

Cognitive, Psychological and Social Drivers of Longevity

Gordon Woo ¹ and Anne Bruce²

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¹ RMS LifeRisks Inc.

² Posit Science Inc.

ABSTRACT

As people advance into their 80s, mental health becomes ever more important. Two nonsmoking octogenarians of identical age and gender, with the same body mass index, type of diet and physical exercise routine, may have markedly different prospects of living to 100. Cognitive and social functioning, and positive well-being, are key to living longer. Many activities that influence longevity are very cognitively demanding. For example, chronic illnesses require self-regulation to limit damage; better knowledge and reasoning help manage disease.

With physical disease, longitudinal studies undertaken over the past half century have provided the empirical data upon which numerical models have been developed for the prevalence of cancer and cardiovascular disease. To explore the longevity impact of cognitive and social functioning and well-being, longitudinal studies have been undertaken over the past decade in many countries. A notable recent Scottish study has highlighted the widowhood effect: Analysis of mortality statistics of 58,000 married couples found significantly enhanced hazard ratios for both men and women.

This paper evaluates the cognitive, psychological and social drivers of longevity by reviewing recent longitudinal studies, and analyzing the latest research on brain plasticity, positive psychology and elderly cohort survival, as well as new geriatric psychological theories on successful aging. A quantitative assessment is then made of the actuarial implications of these drivers for modeling the mortality of elderly annuitants, with new insights into what factors keep people progressing purposefully into advanced age, beyond avoiding disease.

1. HUMAN RESILIENCE

In the past few decades, substantial progress has been made in the medical modeling of underlying causes of mortality, quantifying the risk factors associated with smoking, and high values of blood pressure, cholesterol and body mass index (BMI). Scientific research has focused understandably on the measurable parameters associated with illness and pathology. But mortality analysis is more than the study of what kills people, it is also about what keeