skewed 3MS score distribution, the result was still that a change of >1-point represents a medium effect size.

A 5-point decline (over four years) was considered meaningful by Koster *et al.* in a study of socioeconomic factors and cognitive decline,(Koster, Penninx et al. 2005) and (over five years) by Yaffe *et al.* in studies of the metabolic syndrome, inflammatory markers, and cognition,(Yaffe, Lindquist et al. 2003; Yaffe, Haan et al. 2007) all citing other studies that had also used a 5-point decline as justification. Johnston *et al.* used a definition of ≥1 point annual decline over five years but did not justify their use of this cutoff.(Johnston, O'Meara et al. 2004) A decline of ≥ 5 points was considered high risk for possible dementia in the Cardiovascular Health Cognition Study.(Kuller, Lopez et al. 2003; Lopez, Kuller et al. 2003) These authors found that a decline of ≥5-points did correlate with increased incidence of clinically diagnosed dementia.(Kuller, Lopez et al. 2003)

Cognitive decline has been studied previously in the CSHA.(Maxwell, Hogan et al. 1999; Correa, Perrault et al. 2001; Maxwell, Hicks et al. 2005; Tombaugh 2005) Maxwell *et al.* chose a decline of ≥10 points over 5 years on the 3MS to represent a meaningful change, both citing other studies that had used a 5-point decline, and noting that the 3MS standard deviation in their sample was approximately 10 points. They provided additional

validation for a 5-point change by demonstrating higher admission rates to institutions and higher rates of clinically-diagnosed dementia among those with a decline of ≥10 points.(Maxwell, Hogan et al. 1999) In his sub-study of 3MS change in the CSHA, Tombaugh suggested that a change of 5-10 points over 5 years might be more relevant for individuals at the lower end of the 3MS score distribution due to the phenomenon of regression to the mean upon repeat testing.(Tombaugh 2005) Also using CSHA data, Correa *et al.* found that the discrepancy between repeated 3MS administrations within a three month period in community dwellers with dementia may be as high as +/-16 points.(Correa, Perrault et al. 2001)

Defining meaningful cognitive decline using the 3MS depends on the characteristics of the sample used. In defining meaningful change, a distinction between clinical detectability and clinical meaningfulness is useful. Our findings suggest that a decline of 5-points or possibly less over 5-10 years is meaningful and would be a reasonable choice for definition of endpoints in future studies of cognitive decline.

5.3.7 ACKNOWLEDGEMENTS (3MS)

This analysis was supported by the Canadian Institutes for Health Research grant MOP 62823. The data reported in this article were collected as part of the Canadian Study of Health and Aging. The core study was funded by the Seniors' Independence Research Program, through the National Health Research and Development Program (project no. 6606-3954-MC(S)). Melissa Andrew was supported by a Ross Stewart Smith Fellowship. Kenneth Rockwood receives career support from the Dalhousie Medical Research Foundation as Kathryn Allen Weldon Professor of Alzheimer Research. The sponsors had no input into the analyses, and Dr. Rockwood holds a copy of and has full access to the CSHA dataset at Dalhousie University.

5.3.8 AUTHORS' CONTRIBUTIONS (3MS)

KR is a principal investigator in the CSHA. Both authors participated in the conceptualization of the analysis. MKA did the analyses and wrote the first draft of the paper. KR reviewed the analyses and revised the manuscript. Both authors read and approved the final manuscript.

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5.3.10 GRAPHICS (3MS)

Figure 13. Distributions of Modified Mini-Mental State Exam (3MS) scores at (A) CSHA-1, (B) CSHA-2, and (C) CSHA-3.

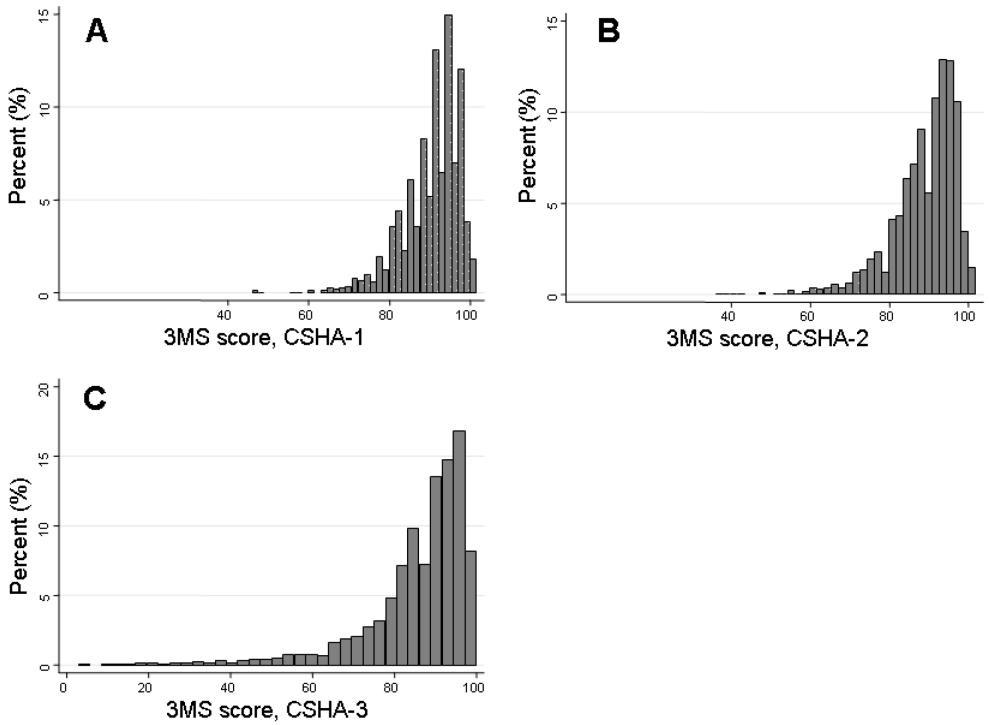
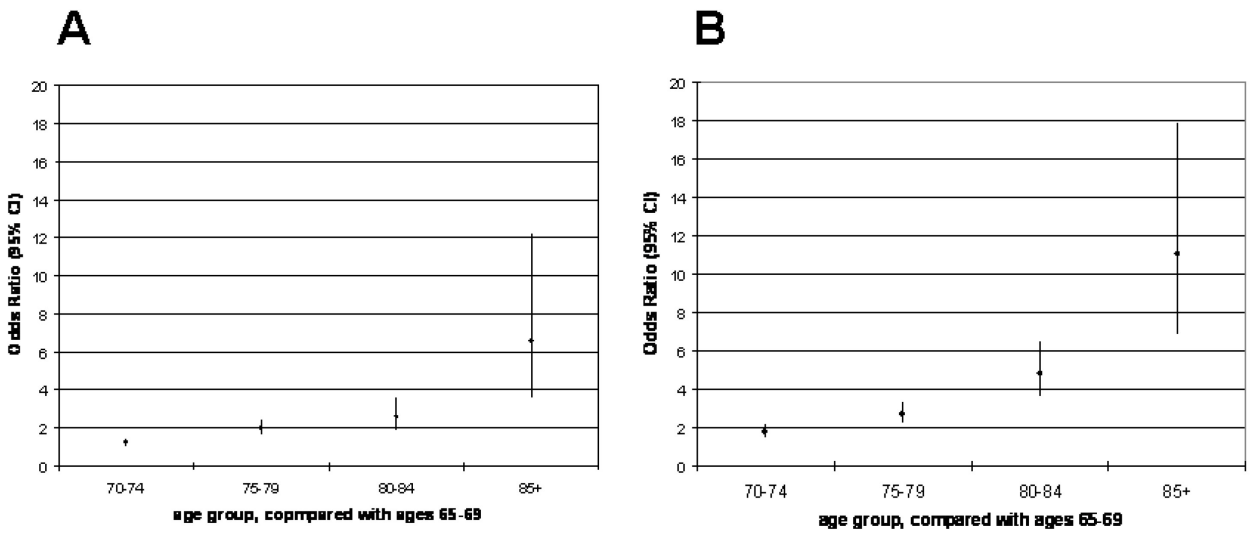


Figure 14. Odds of decline in 3MS score according to age groups. (A) Odds of one point decline in 3MS score over 10 years. (B) Odds of five point decline in 3MS score over 10 years. Odds ratios have ages 65-69 as comparison group. Confidence intervals overlap for a one point decline but not for a five point decline, suggesting that while a one point decline may be clinically detectable, a five point decline in 3MS score has a biological gradient and is more likely to be clinically meaningful.



5.4 PUBLICATION DETAILS:

Andrew, M. K. and K. Rockwood (2010). "Social vulnerability predicts cognitive decline in a prospective cohort of older Canadians." Alzheimers and Dementia **6**(4):319-325.

5.5 SOCIAL VULNERABILITY PREDICTS COGNITIVE DECLINE IN A PROSPECTIVE COHORT OF OLDER CANADIANS

5.5.1 ABSTRACT

BACKGROUND: While numerous social factors have been associated with cognition in older adults, these findings have been limited by the consideration of individual factors in isolation. We investigated whether social vulnerability, defined as an index comprising many social factors, is associated with cognitive decline.

METHODS: In this secondary analysis of the Canadian Study of Health and Aging, 2468 community-dwellers aged 70+ were followed for five years. The social vulnerability index incorporated 40 social variables. Each response was scored as 0 if the "deficit" was absent and 1 if it was present; the 40 deficit scores were then summed. For some analyses, index scores were split into tertiles of high, intermediate and low social vulnerability. Cognitive decline was defined as a ≥5 point decline in the Modified Mini-Mental State Exam (3MS). Associations of social vulnerability with five-year cognitive decline (adjusting for age, sex, frailty, and baseline cognition) were analyzed using logistic regression.

RESULTS: Mean social vulnerability was 0.25 (SD 0.09), or 9.9 deficits of the list of 40. The median cognitive change of -1.0 (IQR -6, 2) points on the 3MS at 5 years. 743 individuals (30% of the sample) experienced a decline of ≥5 points on the 3MS. Each additional social deficit was associated with increased odds of cognitive decline (OR 1.03, 95% CI:1.00-1.06, p=0.02). Compared to those with low social vulnerability, individuals with high social vulnerability had a 36% increased odds of experiencing cognitive decline (OR 1.36, 95% CI: 1.06-1.74, p=0.015).

CONCLUSIONS: Increasing social vulnerability, defined using a social vulnerability index incorporating many social factors, was associated with increased odds of cognitive decline over five years in this study of older Canadians. Further study of social vulnerability in relation to cognition is warranted, with particular attention to potential interventions to alleviate its burden.

Key words: cognition, cognitive decline, frailty, social, social vulnerability

5.5.2 INTRODUCTION

Many social factors have been individually associated with health, including socio-economic status (measured on both individual and group levels), mastery and control over life circumstances, social support from family and friends, social engagement in group activities, social capital, and social cohesion.(Berkman 2000; Kawachi and Berkman 2000; Putnam 2000; Andrew 2010) Social engagement and social support, considered separately, have been associated with higher performance on cognitive tests in older people without dementia.(Krueger, Wilson et al. 2009) In older adults, larger social network size, social engagement, and socio-demographic factors such as income and education each have been shown to be protective against cognitive decline (Bassuk, Glass et al. 1999; Fratiglioni, Wang et al. 2000; Seeman, Lusignolo et al. 2001; Zunzunegui, Alvarado et al. 2003; Holtzman, Rebok et al. 2004). Among older men followed longitudinally in the Honolulu Asia Aging Study, a decline in social engagement between mid life and late life was predictive of incident dementia.(Saczynski, Pfeifer et al. 2006) Another longitudinal study, of Spanish older adults, found that trajectories in cognitive decline were associated with trajectories in social engagement.(Beland, Zunzunegui et al. 2005) Additionally, there is evidence for prevention of dementia with an active and socially integrated lifestyle, which includes participation in physical, social, and mental leisure activities and having strong social networks and ties with others (Fratiglioni, Paillard-Borg et al. 2004). These findings, while supporting the notion that social factors

are important for the maintenance of healthy cognitive function, have been somewhat limited by the consideration of single social factors in isolation rather than taking potentially interacting and inter-related social factors into account.

Ideally, the study of how social factors affect health and cognition in old age would embrace the complexity of the multiple interacting social factors which influence the lives of older adults. Older adults' social circumstances, in their entirety, may be seen as potentially conveying protection (if the social factors are positive) against adverse health outcomes; conversely, a collection of social factors with negative influence (or "social deficits") may convey vulnerability to a variety of health-related insults such as illnesses, functional impairments, and mortality. As such, a social vulnerability index may provide just such an opportunity, allowing conceptual unification of the spectrum of social influences on health, providing a more holistic understanding of older adults' complex social situations, and allowing for study of how social vulnerability may be associated with cognition and cognitive decline. Earlier, we found that increasing social vulnerability, as measured by an index that included socioeconomic factors, social supports, social engagement, and mastery, was associated with decreased survival over 5 and 8 years, and that the properties of the social vulnerability index were replicable in different datasets (Andrew, Mitnitski et al. 2008). Here, we aimed to investigate whether social vulnerability is associated with cognitive decline in community-dwelling older adults aged 70 years and older.

5.5.3 METHODS

Study sample

The Canadian Study of Health and Aging (CSHA) is a representative study of dementia and related conditions in Canadians aged ≥65 years, details of which have been published elsewhere (Rockwood, McDowell et al. 2001). Sampling was population-based and representative of English- and French-speaking older Canadians. The sample was clustered by region and stratified by age, with over-sampling of those aged 75 and older.

In CSHA-1 (1991-92), a screening interview was conducted with 9,008 community-dwelling participants. Follow-up at 5 (CSHA-2) and 10 (CSHA-3) years included repeat screening assessments. At each time point, a clinical examination was also conducted. This was done for all participants who had been institutionalized at baseline, for those who scored below the screening threshold of 78 points on the 3MS, and for a random sample of controls who had 3MS scores >=78.

Here, baseline data were drawn from CSHA-2, as it had included enriched information about social factors. As such the study sample comprised community-dwelling adults aged 70+ at baseline. Of the 5703 participants in the screening interview at CSHA-2, 3776 had complete social vulnerability index data; all of these also had a baseline 3MS score. The 1927 individuals who were missing social vulnerability data were older and more frail than those with complete social data, which may reflect the reliance on proxy respondents for those who were unable to answer for themselves. 2468 individuals completed a follow-up 3MS five years later at CSHA-3 as part of the follow-up screening interview. Of the 1308 who did not complete 3MS at five years, 930 had died and 69 were lost to follow-up. The 309 participants who survived to five years but did not complete the follow-up 3MS included those who were demented or institutionalized at baseline. While these individuals did not complete a screening 3MS at follow up, they did have clinical examination to diagnose dementia. (Figure 15). All 2468 individuals had complete data for the covariates age and sex, though 77 were missing frailty data. Imputation of missing values was not attempted because individuals who were missing data for one variable in the index tended to be missing data for many. The sample sizes were thus necessarily reduced, for analyses adjusting for frailty, as indicated in the presentation of Results.

Measures

A social vulnerability index was constructed using self-report variables relating to potential social "deficits" (Table 12). Each respondent was assigned a score of 0 if a binary (yes/no) social deficit was absent and 1 if it was present; intermediate values were applied in equal increments in cases of response with more than two categories. As such, vulnerability on each deficit was mapped to the 0-1 interval. For example, items with three response categories, such as the social support item "Do you have someone to count on for help or support," were scored 0 for no deficit, 0.5 for intermediate deficit (e.g. "sometimes"), and 1 for a reported deficit (e.g. "never"). Similarly, an item with 5 categories would be coded 0, 0.25, 0.5, 0.75, 1. For each individual, a social vulnerability index was constructed using the sum of the deficit scores for the 40 social variables in the CSHA, yielding a maximum theoretical range of 0-40. This can also be expressed as a "proportion of deficits" index by dividing the summed score by the number of deficits considered (40). For some analyses, the social vulnerability index was grouped into three equal tertiles, designating high, intermediate, and low social vulnerability. The social vulnerability index has previously been validated in relation to frailty (social vulnerability moderately correlated with frailty, r=0.37 for men and r=0.47 for women in the CSHA) and mortality (each additional social deficit was associated with increased odds of mortality over 5 years by 5% in the CSHA: OR 1.05, 95% CI: 1.02-1.07), and its properties appear to be preserved across datasets (Andrew, Mitnitski et al. 2008), with similar results found in the CSHA and the National Population Health Survey.

Frailty was operationalized analogously to the social vulnerability index, as described elsewhere (Mitnitski, Song et al. 2004; Mitnitski, Song et al. 2005). In brief, deficits representing self-reported symptoms, health attitudes, illnesses, and impaired functions (Table 13) were identified and coded with scores between 0 and 1, as described above for the social vulnerability index, with 0 indicating the absence of a deficit and 1 for deficits which were endorsed. As such, higher frailty index values indicate greater burdens of frailty.

Cognition was measured using the Modified Mini-Mental State Examination (3MS) (Teng and Chui 1987). The 3MS is a well-validated cognitive screening tool with a possible score of 0-100, where lower scores indicate worse cognition. It includes items testing immediate and remote memory, orientation, attention and concentration, language and naming, verbal fluency, and executive function (Teng and Chui 1987). For 3MS items in which the subject was limited by blindness, illiteracy, or physical disability, the question was skipped and the score prorated. Cognitive decline was defined as a decline of ≥5 points over the five year follow-up period. Based on effect-size calculations and consideration of additional criteria for clinical meaningfulness, a 5 point change in 3MS is likely to be clinically meaningful (Andrew and Rockwood 2008). The 3MS was administered at baseline (CSHA-2) to all study participants in both the screening and clinical samples, and was repeated in the follow-up screening interview. The 3MS was not repeated in the follow-up clinical examination; as such cognitive change data is missing for those who had been institutionalized or demented at baseline as these participants remained in the clinical sample and did not have a follow-up screening interview. Dementia was diagnosed based on DSM-III-R criteria after a detailed clinical examination conducted on those who were living in long term care facilities, community-dwellers with a 3MS score <78 in the screening interview, and on a random sample of participants with 3MS scores ≥78 in the screen (Rockwood, McDowell et al. 2001).

Statistical analysis

Logistic regression modeling was used to determine the association between baseline social vulnerability (explanatory variable) and cognitive decline (response variable) at five years. In analyses comparing the risk of cognitive decline by level of social vulnerability, social vulnerability was divided into tertiles (low, intermediate, and high). Models were adjusted for age, sex, frailty, and baseline 3MS, as each of these variables was plausibly associated with both the exposure (social vulnerability) and the outcome (cognitive decline). In order to investigate whether the inclusion or exclusion of any single variable accounted for any of the observed associations, we performed a "jackknife by variables" procedure, in which the index was reconstructed 40 times, leaving out a different single variable each time.(Andrew, Mitnitski et al. 2008) Each new 39 item

"subtraction index" was then modeled in relation to cognitive decline using separate logistic regression analyses adjusting for age, sex, frailty, and baseline cognition. Similarly, eight different indices were created, each leaving out all of the items within a particular domain: socioeconomic status (SES), language abilities, living situation, social support, social engagement in leisure activities, and mastery (as grouped in Table 12). Each of these "domain subtraction" indices was analysed in relation to cognitive decline using separate logistic regression analyses adjusting for age, sex, frailty, and baseline cognition. Analyses were done using STATA 8.1.

5.5.4 RESULTS

The mean age of study participants at baseline was 79.1 (SD 6.4) and 61% were women.(Table 14) Mean social vulnerability was 0.26 (SD 0.09), or 10 deficits of the list of 40. No individual was completely free of social vulnerability (Figure 16). The median 3MS scores were 88 (IQR 80-94) at baseline, and 89 (IQR 82-95) at five years, with a median change of -1 (IQR -6, 2) points on the 3MS. 743 (30%) of individuals with known social vulnerability data experienced cognitive decline, as defined by a >=5 point decline in 3MS score.

The 1927 individuals for whom social vulnerability status was missing were older, frailer, had lower baseline 3MS scores, and were more likely to be diagnosed with dementia at follow-up (41% vs. 23%; all $p<0.001$). They also showed greater declines in 3MS scores ($p=0.002$). Higher social vulnerability was predictive of having a missing 3MS score at 5 year follow-up (OR 1.08, 95% CI:1.04-1.12).

Each additional baseline social deficit was associated with increased odds of experiencing incident cognitive decline (OR 1.03, 95% CI 1.00-1.06, $p=0.02$, N=2391, adjusting for frailty, age, sex, and baseline 3MS score). Compared with those in the low social vulnerability group, individuals with high social vulnerability had a 36% increased odds of experiencing cognitive decline (OR 1.36, 95% CI: 1.06-1.74) (Figure 17).

216 of the 3776 individuals with complete social vulnerability data at baseline developed incident dementia during the five year follow-up period. In an unadjusted model, each additional deficit in the social vulnerability index was associated with increased odds of incident dementia (OR 1.07, 95% CI: 1.03-1.11, $p<0.001$). Adjusting for age, sex, frailty, and baseline cognition, the association was no longer statistically significant (OR 1.02, 95% CI: 0.97-1.07, $p=0.5$).

5.5.5 DISCUSSION

We found that increasing social vulnerability, as defined by a social vulnerability index, was associated with incident cognitive decline in this study of older Canadians. For every additional social deficit of the 40 included in the index, the odds of experiencing a clinically meaningful decline in cognition increased by 3%. Thus, people with many deficits have odds which are increasingly stacked against them. Increasing social vulnerability was also associated with incident dementia, but this effect was not independent of confounding by age, sex, frailty, and baseline cognition.

Our findings must be interpreted with caution. The CSHA social vulnerability index relied on self-report of social factors, rather than on "objectively" defined social deficits. Differential predictive power of objective *vs.* subjective social deficits would be an interesting area of further study. It is quite possible, however, that subjective social vulnerability may be as important, or even more important, to an individual's health status as more objective external measures. Our study included only community-dwellers without dementia in the baseline cohort. Individuals who had been demented or institutionalized at baseline (who were in the clinical sample at CSHA-2) or who were too frail or demented to complete the follow-up screening interview and 3MS did not have a 3MS change score and were thus excluded from the analysis. Higher social vulnerability was predictive of having a missing 3MS score at 5 years. Our findings may thus be a conservative estimate of the association between social vulnerability and cognitive decline, because the design necessitated excluding those with the (potentially)

largest cognitive declines. Individuals missing data at baseline (and therefore excluded from the current study) were more likely to be older and frailer, to have lower baseline cognitive scores, and to experience greater cognitive decline and incident dementia. This limitation in our study design may also have led to a conservative bias in our estimates.

While the CSHA was a population-based study, our sample was drawn from the CSHA-2 survival cohort and necessarily excluded some of the most impaired individuals (those who were institutionalized or had dementia at baseline, in whom screening interview with the social vulnerability items was not conducted. Because of these factors, the generalizability of our findings may be limited. The exclusion of the most frail (*e.g*. due to the exclusion of long term care residents from sampling frames or the "silence by proxy" encountered when proxy respondents are unable to answer completely for the participant) is a problem common to many population-based studies of this type.(Andrew 2005)

Although our unified approach considering an index of multiple social factors is novel, our findings are in agreement with some previous studies that have demonstrated associations between individual social factors and cognitive decline. Bassuk *et al*. identified social disengagement as a risk factor for cognitive decline (as measured by the Short Portable Mental Status Questionnaire) over 3, 6 , and 12 years in cohort of community-dwelling older Americans (Bassuk, Glass et al. 1999). Fratiglioni *et al*. found that an extensive social network defined by a summary index of marital status, living arrangement, having children, and close social ties was protective against incident dementia over a 3-year period (Fratiglioni, Wang et al. 2000). Greater emotional social support predicted better cognitive function measured by a battery of tests assessing language, abstraction, spatial ability, and recall over 7.5 years in the MacArthur Studies of Successful Aging (Seeman, Lusignolo et al. 2001), while social engagement and social support were separately associated with higher performance on cognitive tests in older people without dementia.(Krueger, Wilson et al. 2009) Interpersonal interaction within larger social networks was associated with reduced odds of decline in cognition as measured by the Mini-Mental State Examination (MMSE) over 12 years (Holtzman,

Rebok et al. 2004). Social interaction and engagement reduced the probability of declines in orientation and memory in a 4-year study of community-dwelling Spanish older adults (Zunzunegui, Alvarado et al. 2003) and greater social resources (networks and engagement) were similarly associated with reductions in cognitive decline in old age (Barnes, Mendes de Leon et al. 2004). Longitudinal studies have shown that a decline in social engagement between mid life and late life may be predictive of incident dementia,(Saczynski, Pfeifer et al. 2006) and that trajectories in cognitive decline are associated with trajectories in social engagement.(Beland, Zunzunegui et al. 2005) In their study of Spanish older adults, Béland *et al.* found that those with high family ties maintained better cognition until age 80, while the benefit of non-family social integration seemed to accrue mostly after age 75.(Beland, Zunzunegui et al. 2005) The patterns differed between men and women; having friends was particularly important for slowing the rate of cognitive decline among women.(Beland, Zunzunegui et al. 2005) Socioeconomic factors similar to those included in our social vulnerability index also appear to be important: Koster *et al*. found that, independent of biomedical factors, low socioeconomic status predicted decline in older adults' cognition as measured by the MMSE (Koster, Penninx et al. 2005). These studies, and others on social factors which influence health and wellbeing, provide support for the content validity of the social vulnerability index: the index's constituent variables reflect previous work on associations between individual social factors and health.

Our use of a combined index approach to measure social vulnerability differs from the approach previously taken in this field, which has generally seen study of individual social factors in isolation. Critics of our approach might wonder whether the observed association was driven by one or a few factors. For example, is the strength of association between social vulnerability and cognitive decline due to the fact that single variables such as education or income adequacy were included in the index? To address this question a "jackknife by variables" procedure was performed, in which the index was reconstructed 40 times, leaving out a different single variable each time.(Andrew, Mitnitski et al. 2008) Each new 39 item "subtraction index" association with cognitive decline, adjusting for age, sex, and frailty, remained unchanged. This suggests that the

association between the social vulnerability index and cognitive decline that was found in this population-based study is not simply due to the inclusion of any single specific item. Similar results (*i.e.,* robustness of the index to changes in its constituent variables) have been obtained in a previous validation of the social vulnerability index approach in relation to frailty and mortality in older adults (Andrew, Mitnitski et al. 2008). Another approach is to remove groups of variables corresponding to domains of social factors; this was undertaken as a second test of the index's composition. All of the indices created by removing a single sub-domain (as grouped in Table 12, i.e. socioeconomic status, language abilities, living situation, social support, social engagement in leisure activities, and mastery) were statistically significantly associated with cognitive decline independent of age, sex, and baseline 3MS. Two of these indices (those leaving out SES and social engagement) lost statistical significance once frailty was added to the model ($p=0.07$ for engagement and $p=0.06$ for SES), suggesting that these two domains are importantly confounded by frailty. This also provides some groundwork for consideration of what types of policy interventions may be particularly beneficial for the prevention of cognitive decline, and suggests that interventions targeted to improving socioeconomic conditions and social activities may be of particular benefit.

Some social factors remain fixed throughout a person's lifetime. For example, educational attainment and never having had children are unlikely to change in older adulthood. Many other social factors are subject to change – either to the accumulation of social deficits (e.g. widowhood, diminishing social networks as peers become frail and die, and reduced opportunities for social engagement with one's own increasing frailty). How social vulnerability changes over time is unclear, and is motivating further study by our group. It may be that, for such investigations of trajectories in social vulnerability over time, it is best to limit the index to those variables with the potential to change over time.

To date, most studies of social factors in relation to health and cognition have been community-based. Few clinical studies of social vulnerability have been done. We see clinical applicability for the social vulnerability index approach; this is an area which merits further study.

Definitions of cognitive decline have varied, and the issue of clinical meaningfulness of measured cognitive changes has not always been addressed. We defined cognitive decline as a ≥5 point decline in 3MS score. Although meaningful change on the 3MS has not been extensively studied, we recently reported that a change of≥5 points over 5-10 years is likely to be clinically meaningful based on effect size calculations and additional consideration of criteria for clinical meaningfulness using CSHA data (Andrew and Rockwood 2008). Additionally, while the 3MS is a validated instrument which is superior to some other cognitive screening tools such as the Mini-Mental State Examination (MMSE) because it includes additional cognitive domains such as executive function, it is neither completely comprehensive nor perfect as a screening instrument. This is a further limitation of our study.

We found a statistically significant association between social vulnerability and incident cognitive decline, but the association with incident dementia diagnosis was not statistically significant once age, sex, frailty, and baseline cognition were taken into account. It may be that the number of dementia diagnoses was insufficient to detect this association. Another possibility is that the study design, which excluded individuals who had been institutionalized or who were too demented to complete the screening questionnaire and 3MS at baseline, may have led to an underestimation of the association. Additionally, some community-dwelling individuals with dementia may have been missed if they scored above the cutoff of 78 on the 3MS, as this was the trigger for progression to full clinical examination. We did find an association between social vulnerability at baseline and missing 3MS data at follow-up, which would have been due to one of these factors in surviving individuals. Finally, cognitive test scores considered in isolation may not be strongly predictive of clinically diagnosed dementia.(Anthony, LeResche et al. 1982; Barnes, Covinsky et al. 2009) As such, it is possible that social

vulnerability contributes importantly to cognitive decline as measured by changes in 3MS scores while other associated factors, such as frailty and baseline cognition, may add importantly to risk profiling for development of dementia.

5.5.6 CONCLUSION

We found that social vulnerability is associated with cognitive decline in community-dwelling older adults. Further research on the characterization of social vulnerability, on potential contextual effects, and on potential interventions to alleviate social vulnerability, is warranted.

5.5.7 ACKNOWLEDGEMENTS

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5.5.8 AUTHOR CONTRIBUTIONS

KR was a Principal Investigator in the CSHA and holds the data on-site. MKA performed the analyses. MKA and KR designed the study and wrote the manuscript.

5.5.9 REFERENCES

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5.5.10 GRAPHICS

Figure 15: Study sample.

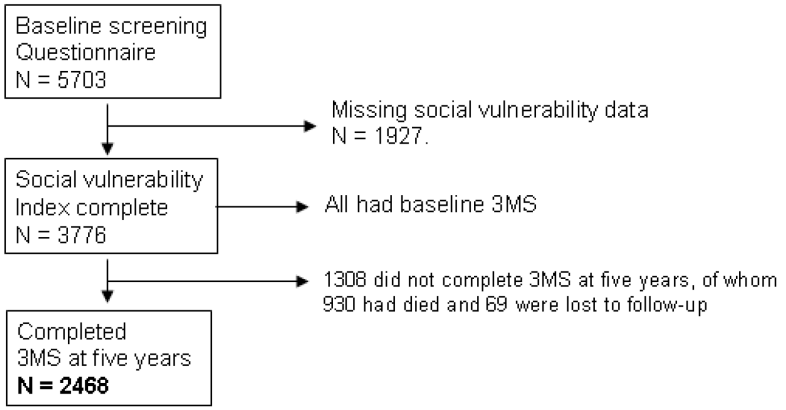

Figure 16: Distribution of the social vulnerability index (N=2468).

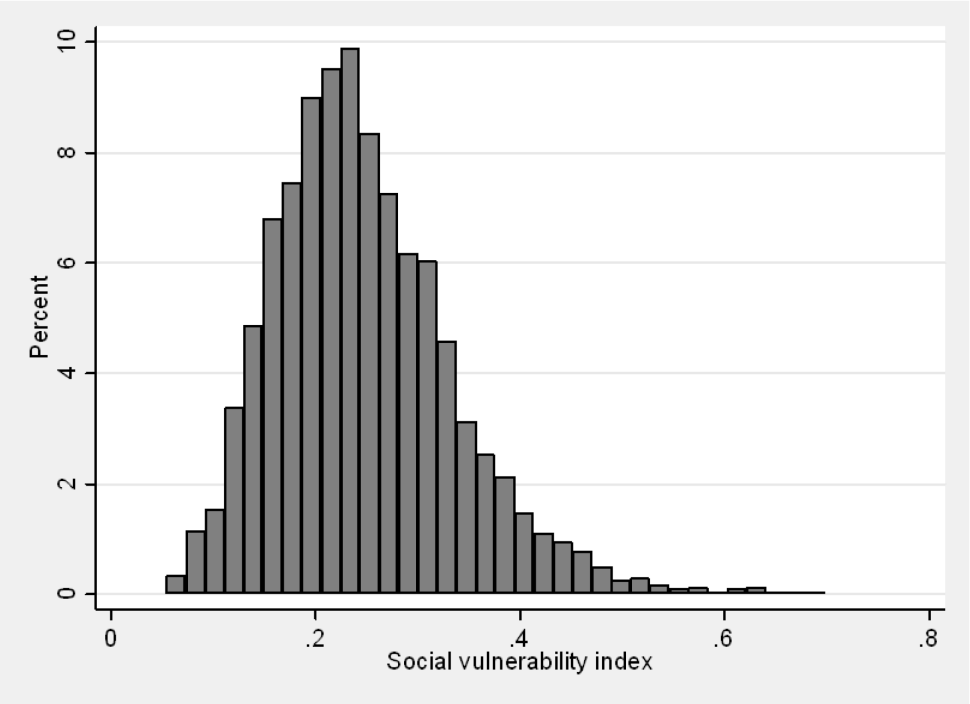

Figure 17: Odds of cognitive decline according to level of social vulnerability (divided into tertiles: high, intermediate, low).

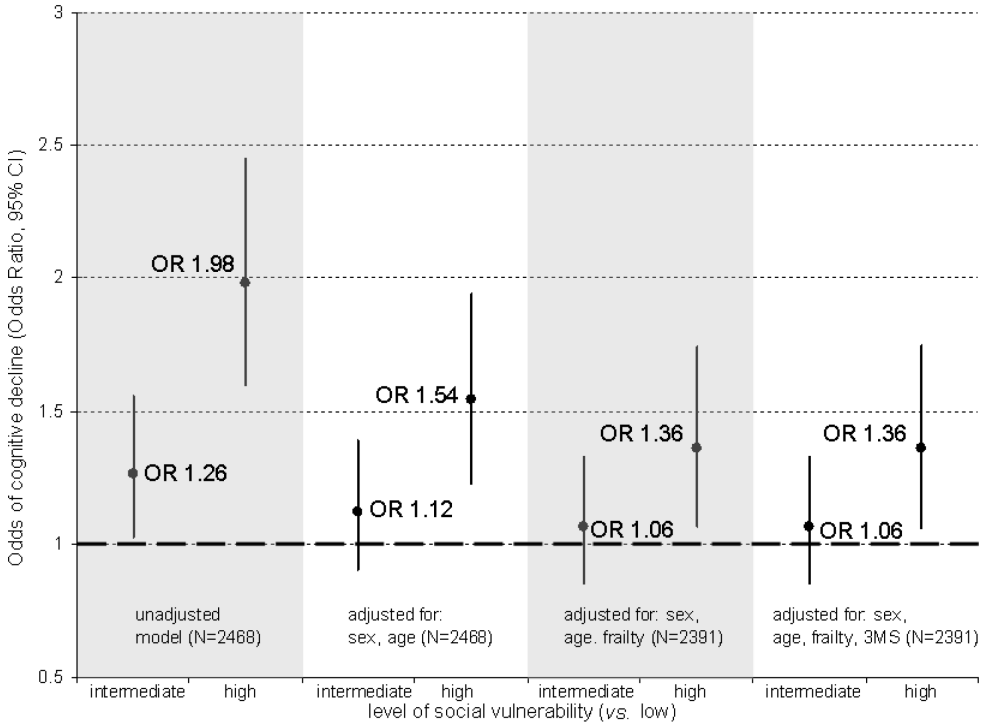

Table 12. Social Vulnerability Index Constituent Variables

Communication to engage in wider community		**# of response categories**
1	Read English or French	2
2	Write English or French	2
Living situation		
3	Marital status	2
4	Lives alone	2
Social support		
5	Someone to count on for help or support	3
6	Feel need more help or support	3
7	Someone to count on for transportation	3
8	Feel need more help with transportation	3
9	Someone to count on for help around the house	3
10	Feel need more help around the house	3
11	Someone to count on to listen	3
12	Feel need more people to talk with	3
13	Number of people spend time with regularly	5
14	Feel need to spend more time with friends/family	3
15	Someone to turn to for advice	2
16	Feel need more advice about important matters	3
Socially oriented Activities of Daily Living		
17	Telephone use	3
18	Get to places out of walking distance	3
Leisure activities		
19	How often visit friend or relatives	3
20	How often work in garden	3
21	How often golf of play other sports	3
22	How often go for a walk	3
23	How often go to clubs, church, community centre	3
24	How often play cards or other games	3
Ryff scales		
25	Feel empowered, in control of life situation	6
26	Maintaining close relationships is difficult and frustrating	6
27	Experience of warm and trusting relationships	6
28	People would describe me as a giving person	6
How do you feel about your life in terms of …		
29	Family relationships	7
30	Friendships	7
31	Housing	7
32	Finances	7
33	Neighbourhood	7
34	Activities	7
35	Religion	7

Table 12. Social Vulnerability Index Constituent Variables (continued)

Communication to engage in wider community		**# of response categories**
36	Transportation	7
37	Life generally	7
Socio-economic status		
38	Does income currently satisfy needs	5
39	Home ownership	2
40	Education	3

Table 13. Frailty Index Constituent Variables

1	Eyesight
2	Hearing
3	Help to eat
4	Help to dress and undress
5	Help to take care of appearance
6	Help to walk
7	Help to get in and out of bed
8	Help to take a bath or shower
9	Help to go to the toilet
10	Help in shopping
11	Help to prepare own meals
12	Help to do housework
13	Ability to take medications
14	Ability to handle own finances
15	Poor self-assessed health
16	Hypertension
17	Heart and circulation problems
18	Stroke or effects of a stroke
19	Arthritis or rheumatism
20	Parkinson's Disease
21	Eye trouble
22	Ear trouble
23	Dental problems
24	Chest problems
25	Stomach problems
26	Bladder control problems
27	Bowel control problems
28	Trouble with feet or ankles
29	Trouble with skin
30	Fractures
31	Frequent trouble with pain

As previously published (Mitnitski, Song et al. 2004) but done using a different wave of the CHSA, leaving out items in the social vulnerability index (living alone, telephone use, and ability to get places out of walking distance).

Table 14. Description of study sample. 3MS = Modified Mini-Mental State Examination, SD=Standard Deviation, IQR=Interquartile Range

Variable	Count	%, Mean (SD), or Median [IQR]
Age	N=5703	79.1 (6.4)
Sex: % women	 N=3,463	 60.7%
Social Vulnerability	N=3776	0.26 (0.09) 0.25 [0.20, 0.31]
Frailty	N=4974	0.18 (0.11) 0.16 [0.10, 0.23]
3MS score at baseline	N=5703	84.4 (13.6) 88 [80, 94]
3MS score at 5 year follow-up	N=3225	85.8 (13.0) 89 [82, 95]
3MS score Cognitive change	N=3255	-3.3 (10.0) -1 [-6, 2]
Cognitive decline >=5 points on 3MS	N=1019	31.3%
Dementia diagnosis	N=360	11.2%
Died by 5 years	N=1789	32.7%

CHAPTER 6 TRANSITIONS IN SOCIAL VULNERABILITY

6.1 PROLOGUE

While the previous Chapters have examined the conceptualization of social vulnerability and its relationship with important health outcomes, in this Chapter we examine another aspect of social vulnerability, namely how it changes over time.

It is easy to imagine that older people might become more and more socially vulnerable as they age, given that many experience the passing of spouse and peers, as well as perhaps their own increasing frailty, disability, and isolation. Nevertheless, how social vulnerability changes over time is not clear from existing studies; the present study aimed to address this question using the Swedish Gothenburg H70 cohort study.

6.2 MANUSCRIPT DETAILS:

Andrew, M., K. Rockwood, I. Skoog and A. Mitnitski "Transitions in social vulnerability among older people: frailty influences how social circumstances change over time." Ms. submitted.

6.3 TRANSITIONS IN SOCIAL VULNERABILITY AMONG OLDER PEOPLE: FRAILTY INFLUENCES HOW SOCIAL CIRCUMSTANCES CHANGE OVER TIME

6.3.1 ABSTRACT

OBJECTIVES: Social circumstances are important to older people's health, but their dynamics are not clear. We studied changes in social vulnerability over time in relation to frailty.

METHODS: In this secondary analysis of the Gothenburg H70 study, a representative sample (N=974) of 70 year olds, a social vulnerability index was constructed from 19 social deficits. Transitions between the number of deficits at baseline and the deficit count 5 and 9 years later were modeled using a parametric Markov chain. Covariates were frailty, sex, education, and income.

RESULTS: Individuals accumulated a mean of 1.8 social deficits at 5 years and 3.5 deficits at 9 years, with additional incremental increases of 0.73 (over 5 years) and 0.55 (over 9 years) deficits for each additional baseline deficit. Even so, an important proportion of people stabilized (10%) or improved (30% over 5 years, 13% over 9 years). Frail people accumulated more social deficits, were less likely to improve their social circumstances and had higher mortality.

DISCUSSION: Increasing social vulnerability with age was common, but social deficits did not accumulate relentlessly. Frail people were at highest risk of worsening social vulnerability; even amongst frail people, mortality was highest in people with high social vulnerability.

6.3.2 INTRODUCTION

The health status of individuals is influenced by the social circumstances in which they find themselves. Such circumstances are diverse and so is their conceptualization. Among older adults, social support, social ties, social engagement, mastery, and neighbourhood social capital have each been found to improve survival.(Berkman and Syme 1979; Blazer 1982; Schoenbach, Kaplan et al. 1986; Seeman, Kaplan et al. 1987; Seeman, Berkman et al. 1993; Lochner, Kawachi et al. 2003; Marmot 2004) Higher socioeconomic status (SES), social engagement and interaction, social support, strong social networks, not feeling lonely, and participation in leisure activities are associated with reduced risk of cognitive decline (Bassuk, Glass et al. 1999; Seeman, Lusignolo et al. 2001; Zunzunegui, Alvarado et al. 2003; Barnes, Mendes de Leon et al. 2004; Koster, Penninx et al. 2005; Czernochowski, Fabiani et al. 2008) and dementia.(Fratiglioni, Wang et al. 2000; Fratiglioni, Paillard-Borg et al. 2004; Wilson, Krueger et al. 2007) Social engagement and having a dense social network have both been associated with lower levels of disability,(Mendes de Leon, Glass et al. 2003; Andrew 2005; Kelley-Moore, Schumacher et al. 2006) and lack of social support is a risk factor for institutionalization.(Rockwood, Stolee et al. 1996; Kersting 2001) Having low SES, living alone, not being married, living in a home in disrepair and social disengagement are associated with higher risk of falls and hip fracture.(Gill, Taylor et al. 2005; Peel, McClure et al. 2007) Low SES, little contact with relatives and neighbours, low social support, and low participation in community/religious activities have also found to be determinants of frailty.(Woo, Goggins et al. 2005)

The many facets of how social circumstances influence health present a pragmatic challenge to their study. Clearly, many disciplines can make a legitimate claim to understanding these influences. In consequence, differences in terminology can obscure agreement and differences in which factors are studied can lead to differing result and interpretations. What is more, individual social factors commonly are studied in isolation. While this can offer a beneficial simplicity, it is often at the cost of a unidimensional representation of a complex set of social circumstances.

Another way to think about social circumstances in relation to health is by using the concept of social vulnerability and the related idea of social reserve. Social vulnerability captures the degree to which a person's overall social situation leaves them susceptible to further insults (either health-related, or social). Considered in the inverse, social reserve is the degree of resilience that a well-connected and supportive social situation might impart. Social vulnerability can be operationalized and measured as an index of social problems, or "deficits", such that the more social deficits one has, the more the vulnerability to adverse outcomes. Measured in this way, social vulnerability is associated with frailty and predicts mortality and cognitive decline.(Andrew, Mitnitski et al. 2008; Andrew and Rockwood 2010)

How social vulnerability status among older adults changes over time is unclear. Is it something that progressively increases, or does it remain stable or even improve? Social vulnerability is also but one aspect of vulnerability to adverse outcomes; this variable vulnerability for people of the same age is also referred to as frailty. Given the importance of frailty to health in older age,(Hogan, MacKnight et al. 2003; Rockwood 2005; Woo, Chan et al. 2010; Yang and Lee 2010) do changes in social vulnerability differ by level of frailty? We aimed address these questions by studying transitions in social vulnerability in a well characterized cohort of 70 year olds followed over 5 and 9 years.

6.3.3 METHODS

The multidisciplinary H70 study started with the aim of studying health and health-related factors in older people from Gothenburg, Sweden in 1971-72. Samples were systematically obtained, based on birth dates, from the Swedish Population Register, which covers names and addresses of all people living in Sweden. A representative sample (30%) of 70-year olds living in Gothenburg, Sweden (in both private households and institutions) was invited to participate.(Steen and Djurfeldt 1993) Detailed interviews and clinical examinations were conducted thereafter; here we report 5- and 9- year follow up.

Measures

Social vulnerability index

The interview included 19 items which were asked at each time period and which had the potential to change (i.e. which were not fixed).(Table 15) For example, "How many children have you had" is fixed, whereas "How often do you have contact with your children" is not (save for those who had never had children). Educational attainment and income were collected at baseline. Each social variable was coded as 0 or 1, with 1 indicating presence of the potential social deficit and 0 indicating its absence. For example, on the "satisfaction with housing" item, those who viewed their housing situation good or neutral were scored as 0 (indicating no deficit) and those who were discontented were scored as 1. Scores for each of the 19 potential deficits were then summed to create a social vulnerability index; for any individual, its value corresponds to the number of social deficits present.

Frailty was operationalized analogously using an index of 110 health deficits (illnesses, symptoms, functional impairments, and disabilities).(Rockwood, Andrew et al. 2007; Rockwood and Mitnitski 2007) This frailty index has been validated in numerous studies and settings, including the Gothenburg H70 cohort.(Mitnitski, Song et al. 2005) Frailty was split at the median into low vs. high frailty.

Educational attainment was assessed at baseline, and categorized as follows: no education, some elementary schooling, finished elementary school, some high school or "folk high school", completed high school examinations, vocational training or some university, or completed university. Because of the low educational attainment of the cohort, the education variable was dichotomized as elementary school or less vs. more than elementary schooling. Income was split at the median into high vs. low income. Age was not included in the models, because all participants were of the same age.

Statistical methods

Transitions between social vulnerability deficit states were summarized in a transition matrix, which shows the number of people from each baseline state (i.e. with each number of social deficits at age 70) who were subsequently in each follow-up state or who had died (entered the absorbing state). To improve stability (due to small numbers), and after evaluation of the distribution of the scores, the 0 and 1 deficit states were combined to constitute the so-called "zero state" (i.e. people with the fewest deficits). Data were fitted to a modified Poisson distribution using a parametric Markov chain model. For the unadjusted models, least squares estimation was used, which allows calculation of a coefficient of determination (R^2) which represents goodness of fit. These models were also generated with stratification by each of sex, frailty, income and education. Maximum likelihood estimation was then used to account for sex, frailty, education, and income in an adjusted model. The output of the modified Poisson model consists of four parameters which describe the probability of transitioning from any baseline deficit state to any other deficit state at follow-up.

Analyses were done using STATA 8.1 and Matlab 7.1.

Ethics

Informed consent was obtained from all subjects. The study was approved by the Ethics Committee for Medical Research at the University of Gothenburg.

6.3.4 RESULTS

974 individuals participated in the H70 clinical interviews; all had complete data for social factors at baseline. All participants were 70 years old at baseline and 525 (54%) were women. Educational attainment was generally low, with 805 individuals (84%) having completed elementary schooling or less. By five years, 166 (17%) had died and 340 (35%) had died at nine years (age 79). The distribution of social deficits was skewed, with the tail towards higher numbers of deficits, with medians of 5 (IQR 4-8) deficits at age 70, 6 (IQR 4-8) at age 75, and 6 (IQR 5-8) social deficits at age 79.

Transition models

The transition matrices are shown in Table 16 for both 5 and 9 years. Results of the transitions models are shown in Table 17. Model fit was good at 5 years (R^2 0.71) and excellent at 9 years (R^2 0.92). (Figure 18a and b)

The unadjusted model predicted that individuals who had the least social vulnerability (i.e. were in the zero state) at baseline (0-1 deficit) accumulated a mean of 1.8 social deficits at 5 years and 3.5 deficits at 9 years. For people with 2 or more deficits (i.e. in more than the zero state) the model predicted an incremental increase of 0.73 deficits for every deficit greater than 1 by five years, and an increase of 0.55 deficits per deficit by nine years. For example, an individual with 3 social deficits at baseline would be predicted to have 3.3 deficits at 5 years (1.8 + 0.73x2) and 5.6 deficits at nine years (3.5 + 0.55x2).

Probabilities of stabilizing (maintaining the same number of deficits as at baseline), improving (shedding deficits), getting worse (accumulating more deficits) and dying are shown in Figure 19. At higher baseline levels of social vulnerability (e.g. 9 or more deficits over five-year follow-up, and 6 or more deficits over nine years of follow-up) the proportion of people who died exceeded the proportion of people in whom social vulnerability had worsened. From these points on, further increases in baseline deficit states are less and less likely to have worsening social vulnerability but more and more likely to die.

The adjusted model shows the contributions of sex, education, income, and frailty. (Table 17) Women had statistically significantly lower mortality at both 5 and 9 years, but accumulated more social vulnerability deficits at 9 years. People with low education accumulated fewer social deficits at 5 years, but this was not statistically significant at 9 years.

In the adjusted model, less educated people had better survival over both the 5-year and 9-year time frames. Even so, people with income below the median had statistically significantly higher mortality at both 5 and 9 years, but there was no statistically significant increase in their accumulation of social deficits. Frailer people accumulated more social vulnerability deficits over both 5- and 9-year horizons, were less likely to improve their social circumstances and had higher mortality over both follow-up periods. (Figure 20)

6.3.5 DISCUSSION

We found that on a group level, social vulnerability tended to increase over both five and nine years. People with no baseline deficits (those in the “zero state”) had accumulated 1.8 deficits at 5 years and 3.5 deficits at 9 years; this can be interpreted as the background incidence of social deficits with aging. Further increases were experienced by those with more social deficits at baseline. Even so, relentless accumulation of social deficits was

not a universal experience: a substantial proportion of people stabilized or improved over both time intervals. These transitions in social vulnerability could be well described using a modified Poisson distribution model. Higher frailty was associated with increased accumulation of social deficits, but this was not so for low education and low income. Frailty also had an important influence on the probabilities of experiencing transitions in social vulnerability, such that frailer individuals were less likely to improve their social circumstances and more likely to die. Women accumulated more social deficits, but had lower mortality than men.

Our findings must be interpreted with caution. The social vulnerability data are based on self-report, thus introducing the potential for biased reporting, either under- or over-reporting of deficits. It is possible that there may be important differences in "objective" social vulnerability (measured using more objective measures, such as mean neighborhood income) *vs*. more "subjective" social vulnerability (based on an individual's perception of his or her own social circumstances). Our measure, while based on self-report, contains elements of both. For example, living alone, being married, or being a member of a social group are fairly objective items, whereas loneliness and perceived adequacy of social contact are inherently subjective. Nevertheless, given the growing evidence that mastery and sense of coherence are important for health,(Dalgard, Mykletun et al. 2007; Jang, Chiriboga et al. 2009) it is likely that an individual's self-perception of their social circumstances is as important for their health as are more objective measures.

We found that the accumulation of social vulnerability deficits per increasing number of baseline deficits was smaller over nine years than over five years. This suggests a survival effect or perhaps a "stabilize or die" phenomenon, such that people who otherwise might have accumulated more deficits instead died. The tapering of the dark grey bars in Figures 19 and 20 also lends support to the idea that at higher levels of social vulnerability there may be no room to get worse, such that people either stabilize or die.

We also found that frailty was associated with important differences in the how social vulnerability changed. As expected, people with low baseline levels of frailty (the fitter people) were less likely to die. Fitter individuals also seemed to demonstrate reserve, in that they were better able to tolerate increases in social vulnerability, and also more likely to improve their social circumstances. The previously reported association between frailty and social vulnerability (Andrew, Mitnitski et al. 2008) was reinforced by our finding that older people with lower frailty had fewer social deficits; no-one in the low frailty group had more than 9 social deficits at baseline, while those who were more frail had up to 14.

Our finding that low education reduces the risk of mortality seems paradoxical and may well be artifactual. In general, most studies show that higher education is associated with improved health and survival. There are a number of potential explanations for our results. One is that the majority of the cohort had low education (primary school or less), introducing the possibility of a floor effect, and highlighting the difficulty of setting a relevant cut-point on which to dichotomize educational attainment for modeling purposes. Related to this, the period norm for the cohort seems to have been lower educational attainment, which may have influenced the life opportunities of this group as they passed through the life course. Despite these potential methodological influences, another possibility is that this cohort lived in Sweden, a relatively egalitarian developed country, which might have mitigated any deleterious effects of low educational attainment. Also, it is possible that during this time period individuals with lower education may have led healthier lifestyles or had less toxic or dangerous occupations.

Some social deficits would be expected to become more common with age. Widowhood and its attendant solitary living, shrinking social circles as peers become frail, housebound, and die, and reduced ability to participate in activities outside the home due to one's own frailty and mobility limitations would all have the potential to increase social vulnerability. Here, we have presented a model that illustrates how social vulnerability as a whole, not just single factors in isolation, changes over time in old age. Of particular import is the finding that "to those that hath shall be given more"[Mark

4:25], but only to a point; people with few social deficits at baseline tend to accumulate more, but those with high burdens of social deficits appear to reach a limit beyond which accumulation of further deficits becomes less likely

Social vulnerability has important ramifications for health, well-being and quality of life. Understanding changes in social vulnerability offers the potential to better address social problems, and to lessen the accumulation of social deficits. Similarly, studying the subset of individuals whose social circumstances remain stable or even improve as they age may offer insights into how to prevent and to mitigate the deleterious effects of increasing social vulnerability. These considerations are motivating additional inquiries by our group.

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6.3.7 GRAPHICS

Table 15. Social variables included in the social vulnerability index, with definition of deficit coding.

Variable	**Deficit**	**No deficit**
Marital status	Single, widowed, divorced, separated	Married, common-law
Living alone	Yes	No
Contact with your children	Less than weekly	At least weekly
Children living nearby	No	Yes
Contact with friends	Less than monthly	At least monthly
Perceived adequacy of social contact	Too little	Just right, too much
Change in contact with relatives after retirement	More seldom	More often, no change
Daily contact with other people	No	Yes
Feeling lonely	Often or sometimes	Seldom or never
Feeling more lonely now than before (10 years ago)	Yes	No or same
Club membership	No	Yes
Club attendance	Less than monthly	At least monthly
Attend church service	Never	Yes (any frequency)
Feeling disturbed by neighbours	At least monthly	Never
Feeling disturbed by your environment or neighbourhood	At least monthly	Never
Satisfied with housing	No	Yes, neutral
Sufficiency of help at home	Insufficient	Sufficient or none needed
Listen to radio	Less than daily	Daily
Travelling for enjoyment	No	Yes

Table 16. Transition matrices. Baseline (age 70) state is on the x axis, follow-up states (including death) are on the y axis. As an example, there were 37 individuals in the 0-1 state at baseline. Of these, eight remained in the 0-1 state at 5 years, while ten had transitioned to having 2 deficits, five had 3 deficits, three had 4 deficits, etc… and three had died.

A). Five year follow-up

5 yrs State / Baseline	0-1	2	3	4	5	6	7	8	9	10	11	12	13	14+	died	total	Prob death
0-1	8	10	5	3	2	2	2	1	0	0	1	0	0	0	3	37	0.0811
2	4	10	14	10	11	2	6	3	0	1	0	0	0	0	8	69	0.1159
3	3	3	16	10	10	16	10	2	3	2	3	2	0	0	13	93	0.1398
4	4	2	14	15	18	16	11	3	6	3	2	2	0	0	18	114	0.1579
5	0	4	16	19	23	19	17	9	6	4	3	1	0	0	15	136	0.1103
6	0	3	4	14	16	20	16	12	5	2	2	0	1	0	16	111	0.1441
7	0	1	0	3	6	12	10	16	8	4	2	2	0	0	17	81	0.2099
8	0	0	1	4	5	9	8	6	7	4	3	2	0	0	16	65	0.2462
9	0	0	2	1	2	5	9	7	9	8	3	1	1	0	19	67	0.2836
10	0	0	0	1	2	3	2	7	9	4	2	0	1	2	13	46	0.2826
11	0	0	0	0	1	1	0	6	5	1	1	0	1	1	8	25	0.3200
12	0	0	0	0	0	0	0	2	1	1	1	0	2	1	6	14	0.4286
13	0	0	0	0	2	0	0	0	0	0	0	2	1	0	2	7	0.2857
14+	0	0	0	0	0	0	1	1	0	0	1	3	0	1	5	12	0.4167

Table 16. Transition matrices (continued)

B). Nine year follow-up

9 yrs State Baseline	0-1	2	3	4	5	6	7	8	9	10	11	12	13	14+	died	total	Prob death
0-1	3	4	2	5	6	4	2	0	0	1	0	0	0	0	7	34	0.2059
2	1	6	9	5	5	7	6	3	1	0	1	0	0	0	19	63	0.3016
3	1	2	7	3	13	10	8	6	1	5	2	0	0	1	29	88	0.3295
4	0	5	5	14	18	9	8	8	3	3	1	2	1	0	33	110	0.3000
5	0	1	7	9	16	18	5	10	3	3	3	2	0	1	51	129	0.3953
6	0	2	5	7	3	12	8	17	2	5	4	1	2	1	38	107	0.3551
7	0	0	1	1	5	10	7	11	3	4	3	2	0	0	34	81	0.4198
8	1	0	0	1	2	3	1	5	12	6	5	1	0	0	26	63	0.4127
9	0	0	1	1	2	1	5	5	7	7	3	1	0	0	30	63	0.4762
10	0	0	0	1	0	1	1	4	4	1	4	2	0	1	20	39	0.5128
11	0	0	0	0	0	1	3	2	0	1	2	1	1	0	17	28	0.6071
12	0	0	0	0	0	0	0	0	0	1	0	2	0	0	9	12	0.7500
13	0	0	0	0	0	0	0	0	1	0	0	0	0	0	6	7	0.8571
14+	0	0	0	0	0	0	0	0	0	0	0	3	0	0	8	11	0.7273

Table 17. Parameter estimates for transitions in social vulnerability. Two models are shown; the unadjusted least squares model allows for determination of model fit, while the MLE model allows inclusion of covariates. The interpretation of each parameter is described, and statistically significant associations with covariates are marked with an "*" and the interpretation of the finding. MLE = Maximum Likelihood Estimation, BL=baseline.

Parameter	Interpretation	5 years		9 years	
		Model 1: social vulnerability (least squares)	Model 2: social vulnerability, sex, education, income (MLE)	Model 1: social vulnerability (least squares)	Model 2: social vulnerability, sex, education, income, frailty (MLE)
α1	conditional mean of the average # of social vulnerability deficits people will have at followup given 0 deficits at BL	1.78 (1.50, 2.07)	2.50 (1.99, 3.00)	3.50 (3.07, 3.94)	2.29 (1.68, 2.90)
β1	incremental change in accumulated mean deficits per increased # of social vulnerability deficits present at BL	0.73 (0.65, 0.80)	0.51 (0.44, 0.58)	0.55 (0.44, 0.66)	0.45 (0.36, 0.54)
α2	Log of probability of death (death rate / 5 or 9 years) for those with 0 deficits at BL	-2.14 (-2.58, -1.82)	-2.26 (-2.85, -1.67)	-1.32 (-1.50, -1.15)	-0.88 (-1.34, -0.42)
	Antilog	0.12 (0.08, 0.16)	0.10 (0.06, 0.19)	0.27 (0.22, 32)	0.41 (0.26, 0.66)
β2	Log of probability of death (death rate/5 or 9 years) per increasing number of social vulnerability deficits present in BL state	0.13 (0.10, 0.17)	0.10 (0.03, 0.17)	0.18 (0.16, 0.21)	0.10 (0.04, 0.15)
R		0.84		0.96	
R^2		0.71		0.92	

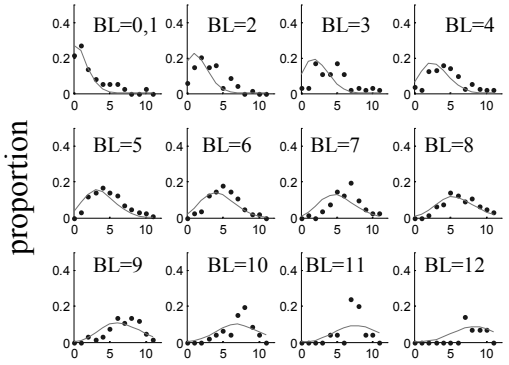
Table 17. Parameter estimates for transitions in social vulnerability (continued)

Parameter	Interpretation	5 years		9 years	
		Model 1: social vulnerability (least squares)	Model 2: social vulnerability, sex, education, income, frailty (MLE)	Model 1: social vulnerability (least squares)	Model 2: social vulnerability, sex, education, income, frailty (MLE)
γ_{11}	Female sex: modifying estimates relating to probability of accumulation of social deficits among survivors		0.31 (-0.02, 0.63)		0.66 (0.24, 1.08)* Women accumulate more social deficits
δ_{11}	Female sex: modifying estimates relating to probability of death		-0.79 (-1.16, -0.42)* Women have lower mortality		-1.16 (-1.47, -0.86)* Women have lower mortality
γ_{12}	Low education: modifying estimates relating to accumulation of social deficits		-0.64 (-1.11, -0.17)* Low education less accumulation of social deficits		0.25 (-0.30, 0.81)
δ_{12}	Low education: modifying estimates relating to probability of death		-0.53 (-1.06, -0.00)* Lower education lower mortality		-0.56 (-0.99, -0.14)* Lower education lower mortality
γ_{13}	Low income: modifying estimates relating to accumulation of social deficits		0.005 (-0.33, 0.34)		0.41 (-0.022, 0.83)
δ_{13}	Low income: modifying estimates relating to probability of death		0.46 (0.05, 0.87)* Lower income higher mortality		0.47 (0.15, 0.79)* Lower income higher mortality
γ_{14}	Frailty: modifying estimates relating to accumulation of social deficits		0.53 (0.16, 0.91)* Frail people accumulated more social deficits		0.55 (0.08, 1.02)* Frail people accumulated more social deficits
δ_{14}	Frailty: modifying estimates relating to probability of death		0.94 (0.50, 1.39)* Frail people had higher mortality		0.79 (0.46, 1.13)* Frail people had higher mortality

Figure 18. Fitted Poisson distribution for transitions from baseline to follow-up states. Each of the 12 small axes = increasing baseline state (# social deficits) 0/1-12.

Within these, each X axis shows # deficits transitioned to over the time interval. BL=baseline state

A) 5 years (R^2 0.71)



B) 9 years (R^2 0.92)

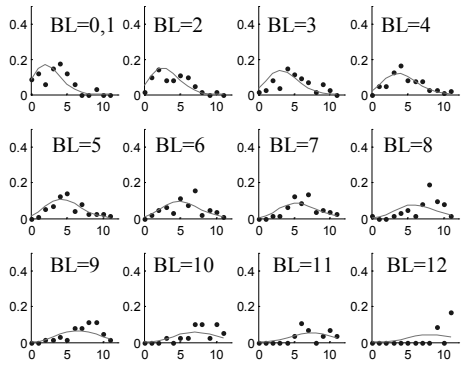


Figure 19. Transitions in social vulnerability over five (panel A) and nine (panel B) years. The lightest grey bars indicate the proportion of the sample who improved in their number of deficits at follow-up; mid grey bars indicate the proportion in whom the number of social deficits remained stable, dark grey bars indicate the proportion of the sample that accumulated additional deficits, and black bars represent the proportion that had died at follow-up. At higher baseline levels of social vulnerability (e.g. 9 or more deficits over five-year follow-up, and 6 or more deficits over nine years of follow-up, indicated by "^" in the figure) the proportion dying exceeded the proportion with worsening social vulnerability. From these points on further increases in baseline deficit states are less and less likely to show worsening social vulnerability but more and more likely to die. Y axis = cumulative probability.

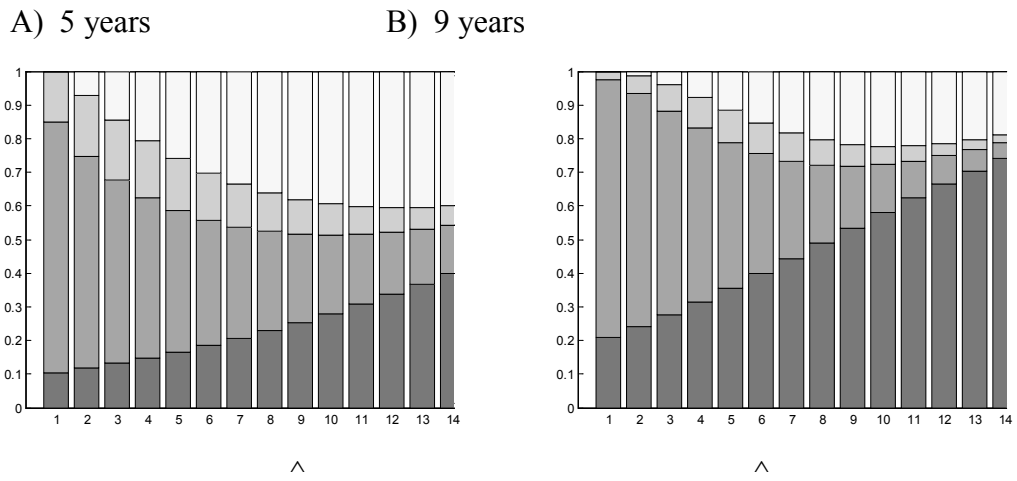
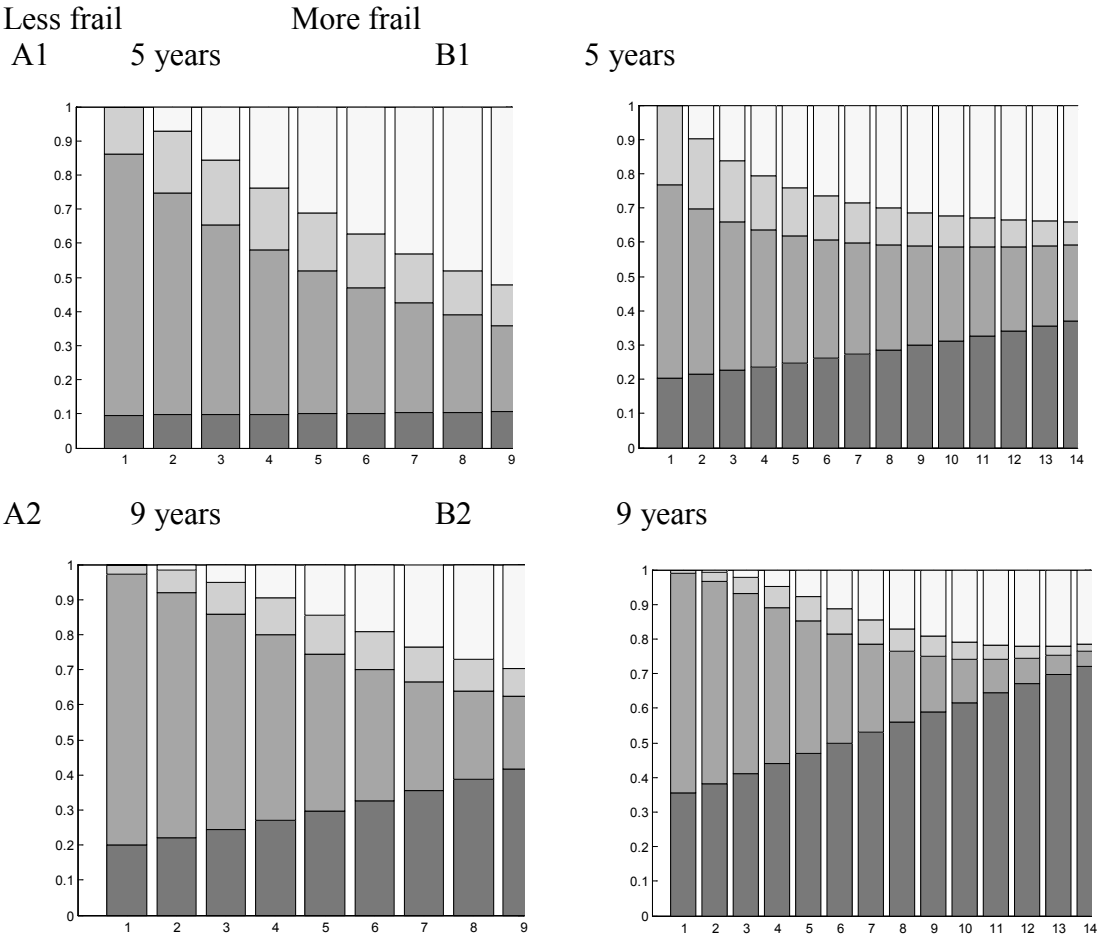


Figure 20. Transitions in social vulnerability for over five and nine years for people with frailty below (panels A1 and A2) and above (panels B1 and B2) the sample median. The lightest grey bars indicate the proportion of the sample with an improved number of deficits at follow-up; mid grey bars indicate stability in the number of social deficits, dark grey bars indicate the proportion of the sample that accumulated additional deficits, and black bars represent the proportion that had died at follow-up. Y axis = cumulative probability.



CHAPTER 7 SOCIAL VULNERABILITY AND THE SURVIVAL OF THE FITTEST

7.1 PROLOGUE

In Chapter 4, we saw that social vulnerability was associated with both frailty and increased mortality. Here, we turn our attention to the special case of how social vulnerability affects survival of the fittest older adults, those who are not at all frail.

Limiting the analysis to just the fittest older people allows for more pointed investigation of the impact of "extrinsic vulnerability" relating to social circumstances. In effect, it allows for estimation of what might be considered the ambient health of a population by providing a quantitative measure of the "background effects" that explain differences in survival between groups of people living in different social conditions.

7.2 MANUSCRIPT DETAILS:

Andrew, M., A. Mitnitski, S. A. Kirkland and K. Rockwood "The impact of social vulnerability on the survival of the fittest older adults." Ms. submitted

7.3 THE IMPACT OF SOCIAL VULNERABILITY ON THE SURVIVAL OF THE FITTEST OLDER ADULTS.

7.3.1 ABSTRACT

BACKGROUND: Even older adults who are fit experience adverse health outcomes, including death. Understanding the risks for adverse outcomes of the fittest offers some insight into the ambient health risk of the environment in which they find themselves. The current study evaluated mortality risk in relation to social vulnerability amongst the fittest older adults seen in a representative community-dwelling sample of elderly Canadians.

METHODS: Participants came from the second wave of the Canadian Study of Health and Aging, in which participants were aged 70 years and older at baseline. A Frailty Index was used to grade relative levels of fitness and frailty, using 31 self-reported health deficits. Those who reported 0 or 1 deficit (i.e. the fittest people) were selected. Social vulnerability was trichotomized from a social vulnerability scale, which consisted of 40 self-reported social vulnerability deficits.

RESULTS: In this sample of the fittest respondents, the absolute risk of mortality rose with increasing social vulnerability. In those with the lowest level of social vulnerability, the 5-year mortality rate was 10.8%, increasing to 22.4% in the intermediate group, and 32.5% in those with the highest social vulnerability (adjusted Hazard Ratio 2.5, 95% CI:1.5-4.3, p=0.001).

CONCLUSIONS: A 22% absolute mortality difference in the fittest older adults is of considerable clinical and public health importance. Routine assessment of social vulnerability by clinicians could have value in predicting the risk of adverse health outcomes in older adults.

7.3.2 INTRODUCTION

At any age, on average, older people have more health deficits (broadly defined to include illnesses, symptoms, and functional limitations) than do younger people. Even so, some people live into old age having accumulated very few health deficits. This group of apparently very healthy elderly people is of some interest. In particular, it appears that they offer some insight into the overall health of a population. This is because the health and mortality outcomes of the fittest people of a society may depend on attributes of that society and the environment in which it is located.

The age-related accumulation of health deficits can shed some insights on frailty, i.e. on the problem of heterogeneity in health outcomes of people of the same chronological age. Health deficits are defined broadly, to include symptoms, signs, diseases, disabilities, or laboratory abnormalities. A number of studies have found that the more deficits that people have, the more likely they are to experience adverse health outcomes, such as death, institutionalization or worsening in their health.(Mitnitski, Song et al. 2004; Goggins, Woo et al. 2005; Mitnitski, Song et al. 2005; Kulminski, Yashin et al. 2006; Rockwood, Andrew et al. 2007; Kulminski, Ukraintseva et al. 2008; Yang and Lee 2010) This relationship to adverse health outcomes is true across the entire range of health deficits, so that people in whom deficits are not demonstrable (whom we refer to as being in the “zero state” of frailty) have the lowest rate of death, institutionalization and worsening health.

Social conditions, including socioeconomic status, social support, social engagement, and mastery, have powerful influences on health.(Berkman 2000; Kawachi and Berkman 2000; Putnam 2000; Veenstra 2000; Woo, Goggins et al. 2005; Andrew 2010) However, the influence of social factors such as socioeconomic status in older age is debated.(Marmot and Shipley 1996; Robert and House 1996; Crimmins, Kim et al. 2009) Nevertheless, we have previously reported that a holistic social vulnerability index, akin to the frailty index, which includes social factors from various domains including socioeconomic status, social support, social engagement, and mastery, predicts both

mortality and cognitive decline among older adults.(Andrew, Mitnitski et al. 2008; Andrew and Rockwood 2010) Here, our objective was to investigate the impact of social vulnerability, quantified using a social vulnerability index, on the survival of the fittest older adults, defined using a frailty index.

7.3.3 METHODS

The sample came from the second phase of the Canadian Study of Health and Aging (CSHA-2, conducted in 1996-1997). The CSHA is a representative study of dementia and other health problems in older Canadians.(Rockwood, McDowell et al. 2001) Of 5703 participants in the CSHA-2 screening interview, 729 (13%) were missing frailty status. People with missing frailty data were older (83.2 vs. 78.5 years, $p<0.0001$), often relying on proxy respondents. The fittest individuals were defined as the 584 who were in the "zero state" of frailty, i.e. those in whom either 0 or only 1 health deficit were reported. Of these, 541 (93%) had social vulnerability status data allowing for a social vulnerability index to be calculated. The cohort was followed for five years, at which time vital status was known for all but 3 of these 541 individuals; 95 (17.6%) had died.

Frailty and social vulnerability were based on self-report. Responses to 40 social variables were assigned a value of "1" if representing a deficit and "0" otherwise. The sum of this deficit count, divided by 40, is the social vulnerability index, so that the theoretical range is from 0 (none of the 40 social deficits) to 1 (all 40/40 social deficits); higher scores indicate greater vulnerability.(Andrew, Mitnitski et al. 2008) Social vulnerability was divided into tertiles of low, intermediate, and high index values. Individuals missing data for 1 or 2 of the social deficits were assigned to the tertile of social vulnerability based on their existing data. The 43 individuals who were missing more than 1-2 variables were coded as missing social vulnerability status and therefore excluded from further analysis.

The frailty index was operationalized using 31 health deficits. Both the frailty and social vulnerability indices have been validated and lists of their constituent variables have been published.(Mitnitski, Song et al. 2004; Andrew, Mitnitski et al. 2008) The association between level of social vulnerability (independent variable) and mortality (dependent variable) was analysed using Cox regression. The absolute risk of mortality was calculated for the three strata of social vulnerability, and Kaplan-Meier survival curves were generated.

Exercise, smoking, and alcohol histories were obtained from a self-reported questionnaire conducted at the first phase of CSHA, five years prior to the baseline data for this analysis. These variables were not updated in later phases of the CSHA, so previous reported history is all that was available. Exercise was categorized as high (regular exercise, three or more times per week, more intense than walking), intermediate (regular exercise but either less frequent or of walking intensity or less), and low (no regular exercise reported). This definition of exercise has been validated in the CSHA.(Middleton, Mitnitski et al. 2008; Hubbard, Fallah et al. 2009) Smoking was defined as a lifetime history of ever having "smoked cigarettes, pipe or cigars regularly (nearly every day)". Alcohol intake was similarly defined as ever having been a regular drinker of beer, wine, or spirits.

7.3.4 RESULTS

Of 4974 people with known frailty status, 584 (12%) reported only 0 or 1 deficit. Characteristics of the groups with and without deficits are presented in Table 18. Adjusting for age and sex, high social vulnerability was associated with an increased risk of death (HR 2.5, 95% CI:1.5-4.3, p=0.001) (Figure 21). Among those in the zero state of frailty, the absolute risk of mortality rose with increasing social vulnerability. Among those with low social vulnerability, 32 of 296 died (10.8%), as compared with 37 of 165 (22.4%) with intermediate social vulnerability In the high social vulnerability group, 26 of 80 (32.5%) had died within five years.

Previously reported exercise, previous history of smoking, and previous alcohol intake were not statistically significantly associated with mortality among those in the zero state of frailty. In the survival models adjusted for these covariates, the association between high social vulnerability and mortality was strengthened (HR 3.22, 95% CI: 1.80-5.78, $p<0.001$).

7.3.5 INTERPRETATION

We found that, amongst the fittest Canadian older adults, the third with the highest social vulnerability were more than twice as likely to die as the third with the lowest social vulnerability. This increase in risk represents a 22% absolute mortality difference between those with low and high social vulnerability.

While these findings are limited by being based on a single, relatively small sample of older adults, the effect size is striking and warrants further investigation. In particular, replication in samples from countries in different stages of development may be instructive. In addition, possible gender differences and the respective impact of mid-life *vs*. older age social conditions especially warrant further inquiry. The use of self-report data is a further limitation of this study, although we have shown, in relation to the frailty

index, that self-report, observer assessed and test data give comparable estimates in the average rate of deficit accumulation, and in the maximum observed values. (Mitnitski, Song et al. 2005) Moreover, for social vulnerability, it may be that self perception of one's social circumstances is particularly important.

Frailty and social vulnerability status were missing for some of the CSHA cohort. Those who were missing these indices were older and had more illnesses than those with complete data. They more often relied on proxy reports, making collection of many self-report items impossible. This is unlikely to have affected the findings of the current study, because the cohort was limited to those in the "zero state" of frailty, who had 0 or 1 health deficit, because those with missing frailty index data generally had many health problems. However, it is possible that the exclusion of these 43 individuals (7.4% of the zero state sample) may have affected the analysis of the association between social vulnerability status and health.

The lifestyle data was collected five years prior to the current baseline data, and we have no means of verifying whether the previous self-reports correlate with current behaviour, although they do correlate with outcomes.(Middleton, Mitnitski et al. 2008; Hubbard, Fallah et al. 2009) Nevertheless, it is interesting to note that the association between social vulnerability and mortality that we have identified seems to be robust to an initial consideration of confounding by lifestyle factors, though the influence of health-related behaviours on the association between social circumstances and health in older people remains an area for further investigation.

The influence of social factors, usually limited to consideration of socioeconomic status, on health in older age has been debated. A recent US study found that socioeconomic differences in mortality became insignificant at older ages (ages 70 years and older); this was felt to relate to important differences in health and mortality experienced at earlier ages, possibly leading to a "survival of the fittest" phenomenon. (Crimmins, Kim et al. 2009) In the Whitehall studies in the United Kingdom, the magnitude of association between occupational status and health was found to diminish after retirement, while the

importance of other socioeconomic indicators was maintained.(Marmot and Shipley 1996) Others have argued that while the importance of more limited indicators of SES such as income and education may diminish at older ages, consideration of other factors such as financial assets remains important.(Robert and House 1996) These sorts of findings have contributed to discussion of how to best measure SES in older age, where occupational status, income, and education may have more limited import due to retirement, pension schemes, and cohort educational norms. (Grundy and Holt 2001) Here, we have broadened our consideration of social factors to create a more holistic representation of aggregate social circumstances, not limited to consideration of a few socioeconomic factors, which may explain the differences between our findings and some previous literature reports.

The outcomes of people in the zero state of frailty are of considerable interest. That is because changes in the health of individuals are the sum of ambient changes, plus changes associated with their given state of health.(Mitnitski, Bao et al. 2006) Although mortality outcomes will always be higher as people grow older, the environment will undoubtedly be important – the mortality of the fittest older adults in Somalia for example, will be higher than that of their counter-parts in Saskatchewan. The outcomes of people in the zero state of frailty provide a quantitative estimate of these background effects, an application of considerable potential. For example, the chance of dying for an individual with three health deficits is a function of the chance of the healthiest people dying - those in the zero state - plus the chance of dying as the number of deficits increases to three.(Mitnitski, Bao et al. 2006)

Older people who have aged without accumulating health deficits can be considered examples of healthy aging. Study of this group of individuals presents an important opportunity to understand predictors and facilitators of healthy aging, which could in turn lead to new ideas about how to improve the health and quality of life of our aging populations.

Investigating how social factors affect the healthiest gives a quantitative estimate of those influences on the ambient health of the population. Limiting the analysis to the fittest individuals may allow for improved isolation of what factors in a society make it healthy or unhealthy. We suggest that survival in the zero state of frailty is a candidate marker for the health of populations.

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7.3.7 GRAPHICS

Figure 21. Kaplan-Meier curves showing survival those in the zero state of frailty (having 0-1 health deficit) by level of social vulnerability (low, intermediate, and high). SV = social vulnerability.

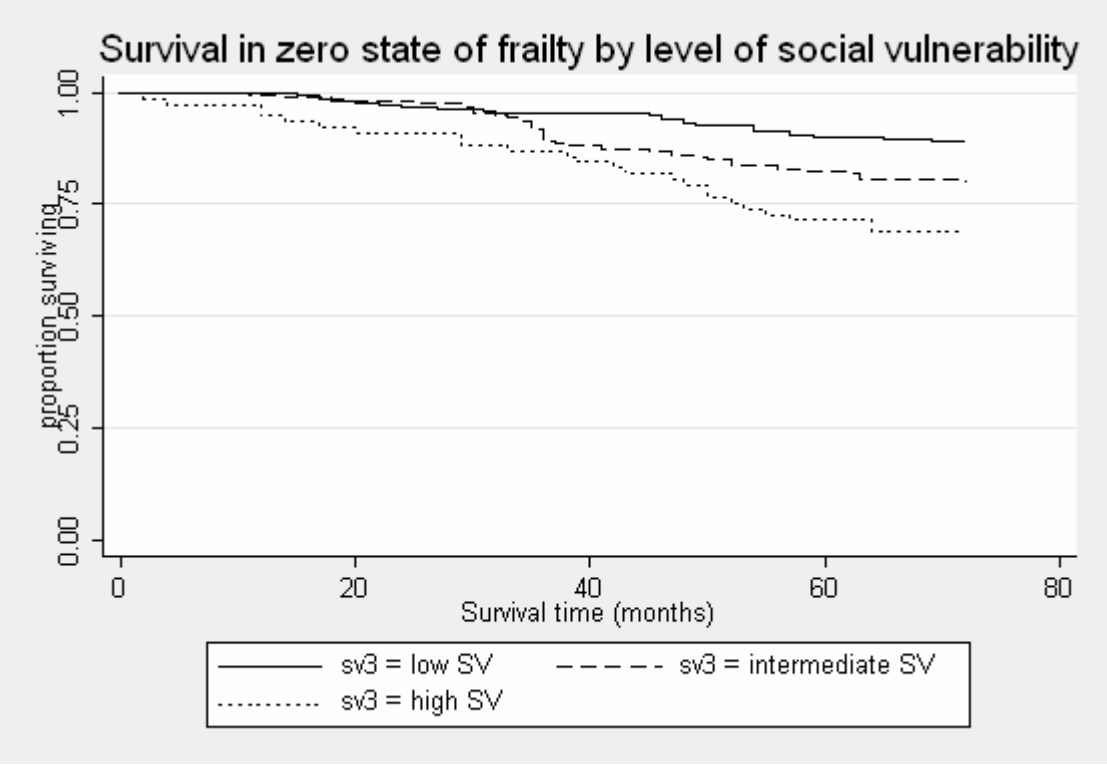

Table 18. Characteristics of the zero frailty state group (0-1 deficits) compared with those not in the zero frailty state group (who had 2+ health deficits).

	Zero State (N=584)	Non-zero state (N=4390)	
Age: mean (SD)	76.3 (5.3)	78.8 (6.2)	p<0.0001
Sex: % female	46.8 %	61.6 %	p<0.001
Education: mean (SD) years	11.3 (3.9)	10.5 (3.8)	p<0.001
Marital status: % married	43.2 %	52.6 %	p<0.001
MMSE score: mean (SD)	27.1 (0.12)	26.7 (0.05)	p=0.001
History of smoking (asked 5 years previous)	55.3 %	53.3 %	p=0.4
Alcohol consumption (asked 5 years previous)	46.5 %	40.4 %	p=0.009
Exercise (asked 5 years previous) Regularly, >3/week, more intense than walking Regularly but less frequent and/or less intense No regular exercise	 23.4 % 56.9 % 19.8 %	 18.0 % 50.5 % 31.5 %	p<0.001

CHAPTER 8 SOCIAL VULNERABILITY AND PREFRONTAL COGNITIVE FUNCTION

8.1 PROLOGUE

While the previous studies have examined the construct of social vulnerability, how it relates to health outcomes, and how it changes as older people age, they have not concentrated on possible mechanisms for these associations. The final study in this thesis does so by examining whether social vulnerability is associated with frontal lobe function.

This is of interest because the frontal lobes are known to influence social behaviour in humans. Associations between social vulnerability and frontal lobe function might therefore suggest one of the possible ways that social vulnerability affects human health. However, the picture is unlikely to be so clear; it seems likely that any association may in fact be bidirectional, with frontal lobe function influencing social vulnerability just as social vulnerability influences the function of these most social parts of the brain.

8.2 PUBLICATION DETAILS

Andrew, M. K., J. D. Fisk and K. Rockwood (2010). "Social vulnerability and prefrontal cortical function in elderly people: a report from the Canadian Study of Health and Aging." International Psychogeriatrics **In press**.

8.3 SOCIAL VULNERABILITY AND PREFRONTAL CORTICAL FUNCTION IN ELDERLY PEOPLE: A REPORT FROM THE CANADIAN STUDY OF HEALTH AND AGING

8.3.1 ABSTRACT

BACKGROUND: Prefrontal cortical lobe function is related to social behaviour in humans. We investigated whether performance on tests of prefrontal cortical function was associated with social vulnerability. Associations with non-frontal cognitive function were investigated for comparison.

METHODS: 1216 participants aged 70+ of the Canadian Study of Health and Aging-2 screening examination who also underwent detailed neuropsychological testing comprised the study sample. Performance on WAIS-R abstraction, WAIS-R comprehension, Trails B, FAS and category verbal fluency, Block construction, Token Test and Wechsler Memory Scale Information Subset was tested in relation to the participant's level of social vulnerability using regression models adjusted for age, education, sex, frailty, MMSE score, diagnosis of depression, and use of psychoactive medications. Social vulnerability was measured by an index comprising many social problems or "deficits".

RESULTS: The most socially vulnerable group had worse performance on FAS verbal fluency, generating 4.1 fewer words (95% CI:1.8-6.4, $p<0.001$) than those in the least socially vulnerable group; those with intermediate social vulnerability generated 2.6 fewer words (95% CI:0.4-4.8, $p=0.02$). Social vulnerability was also associated, though less strongly, with category verbal fluency. The most socially vulnerable people had impaired performance on the Trails B, taking 37 (95% CI: 11-63, $p=0.005$) seconds longer. These results were independent of age, education, sex, frailty, MMSE score, depression, and psychoactive medications. Social vulnerability was not associated with performance on WAIS-R abstraction, WAIS-R comprehension, Block Design, Token Test or Wechsler Memory Scale tests.

CONCLUSIONS: High social vulnerability was associated with impaired performance on verbal fluency and set shifting but not with common sense judgment, abstraction, long-term memory, constructional ability, or language comprehension. The association between social functioning and the cognitive functions subserved by prefrontal cortex warrants further study.

8.3.2 INTRODUCTION

Social vulnerability refers to a holistic measure of people's social circumstances which includes assessment of many different factors, including social support, social engagement, living situation, mastery, and socioeconomic status.(Andrew 2005; Andrew, Mitnitski et al. 2008; Andrew 2010) Using a deficit accumulation approach, increasing social vulnerability is associated with increased risk of death and of cognitive decline.(Andrew, Mitnitski et al. 2008) Considered in this way, social vulnerability represents a spectrum of vulnerability to insults, from low to high.

While social vulnerability influences health outcomes in longitudinal studies, it is not clear how it comes about; for example, what makes some individuals more socially vulnerable than others, given a similar set of "objective" socioeconomic circumstances? Personality factors are likely to play an important role, as are previously held values and patterns of behaviour. For instance, as the continuity theory of aging postulates, (Atchley 1989) some individuals have never been "joiners", preferring instead to live relatively solitary lifestyles. Neuropsychological factors may also be at play. For example, people with frontal lobe damage or with frontotemporal lobar degeneration present with signs and symptoms that include impaired social judgment and behavioural disinhibition as well as difficulties with executive abilities (including problems with sequencing, organizing, abstraction, and planning). As prefrontal cortical lobe functions are related to social behaviour in humans, they may therefore also be related to profiles of social vulnerability.

With this study, we aimed to test the hypothesis that performance on neuropsychological tests of prefrontal cortical function is associated with social vulnerability, operationalized using a social vulnerability index comprising many potential social problems or "deficits".

8.3.3 METHODS

Study sample

The Canadian Study of Health and Aging (CSHA) is a representative study of dementia and aging-related conditions. Sampling was population-based and representative of English and French-speaking Canadians aged 65 and older, though its design excluded those who lived in the Yukon or Northwest Territories, residents of Aboriginal Reserves or military bases, and those with an immediately life-threatening illness.(Rockwood, McDowell et al. 2001) The sample of 10,263 individuals was clustered within 5 geographical regions and was stratified by age, with oversampling of those ≥age 75. Baseline assessments were conducted in 1991 at 18 study centres throughout Canada, with follow-up at five (CSHA-2) and ten (CSHA-3) years. In CSHA-1, 9,008 community-dwelling older people participated in a screening interview, of whom 5,703 had a repeat screening interview at CSHA-2. At each wave, institutionalized older people, those with evidence of cognitive impairment based on a Modified Mini Mental State Examination (3MS) score <78, and a random sample of those with 3MS score ≥78 had a comprehensive clinical assessment, which included (for those with a 3MS ≥50) detailed neuropsychological testing.(Rockwood, McDowell et al. 2001) Here, we included the 1,216 people who participated in both the CSHA-2 neuropsychological assessment and the CSHA-2 screening interview, which was enriched in social variables used to create the social vulnerability index. The mean age was 81.9 (SD 6.7) years and 677 (55.7%) of the sample were women.

Measures

Tests of prefrontal cortical function

The FAS verbal fluency test is a widely-used test of phonemic verbal fluency, in which participants are asked to verbally generate as many words (excluding proper names) as they can starting with the letters "F", "A" and "S", each in a minute.(Spreen and Benton 1977) This task differs from assessments of semantic fluency, in which a list of words is generated from the same semantic category – *e.g.* animals. Here, the total number of words generated for all three letters was used as the measure of performance. Phonemic verbal fluency using the FAS test has been found to be impaired in individuals with frontal lobe lesions,(Baldo and Shimamura 1998; Kramer and Quitania 2007) particularly left-sided lesions.(Stuss, Alexander et al. 1998) Category verbal fluency, in which subjects were asked to name as many animals as they could in a minute, was also tested. The FAS verbal fluency test is classically considered to test pre-frontal cortical function due to its requirement for efficient and strategic memory search but this association is less clear for semantic category verbal fluency, which can also be associated with anomia and pathology of the language-dominant posterior temporal lobe region. Regardless, while the localizing and diagnostic value of relative performance differences on these fluency tasks can be debated, both are commonly impaired in association with prefrontal cortical dysfunction. (Delis, Kaplan et al. 2001; Lezak, Howieaon et al. 2004; Strauss, Sherman et al. 2006)

The Trail Making Test is a widely-used and validated neuropsychological test.(Reitan 1992) In the Part B Trail Making Test, the subject draws a line connecting letters and numbers in sequence (1-A-2-B…) that are pseudorandomly arranged on a paper. If errors occur, the subject is immediately corrected and re-directed, and the task is timed. The Trails B is a test of divided attention and response alternation, and performance has been shown to be impaired in individuals with frontal lobe (particularly dorsolateral frontal) lesions.(Stuss, Bisschop et al. 2001)

The Wechsler Adult Intelligence Scale-Revised (WAIS-R) similarities subtest assesses abstraction and verbal problem-solving.(Wechsler 1981) Participants were asked in what way two things are alike (*e.g.* banana-orange, coat-suit, table-chair). The response for each pair of words was scored as 0 (incorrect generalizations, only providing specifics about each of the pair), 1 (concrete similarity), or 2 (abstract similarity, general classification). Consecutive test items increased in difficulty. The scores were added for the seven word pairs of the abbreviated version of this test used in the CSHA test battery, yielding a total possible score range of 0-14.(Tuokko, Kristjansson et al. 1995) Interpretation of similarities is a well-validated test of abstraction which is commonly used in clinical settings as a test of frontal lobe function (Kramer and Quitania 2007) and is an element of screening assessments such as the Frontal Assessment Battery (Dubois, Slachevsky et al. 2000) and the 3MS.(Teng and Chui 1987)

The WAIS-R comprehension subtest required the subject to provide socially appropriate responses to hypothetical questions.(Wechsler 1981) For example, questions included "Why do we wash clothes?" and again increased in difficulty as the test proceeds. Each response was then scored as 0 (a response containing no correct element), 1 (an incomplete response, missing the key element - *e.g.* "to look attractive") or 2 (a response indicating good understanding, *e.g.* "to clean them"). This is a validated test of judgment and problem solving in relation to hypothetical social situations.(Wechsler 1981)

Tests of other cognitive domains

The Wechsler Memory Scale Information Subset tests long-term recall.(Wechsler 1974) Subjects were asked six questions about their age and birthdate and current political leaders relevant to their area of residence, yielding a total score of 0-6.

The Token Test assesses language comprehension through the ability to understand and perform simple commands.(Benton and Hamsher 1989) The range of possible scores for this test was 0-44.

The WAIS-R Block Design test assesses constructional ability, or ability to copy designs correctly.(Wechsler 1981) In the CSHA, a shortened version of the test was performed, in which five of the nine tests in the full version were administered. According to standard practice, time limits were observed and bonus points were awarded for speed. Possible scores ranged from 0-29.

For all of the neuropsychological tests, CSHA study neuropsychologists administered the tests using standardized methods and instructions to participants. Individuals who were unable to complete the test due to a physical disability, who refused the test, or who were unable to understand the task were coded as missing.

Social vulnerability was measured using a social vulnerability index which included 39 self-report social factors covering various domains of social circumstance, including socioeconomic status, social support, living situation, social engagement, and mastery. (Table 19).(Andrew, Mitnitski et al. 2008) Respondents were assigned a score between 0 and 1 on each of the potential social "deficits"; 0 if the deficit was absent and 1 if it was endorsed, with intermediate values applied for ordinal response categories. For example, on the item "do you ever feel you need more help or support", the three possible responses of "never", "sometimes" and "often" were assigned values of 0, 0.5 and 1, respectively. The sum of the deficit scores provided a social vulnerability index value for each individual with a maximum theoretical range of 0-39, in which higher scores indicated increased social vulnerability. For the purposes of this analysis, the sample was stratified into three tertiles of social vulnerability: high, intermediate, and low. This approach to measuring social vulnerability as an index of deficits builds on a similar approach to the operationalization of frailty,(Mitnitski, Song et al. 2005; Rockwood, Andrew et al. 2007) which has been multiply and independently cross-validated.(Goggins, Woo et al. 2005; Hastings, Purser et al. 2008; Kulminski, Ukraintseva et al. 2008; Gu, Dupre et al. 2009)

Here, frailty was operationalized as an index of 31 health deficits representing self-reported symptoms, health attitudes, illnesses, and impaired functions which were assigned scores in the 0-1 interval as described above.(Table 20) These deficit scores were then summed and divided by the total number of deficits considered (31) to generate a frailty index, such that a greater score corresponded to worse health status and increased frailty.(Mitnitski, Song et al. 2004; Mitnitski, Song et al. 2005) The frailty index (FI) was dichotomized based on the previously-published threshold: people with FI $\geq$ 0.25 were considered frail.

Educational attainment was reported by the participants as the number of years of formal schooling that they had completed. It was dichotomized such that <12 years of formal schooling represented low education.

The Mini Mental State Examination (MMSE) was used as a measure of general cognitive function. This is a widely-used and well-validated screening instrument that tests orientation, concentration, memory, visuospatial ability, and language (Folstein, Folstein et al. 1975) and does not address the cognitive domains of prefrontal cortical functioning of interest in our analysis. The published cutoff of <24/30 was used to indicate cognitive impairment.

Depression was diagnosed clinically using DSM-III-R criteria.

Participants who were taking medications which might impair performance on neuropsychological testing (sedative hypnotics, anxiolytics, antipsychotics, opioids, and other psychoactive drugs) were identified using the CSHA's comprehensive data on medication use. For each participant, all prescription and non-prescription medications were recorded and coded according to the class of agent. All individuals who were taking one or more medication with the potential to impair test performance were identified in order to adjust the analyses for any confounding by medication use.

Statistical analyses

Performance on each of the neuropsychological tasks was tested in relation to the participant's tertile of social vulnerability using linear regression models adjusted for age, educational attainment, sex, frailty, general cognitive function (MMSE score), depression and medication use. Interaction terms were tested for all covariates. Chi square testing was used for proportions. All analyses were done using STATA 8.1 software.

Ethics

Ethical approval was obtained from the ethics committees of each of the 18 CSHA study centres. Written, informed consent for participation in the CSHA was obtained from each participant or proxy respondent.

8.3.4 RESULTS

The mean age was 81.9 years (SD 6.7); 56% of the sample were women. Participants had a mean educational attainment of 9.9 (SD 4.0) years, and 32.4% had completed ≥12 years of formal schooling. The mean frailty index was 0.19 (SD 0.11) which is below the established cutoff for frank frailty. 28% of the sample were frankly frail, with frailty index ≥0.25. The distribution of MMSE scores was skewed, with the tail trailing toward lower values. The median score was 26 (IQR 23-28) and 30.9% of the sample scored less than 24 points, the suggested cutoff for cognitive impairment. Higher social vulnerability was associated with female sex ($p<0.001$), increasing age ($p<0.001$), and frailty ($p<0.001$), but not with cognitive impairment on the MMSE ($p=0.3$) or low education ($p=0.09$). Women had more prevalent use of psychoactive medications (29% vs. 17% for men, $p<0.001$) but prevalence of depression did not differ between the sexes. Frail individuals were more likely to be taking psychoactive medications (35% vs. 17% for non-frail individuals, $p<0.001$).

The most socially vulnerable group had worse performance on the FAS verbal fluency assessment, generating 4.1 fewer words (95% CI:1.8-6.4, p<0.001) than their counterparts in the least socially vulnerable group; the intermediate social vulnerability group generated 2.6 fewer words (95% CI:0.4-4.8, p=0.02).(Table 21) Category verbal fluency (animal naming) was also associated with social vulnerability. The most socially vulnerable people generated 1.5 fewer animal names (95 CI: 0.7-2.3, p<0.001), while those with intermediate social vulnerability generated 1.0 fewer words (95% CI: 0.2-1.8, p=0.01). The most socially vulnerable people also had impaired performance on the Trails B test, taking 37 (95% CI: 11-63) seconds longer to complete the task than the least vulnerable group (p=0.005). These results were independent of age, educational attainment, sex, frailty, cognitive impairment on the MMSE, depression, and use of psychoactive medications. Social vulnerability was not associated with performance on the WAIS-R subtests of abstraction or judgment. Additionally, in these fully adjusted regression models, social vulnerability was not associated with performance on the Wechsler Memory Scale test of long term memory, the WAIS-R Block Design subtest of constructional ability, or the Token Test of language comprehension.

In each of the full regression models which included all of the covariates, education and the MMSE score were independently strongly associated with performance on all of the cognitive tests, and contributed importantly to the final models. There was statistically significant interaction between frailty and MMSE score in the Trails B regression model, such that individuals who were both frail and cognitively impaired took 112 seconds longer to complete the task (95% CI: 42-183, p=0.002). However, there was no other evidence of statistically significant interaction between these covariates in the remaining regression models.

8.3.5 DISCUSSION

We found that the most socially vulnerable elderly people had lower performance on tests of executive function and verbal fluency, as measured by the Trails B test, FAS verbal fluency, and animal naming. This association was independent of age, educational

attainment, sex, frailty, cognitive impairment as judged by the MMSE, depression, and use of psychoactive medications. However, performance on the WAIS-R Comprehension and Abstraction subtests, which assesses common sense judgment and abstract thinking, were not associated with social vulnerability. Tests of other domains of cognition (long term memory, constructional ability, and language comprehension) were not associated with social vulnerability.

Educational attainment is strongly associated with performance on the tests of prefrontal systems function used in this study and age is commonly associated as well.(Strauss, Sherman et al. 2006) Thus, our finding that socially vulnerable people have worse performance on these tests independent of educational attainment and age is important. Performance on the Trails B and WAIS-R abstraction tasks declined with age, as did scores for long term recall, language comprehension and constructional abilities (Table 21). The lack of statistically significant association between age and FAS verbal fluency may reflect the relatively restricted age range (70+) of the sample. Similarly, as Table 21 illustrates, both education and MMSE independently influenced performance on each of the cognitive tests. Despite this, socially vulnerable people had worse performance on these tests of executive function and verbal fluency, even when cognitive impairment on the MMSE was accounted for. While the MMSE has been criticized as being a suboptimal cognitive screening instrument in some respects, (Strauss, Sherman et al. 2006) we chose it in part for the reason that its relatively poor assessment of prefrontal cognitive functions allowed for adjustment of the presence of general cognitive impairment without "adjusting away" the primary association being considered. Of course, it remains possible that there are additional confounders that we have not taken into account in our models, although by also adjusting for sex, and frailty (a global measure of health and vulnerability), depression, and medication use we have aimed to reduce this risk.

A statistically significant interaction between frailty and prefrontal cognitive test performance was identified for only one of the tasks, the Trails B. Those who were both frail and had general cognitive impairment on the MMSE performed much more slowly on this task, by an average of 112 seconds. This interaction was not evident for any of the

other tests but is in keeping with the combined physical and cognitive elements of the Trails B. Specifically, Trails B is a timed test requiring efficient ocular motor scanning and manual dexterity in addition to its cognitive requirements of sequencing, divided attention and response alternation.

Our results must be interpreted with caution since our study was cross-sectional, and thus no assertions can be made regarding causation. Nevertheless, the association of social vulnerability with executive dysfunction and reduced verbal fluency in our sample highlights the importance of identifying patients with prefrontal cognitive impairment who present to clinical settings, particularly given that social vulnerability is associated with increased risk of mortality and cognitive impairment.(Andrew, Mitnitski et al. 2008; Andrew and Rockwood 2010) Paying particular attention to the social circumstances of such patients may prove beneficial. Additionally, those with prefrontal cognitive impairment may have difficulty participating in interventions (*e.g.* group activities) to reduce social vulnerability, and this should be born in mind when such programs are designed and implemented. Our study may also be limited in that social vulnerability was based on self-report, and is thus not an "objective measure". It seems likely, however, that given the subjective nature of a number of the elements used in this measure (such as mastery and perceived adequacy of social supports), self-perception of social vulnerability would be an important problem even in the absence of more objectively measured vulnerability.

To aid interpretation of our models, we dichotomized MMSE scores, educational attainment, and frailty. In reality, these factors show continuous distribution which is likely reflective of a clinically relevant gradient. Reassuringly, the results of "sensitivity analysis" regression models which treated these variables as continuous were not materially different from those using dichotomized variables based on the clinically meaningful cut-offs presented above.

The clinical diagnosis of depression is a strength of this study, however because the CSHA was designed to focus on dementia, participants who had both depression and dementia would have been given a study diagnosis of dementia, likely leading to under-

diagnosis of depression in those with co-existing dementia. However, individuals with more profound cognitive impairment (screening 3MS<50) were not subjected to the full battery of neuropsychological tests, and so they have been necessarily excluded from the present analyses.

Drugs that cause psychomotor slowing might be expected to disproportionately affect timed tests including tests of pre-frontal cortical function such as Trails B and verbal fluency tests. However, we accounted for this possible confounder by adjusting our analyses for use of medications which may impair performance on these tests. The CSHA collected detailed medications lists for all participants in our sample, so it is unlikely that participants would have been misclassified on this variable.(Rockwood, McDowell et al. 2001)

Our study also has certain strengths in that the sample was representative of community dwelling older people living in Canada and participants underwent standardized assessments by trained test administrators. The properties of our measures of frailty and social vulnerability have been previously studied, replicated, and validated.(Mitnitski, Song et al. 2004; Mitnitski, Song et al. 2005; Andrew, Mitnitski et al. 2008)

Impaired prefrontal cortex functioning has previously been identified in clinical samples of individuals with vascular cognitive impairment,(Sachdev, Brodaty et al. 2004) alcoholism, (Deckel 1999) and schizophrenia (Legendre Ropacki and Perry 2007) who may (in the case of people with schizophrenia and problem drinking) be more socially vulnerable than those without these conditions. However, to our knowledge this is the first population-based study of the association between prefrontal cortical function and social vulnerability in elderly people.

Neuropsychological evaluation of prefrontal lobe functioning is complex.(Stuss and Benson 1984; Stuss 2007) and impaired performance on tests that purport to assess so-called "executive" abilities can arise for many reasons. We do not claim that the neuropsychological tests examined here represent a definitive test battery for prefrontal cortical function; rather that they are widely used tasks in clinical practice that are understood to be influenced at least in part by prefrontal lobe function.

It is interesting to note that the ability to rapidly organize verbal output, as measured by the FAS verbal fluency task, showed the strongest and most graded association with social vulnerability in our sample. Category verbal fluency, which also draws on executive functions, but which does not require the same degree of effort in organizing and switching between search strategies, was also diminished in those who were socially vulnerable. Perhaps expressive language abilities are particularly vital to social engagement such that it is those neuropsychological tests that reflect both "executive" and expressive language abilities that show the strongest associations with social vulnerability. Clearly, the various functions of the prefrontal cortex may have different implications for social function and social vulnerability but our cross-sectional design does not allow the direction of causation to be determined. Moreover, the association between social vulnerability and lower performance on tests of executive functions and verbal fluency is likely to be complex and bidirectional. It is possible, for example, that people with difficulties in language-based functions such as verbal expressive difficulties may withdraw from social activities and contact. On the other hand, those with social disinhibition or challenging deportment may offend their peers and be socially excluded as a result. Those who are socially disengaged may even lose the opportunities necessary to maintain their cognitive skills, thus resulting in poorer performance on tests of these abilities. Regardless of the direction of the causal relationship, our finding that social vulnerability is associated with impaired performance on tests of prefrontal cortical function in a representative sample of elderly persons is noteworthy, and illustrates the need for further inquiry in this area.

8.3.6 AUTHOR CONTRIBUTIONS

M. K. Andrew and K. Rockwood conceived the study. M. K. Andrew performed the analyses and wrote the initial drafts of the manuscript. J. D. Fisk contributed to the analyses and to interpretation or results. All authors contributed to manuscript revisions. K. Rockwood was a Principal Investigator in the CSHA and holds the data on-site.

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8.3.9 GRAPHICS

Table 19. Canadian Study of Health and Aging social vulnerability index.(Andrew, Mitnitski et al. 2008)

Communication to engage in wider community	
1	Read English or French
2	Write English or French
Living situation	
3	Marital status
4	Lives alone
Social support	
5	Someone to count on for help or support
6	Feel need more help or support
7	Someone to count on for transportation
8	Feel need more help with transportation
9	Someone to count on for help around the house
10	Feel need more help around the house
11	Someone to count on to listen
12	Feel need more people to talk with
13	Number of people spend time with regularly
14	Feel need to spend more time with friends/family
15	Someone to turn to for advice
16	Feel need more advice about important matters
Socially oriented Activities of Daily Living	
17	Telephone use
18	Get to places out of walking distance
Leisure activities	
19	How often visit friend or relatives
20	How often work in garden
21	How often golf of play other sports
22	How often go for a walk
23	How often go to clubs, church, community centre
24	How often play cards or other games
Ryff scales	
25	Feel empowered, in control of life situation
26	Maintaining close relationships is difficult and frustrating
27	Experience of warm and trusting relationships
28	People would describe me as a giving person
How do you feel about your life in terms of …	
29	Family relationships
30	Friendships
31	Housing
32	Finances
33	Neighbourhood
34	Activities
35	Religion
36	Transportation
37	Life generally
Socio-economic status	
38	Does income currently satisfy needs
39	Home ownership

As previously published,(Andrew, Mitnitski et al. 2008) but excluding education which was treated as a stand-alone covariate in the present study due to its uniquely important association with performance on cognitive testing.

Table 20. Canadian Study of Health and Aging frailty index.(Mitnitski, Song et al. 2004)

	Variable
1	Eyesight
2	Hearing
3	Help to eat
4	Help to dress and undress
5	Help to take care of appearance
6	Help to walk
7	Help to get in and out of bed
8	Help to take a bath or shower
9	Help to go to the toilet
10	Help in shopping
11	Help to prepare own meals
12	Help to do housework
13	Ability to take medications
14	Ability to handle own finances
15	Poor self-assessed health
16	Hypertension
17	Heart and circulation problems
18	Stroke or effects of a stroke
19	Arthritis or rheumatism
20	Parkinson's Disease
21	Eye trouble
22	Ear trouble
23	Dental problems
24	Chest problems
25	Stomach problems
26	Bladder control problems
27	Bowel control problems
28	Trouble with feet or ankles
29	Trouble with skin
30	Fractures
31	Frequent trouble with pain

As previously published, (Andrew, Mitnitski et al. 2008) using the second wave of the CHSA, and excluding items in the social vulnerability index (living alone, telephone use, and ability to get places out of walking distance).

Table 21. Fully adjusted models of performance on the four prefrontal neuropsychological assessments by level of social vulnerability and adjusted for covariates. Statistically significant associations are shaded.

Cognitive Test / Covariates	Trails B (seconds)	Abstraction (points scored)	Judgment (points scored)	FAS verbal fluency (words generated)	Category verbal fluency (words generated)	Long term recall (points scored)	Token test (points scored)	Block design (points scored)
Intermediate social vulnerability (vs. low)	11.7 (-11.8, 35.3) p=0.3	-0.1 (-0.9, 0.6) p=0.7	0.2 (-0.4, 0.7) p=0.6	-2.6 (-4.8, -0.4) p=0.02	-1.0 (-1.8, -0.2) p=0.01	-0.9 (-0.3, 0.2) p=0.5	-0.8 (-1.9, 0.4) p=0.2	-0.09 (-0.9, 0.7) p=0.8
High Social Vulnerability (vs. low)	37.0 (11.4,62.6) p=0.005	-0.7 (-1.5, 0.01) p=0.054	-0.1 (-0.7, 0.5) p=0.7	-4.1 (-6.4, -1.8) p<0.001	-1.5 (-2.3, -0.7) p<0.001	-0.3 (-0.5, 0.003) p=0.053	-1.0 (-2.2, 0.3) p=0.1	-0.5 (-1.3, 0.4) p=0.3
Older age	2.9 (1.3, 4.5) p<0.001	-0.05 (-0.1, -0.01) p=0.02	-0.03 (-0.07, 0.004) p=0.08	0.04 (-0.1, 0.2) p=0.6	-0.1 (-0.2, -0.7) p<0.001	-0.02 (-0.04, -0.01) p=0.001	-0.1 (-0.2, -0.03) p=0.007	-0.1 (-0.2, -0.07) p<0.001
Female sex	-13.8 (-33.1, 5.6) p=0.2	0.07 (-0.5, 0.6) p=0.8	-0.5 (-1.0, -0.08) p=0.02	1.3 (-0.5, 3.0) p=0.2	-0.6 (-1.3, 0.002) p=0.05	-0.3 (-0.5, -0.1) p=0.003	0.8 (-0.2, 1.7) p=0.1	-0.5 (-1.2, 0.2) p=0.1
Low education (<12 years)	34.7 (15.9, 53.2) p=0.001	-3.1 (-3.7, -2.5) p<0.001	-2.2 (-2.6,-1.7) p<0.001	-9.1 (-10.9, -7.3) p<0.001	-1.6 (-2.2, -0.9) p<0.001	-0.2 (-0.4, -0.1) p=0.04	-3.3 (-4.3, -2.4) p<0.001	-1.9 (-2.6, -1.2) p<0.001
Frailty (FI >0.25)	17.0 (-8.0, 41.9) p=0.2	0.1 (-0.6, 0.8) p=0.7	-0.06 (-0.6, 0.5) p=0.8	-1.2 (-3.3, 1.0) p=0.3	0.2 (-0.6, 0.9) p=0.5	-0.06 (-0.3, 0.2) p=0.6	-0.3 (-1.5, 0.8) p=0.6	-1.1 (-1.9, -0.3) p=0.01
Low MMSE score (<24/30)	107.3 (71.1, 143.4) p<0.001	-3.5 (-4.2, -2.7) p<0.001	-2.6 (-3.2, -2.0) p<0.001	-9.7 (-12.1, -7.4) p<0.001	-3.7 (-4.5, -2.9) p<0.001	-1.0 (-1.3, -0.7) p<0.001	-5.3 (-6.6, -4.1) p<0.001	-2.9 (-3.8, -2.1) p<0.001
Clinically diagnosed depression	-11.6 (-94.0, 70.8) p=0.8	-1.7 (-3.8, 0.5) p=0.1	-1.4 (-3.1, 0.4) p=0.1	-0.4 (-7.0, 6.2) p=0.9	-0.2 (-2.6, 2.2) p=0.9	-0.07 (-0.8, 0.7) p=0.9	0.9 (-2.6, 4.4) p=0.6	-0.4 (-2.8, 2.1) p=0.8
Psychotropic medication	4.5 (-19.9, 28.8) p=0.7	-0.4 (-1.1, 0.3) p=0.3	-0.2 (-0.7, 0.4) p=0.5	-0.2 (-2.3, 1.9) p=0.9	-0.1 (-0.9, 0.6) p=0.7	-0.3 (-0.5, -0.03) p=0.03	-1.7 (-1.9, -0.6) p=0.003	-0.1 (-1.0, 0.7) p=0.7
High frailty and low MMSE interaction	112.2 (41.9, 182.5) p=0.002	--	--	--	--	--	--	--
Constant	-88.7 (-215.5, 38.2) p=0.2	14.2 (10.6, 17.7) p<0.001	9.9 (7.1, 12.8) p<0.001	30.4 (19.3, 41.3) p<0.001	26.8 (22.8, 30.8) p<0.001	7.8 (6.6, 9.1) p<0.001	48.6 (42.7, 54.5) p<0.001	22.0 (17.8, 22.3) p<0.001

CHAPTER 9 CONCLUSION

9.1 OVERVIEW

The objective of this thesis was to develop and explore the concept of social vulnerability in relation to health in older people. The first chapter provided an overview of existing literature pertaining to social circumstances and health, with special consideration of health outcomes important to older people. The second outlined the methods used in the thesis. The third chapter was an exploration of the concept of social vulnerability and the inter-relationships among its various dimensions, using a social ecology perspective. The fourth and fifth examined social vulnerability in relation to important health outcomes (mortality and cognitive decline); the sixth examined how profiles of social vulnerability change over time. The seventh chapter examined the special case of how social vulnerability affects survival in the fittest older people, while the eighth began a mechanistic exploration by examining social vulnerability in relation to prefrontal cognitive function.

In this conclusion, the results of each study will be summarized and then discussed as an integrated whole in relation to the thesis' objectives. This will lead into a discussion of how this thesis builds the case for the clinical and policy relevance of social vulnerability, and finally, to directions for continued research.

9.2 STUDY SUMMARIES IN RELATION TO THE OBJECTIVES

9.2.1 OBJECTIVE i: WHAT IS SOCIAL VULNERABILITY?

The first study (Chapter 3) explored the construct of social vulnerability using a social ecology perspective, which considers inter-connected spheres of influence from the individual through close family & friends, wider peer networks, institutions,

neighbourhoods, and society at large. In this secondary analysis of both individual and neighbourhood social factors in the NPHS, seven dimensions of social vulnerability were identified (engagement, contextual socio-economic status, social support, living situation, self-esteem, mastery, and relations with others); these were situated within the ecological framework to illustrate the inter-connections between spheres of influence. Associations between dimensions were multiple and complex, suggesting that the spheres of influence are likely intertwined rather than clearly distinct from one another, and emphasizing the importance of considering social circumstances as a whole rather than in isolation. The social vulnerability index was presented here, and was predictive of mortality, introducing its potential as a measure that embraces the complexity of social circumstances and reduces dimensionality using a single interval scale with high explanatory value.

Some interesting differences emerged when the dimensions of vulnerability were studied in relation to age, sex, education and frailty. Women reported lower vulnerability in social engagement and social support, but were more often in a vulnerable living situation (living alone and being single or widowed). Of interest, both vulnerability in living situation and mastery increased with increasing age. People who were more frail had more vulnerability in the engagement, mastery, and self-esteem dimensions. Those with lower education reported more vulnerability engagement, mastery, contextual SES, and self-esteem. These differences suggest future directions for research in this area. For example, what qualitative and quantitative differences are there in social vulnerability as experienced by women and men?

9.2.2 OBJECTIVE ii: HOW DOES SOCIAL VULNERABILITY RELATE TO HEALTH?

As we saw in the first study (Chapter 3), many social factors that individually have been associated with health have complex inter-relationships, so that social vulnerability may therefore be best understood as an integrated whole. The second study (Chapter 4) builds

on the exploration of constituent domains of social vulnerability presented in the first study, by examining the association between a comprehensive social vulnerability index and mortality in two population-based studies, the CSHA and the NPHS. The results of this study showed that 1) social vulnerability increased with age, 2) women had higher levels of self-reported social vulnerability than men, 3) frailty and social vulnerability were correlated, but only moderately so, such that they remain distinct entities, and 4) increasing social vulnerability was associated with increased odds of death. In fact, there was a survival gradient across quartiles of social vulnerability, independent of age, sex, and frailty. Importantly, unlike frailty, in which some individuals are not at all frail (*i.e.,* are in the "zero state" of frailty; see study 5), *all* older people in this study had some degree of social vulnerability.

Another interesting direction taken in this study was further exploration of the properties of social vulnerability as an index. In particular, when dealing with indices, it is important to consider whether it is the index as a whole that is informative, or whether one or a few elements of the index are driving the observed associations, with the rest of the constituent variables being mere "fluff", padding the index and clouding the picture. Two novel techniques were used to explore this possibility. The first was a "jackknife by variables" approach in which the index (which consisted of *n* variables) was reconstructed *n* times, each time using *n-1* variables (*i.e.,* leaving out a different constituent variable each time). Each of these "subtraction indices" was then tested for association with the outcome (mortality). Each time the observed association with mortality was the same, supporting the assertion that no single variable was driving the association. The second test of the robustness of the index was a "re-sampling by variables" technique based on bootstrapping, in which a sub-sample of variables was randomly re-sampled many (hundreds of) times to create multiple indices. The survival analysis was re-run for each, yielding similar results, which suggests that the index is valid and that no sub-set of constituent variables was accounting for the observed association with mortality.

This study raised some interesting questions about social vulnerability, which led, in part, to the subsequent studies presented here. These included what associations exist with other important health outcomes such as cognitive decline, and whether the observed increase with age was an effect of aging (*i.e.* deficit accumulation) or a cohort effect. The association with frailty also begged further investigation, particularly trying to tease out how intrinsic (frailty) and extrinsic (social) vulnerabilities relate to one another. These questions formed the groundwork for studies 3, 4, and 5. Other questions, such as how gender influences social vulnerability and its outcomes, and whether interventions to decrease social vulnerability might lead to improved outcomes, remain to be addressed in future studies.

Cognitive decline is an outcome dreaded by most people as they age, and one which can have particularly devastating consequences. The third study (Chapter 5) examined how social vulnerability might increase older people's chances of experiencing clinically meaningful cognitive decline over a five year time period. In order to do so, the first exercise was to explore the idea of what represents a clinically meaningful decline in performance on the 3MS, a frequently-used cognitive screening test for which no measure of meaningful decline had previously been published. Using effect size as a measure of meaningful change, it was found that while a 1 point change was *clinically detectable*, a 5 point change likely represents a *clinically meaningful* change over time, and is a reasonable choice for a cutoff in studies in which the 3MS is used to define cognitive change over time. Using this 5 point definition of meaningful decline in a secondary analysis of the CSHA, the third study found that for each additional social deficit, the odds of cognitive decline increased by about 3%, and that compared to those with low social vulnerability, individuals with high social vulnerability had 36% increased odds of experiencing cognitive decline over five years.

Also pertaining to this objective on how social vulnerability relates to health, study 5 (Chapter 7) examined the special case of how social vulnerability influences health in the fittest older adults, those in the "zero state" of frailty. Limiting the analysis to just the fittest older people allows for more pointed investigation of the impact of "extrinsic

vulnerability" relating to social circumstances. This secondary analysis of 584 individuals aged 70+ in the CSHA who had 0-1 health deficit found that there was dramatic 22 % absolute increase in mortality when those with the highest social vulnerability were compared with those who were the least socially vulnerable.

It is interesting to note that the influence of socioeconomic factors on health in older age is debated. The findings of Study 5 suggest that perhaps this has been due to consideration of only a limited set of socioeconomic factors such as poverty, income, and occupational status in previous studies. When a more holistic view of social circumstances is considered, such as is allowed using the idea of social vulnerability, the ongoing import of social factors into older age seems clearer. The findings of Study 5 also have the potential to inform study of healthy aging, given that the older people who are in the zero state of frailty have aged without accumulating a burden of health problems. As such, studying the predictors and facilitators of this healthy aging could lead to new ideas about how to improve the health and quality of life of our aging populations.

9.2.3 OBJECTIVE iii: HOW DO PROFILES OF SOCIAL VULNERABILITY CHANGE OVER TIME?

It might seem intuitive that changes in social circumstances in older age, such as widowhood and its resulting solitary living, shrinking social circles as peers pass away, and reduced ability to participate in community activities due to one's own increasing frailty and mobility limitations, would lead to increases in social vulnerability over time. However, it is also possible that older people may develop compensative strategies to mitigate the effects of these limitations.

The fourth study (Chapter 6) examined data from a cohort study of older people in Gothenburg, Sweden, to explore how social vulnerability changes with time, as people age. Using a state transitions model based on a parametric Markov chain, this study found that, while individuals did tend to accumulate social deficits with time (and those with more baseline deficits tended to show even greater accumulation, to a point), an important subgroup of people stabilized (10%) or improved (30% over 5 years and 13% over 9 years) their social circumstances as they aged. As such, relentless accumulation of social problems was not a universal experience. One future direction suggested by this study is why this is this: do people who improve their social circumstances with time differ from those who don't in important ways? Might this be an approach that would allow study of healthy aging? Frailty was one important predictor of worsening social circumstances; frail individuals tended to accumulate more social deficits, were less likely to improve their circumstances, and had higher mortality.

9.2.4 OBJECTIVE iv: DOES SOCIAL VULNERABILITY RELATE TO PRE-FRONTAL COGNITIVE FUNCTION?

The frontal lobes of the human brain are known to influence social behaviour. Study 6 (Chapter 8) investigated whether performance on neuropsychological tests of frontal lobe function was related to social vulnerability, and found that the most social vulnerable people did have worse performance on tests of verbal fluency and executive dysfunction, which are both tests of frontal function, but that social vulnerability was not associated with non-frontal tasks such as long term memory, constructional design, and language comprehension. While these associations were cross-sectional and no assertions can be made regarding causation, it is interesting to hypothesize that cognition may be a mechanism whereby social circumstances are related to health. In fact, the observed associations are likely to be complex and bi-directional, in that people with language difficulties and may withdraw from social contact, while those who are disinhibited or have challenging behaviours may offend their peers and be socially excluded as a result. Additionally, the association itself has important clinical significance, suggesting that

clinicians should pay particular attention to the social circumstances of patients with impaired frontal lobe function. Also, individuals with this type of cognitive impairment may have difficulty participating in interventions designed to reduce social vulnerability, and this should be considered when such programs are designed.

9.3 THESIS SUMMARY

This body of work has developed and tested a holistic measure of social vulnerability in relation to the health of older adults. It started with the observation that, while the health impact of many social factors has previously been studied, the current literature was limited by fragmentation and artificial compartmentalization of individual social factors considered in isolation. This thesis therefore aimed to develop and explore a measure of overall social vulnerability that would embrace the complexity of social circumstances experienced by older people.

If we consider what sorts of factors influence health, it is useful to think in terms of "intrinsic" and "extrinsic" vulnerability. Frailty, comorbidity, and genetic factors would contribute to *intrinsic* vulnerability. The social and physical environments would contribute to *extrinsic* vulnerability. As such, much of this thesis has focused on the relationship between frailty and social vulnerability in older adults, in order to further explore these domains of vulnerability.

The findings, taken as a whole, suggest that social vulnerability is related to important health outcomes such as mortality and cognitive decline in older people. It adds to existing literature on social determinants of health through its holistic nature, accounting for many social factors at once. In lending this holistic focus specifically to the consideration of older people's health, it emphasizes the importance of considering older adults separately and distinctly from other population groups when studying social determinants of health, given that older adults have unique health and social needs.

We have also seen that social vulnerability is not static, and that while it tends to increase as people age, unabated accumulation of social problems is not a universal experience. In addition, social vulnerability appears to be related to function of the brain's frontal lobes, which are known to be involved in regulating social behaviour.

9.3.1 SOCIAL VULNERABILITY: BUILDING THE CASE

While this thesis does not claim to have established that social vulnerability causes poor health in older people, the Bradford Hill criteria for causation present a useful framework around which to build an argument in support of social vulnerability's importance in relation to health.(Hill 1965; Rockwood and MacKnight 2001) This thesis has raised points related to a number of these criteria, which are discussed below in turn.

Strength of the association

The 22% absolute increase in mortality among those with high social vulnerability compared with those with low vulnerability described in Chapter 7 is striking and hard to ignore. In a more incremental fashion, Chapters 4 and 5 demonstrate that each additional social deficit from the list that comprises the social vulnerability index was associated with a 5-8% increase in the odds of death and with a 3% increase in the odds of clinically meaningful cognitive decline over time. Given the number of social deficits included in the social vulnerability index, these add up to important associations.

Consistency/Reproducibility

The properties of the social vulnerability index have been remarkably reproducible across all three datasets in which it has been studied. Distributions have been similar, as have been associations with age, sex, frailty and mortality. Social vulnerability was also similarly predictive of outcomes across several studies.

Temporality

In studies 3-7, social vulnerability was independently predictive of the outcomes under consideration over a period of 5-10 years. It is interesting to ponder what, in fact, would be the best point in the life course at which to consider the importance of social vulnerability for health. Perhaps going farther back, to middle age or earlier, would be even more informative. This presents an interesting direction for further study. For the purposes of this discussion, it seems reasonable that, even when we limit our analyses to older adults, there is some evidence of temporality in the association between social vulnerability and health outcomes.

Biological gradient

Studies 4 and 7 both include survival curves that illustrate the gradient in survival across degrees of social vulnerability. The index associations presented in Studies 4 and 5, with each additional social deficit being associated with an increase in mortality or cognitive decline also support the claim of a biological gradient.

Plausibility

A number of plausible mechanisms have been advanced in the literature to explain observed associations between social circumstances and health. As outlined in section 1.4.4, these include *physiological* changes in endocrine and immune systems, differences in health-related *behaviours*, socioeconomic differences in access to *material* goods and services, and *psychological* differences in self-efficacy and coping strategies.

With its finding of an association between social vulnerability and pre-frontal cognition, Study 8 adds evidence for an additional *neuro-cognitive* mechanism, though it is quite likely bi-directional. People with pre-frontal cognitive deficits (e.g. problems with language and executive function) may have difficulty with social contact and become isolated and withdrawn, while those who are disinhibited or have challenging behaviours may offend their peers and be socially excluded as a result.

Coherence/convergence of measures

Study 4 studied social vulnerability in relation to frailty, and found that while the two constructs are positively associated, they are not so closely linked as to be redundant. The observation that as people become more socially vulnerable they also tend to be more frail (with the attendant increase in generalized vulnerability to adverse outcomes that this brings) supports the coherence of the construct of social vulnerability.

Experimental evidence would further strengthen the case; this criterion has not been achieved at present, but may be addressed by future studies in which interventions to reduce social vulnerability are tested.

9.3.2 CLINICAL RELEVANCE

The line of inquiry presented in this thesis started with the observation that social circumstances matter for patient outcomes, with those who are supported and integrated generally faring better that those who are isolated and marginalized. The studies presented here have demonstrated that social vulnerability is predictive of health outcomes, including mortality and cognitive decline. As such, the clinical relevance of social vulnerability seems clear. What is less clear is how to operationalize social vulnerability in clinical settings. To date, few studies have examined the association of social circumstances with clinical outcomes. Clinical assessment of social vulnerability thus requires further study, and is a future direction of the work described in this thesis.

At the present state of knowledge, clinician awareness of patients' social circumstances and attendant vulnerability to adverse health outcomes is advisable. However, mindfulness of social vulnerability in relation to patient management needs to be bi-directional. Not only are patients who are socially vulnerable more likely to suffer adverse outcomes, but they may also have challenges in participating in therapies designed to manage their health conditions. For example, they may have difficulty accessing transportation or required caregiver support to attend appointments or

rehabilitation sessions, and they may not be supported in following through on clinician advice. Additionally, as discussed in Chapter 8, there appear to be associations between certain cognitive functions and social vulnerability, which may impact on patients' ability to participate in therapeutic interventions; these factors need to be borne in mind in the design of clinical programs and services targeted to potentially vulnerable older people.

9.3.3 POLICY RELEVANCE

The social ecology framework of social vulnerability presents an opportunity to consider policies targeted at each of the various spheres of influence (Chapter 3, Figure 6). For example, at the individual level, policy interventions might include educational opportunities throughout the life course, support for pensions, and sensible medical care to address problems such as frailty and disability. Policies to support caregivers, and facilitation of opportunities for informal interaction with friends (e.g. common spaces in seniors' housing facilities) could target the family and friends sphere, while support for community groups and transportation services to enable participation in one's wider community could address vulnerability in the peer groups sphere. In terms of the institutional sphere, design of seniors' housing has the potential to enhance opportunities for formal and informal socialization and engagement. At the community level, initiatives to enhance the age-friendliness of communities represents an important potential means of reducing social vulnerability among older people. Examples of age-friendly policy initiatives include sidewalks that are navigable by those with mobility aids, senior-friendly crosswalks and accessible, efficient public transportation.

This thesis has argued that social vulnerability is best considered as a whole, which presents a challenge for policy-making, given that it may be difficult to appropriately design and target interventions to address overall social vulnerability. However, given the inter-connectedness of the spheres within the social ecology model, in designing the types of policies mentioned above, it may in fact be possible to target several overlapping spheres of influence with a single policy intervention.

9.4 FUTURE RESEARCH

The work described in this thesis lays the groundwork for numerous further directions for continued research into the importance of social vulnerability for the health and well-being of older adults.

All of the studies presented here were secondary analyses of epidemiological studies, usually based on survey data. This has been the case for much of the existing body of research into the associations between many different social factors and health. This suggests a logical next step to extend the study of social vulnerability to a clinical setting. In my clinical work as a geriatrician, I see many older people who have various degrees of social vulnerability, and working to understand how social circumstances affect their clinical outcomes has the potential to be very instructive. Relating to this clinical relevance, interventional studies investigating how we might intervene to lessen the impact of social vulnerability would also be a useful next step. Considering such interventions in light of social gerontology theories of aging will be helpful; for example, people are not likely to benefit from being forced to socialize in ways that are uncomfortable for them.

Another important further direction which I plan to pursue is an investigation into gender differences in social vulnerability. As found in Studies 1 and 2, women report higher levels of social vulnerability, but the reasons for this are not clear. Study 1 suggested that there may be qualitative differences in the domains of vulnerability experienced by women. It is also possible that men and women may experience social vulnerability differently, have differences in how their social circumstances change over time, and show different health effects.

Further investigation into the insights presented by social vulnerability also has the potential to add to our understanding of healthy aging. As found in Study 5, social vulnerability status appears to have important implications for survival, even for the fittest older people. Further study of the healthiest older adults presents an opportunity for

clarifying the importance of the social environment for healthy aging. In this vein, it would also be very important to replicate this work using samples from other countries in different stages of development. Additional study of how characteristics of the neighbourhoods and societies in which people live contribute to their overall social vulnerability is another future direction of interest.

Further clarification of the importance of lifestyle behaviours, such as exercise, smoking and alcohol use, to social vulnerability is another further direction raised by the work described in this thesis. As discussed in the Introduction chapter, health behaviours are one mechanism though which social circumstances may impact health. The extent to which this remains the case for older people would be an interesting direction of study.

The current studies have focused on social vulnerability in older age. Another further direction will be to extend the populations studied to include middle-aged and younger people. This might allow further understanding of the respective impact of mid-life *vs*. older age social conditions how social vulnerability influences health across the lifespan.

The findings from Study 6 on frontal lobe function in relation to social vulnerability are intriguing, if preliminary. Further investigation on this topic, ideally in a longitudinal study, would be of interest in exploring whether cognition might be added to the list of possible mechanisms through which social circumstances affect health.

Finally, I hope to eventually translate what is learned from this area of study to contribute to policy development so that we might help older people in our communities be as healthy and socially fulfilled as possible.

9.5 THE FINAL WORD

The social circumstances of older adults are complex. The social vulnerability index allows us to embrace this complexity while reducing dimensionality to a single interval scale with high explanatory value. The study of social vulnerability presents a way forward to enrich understanding of how social factors affect health and, enticingly, to start to figure out what can be done to improve the health and well-being of older people in our communities.

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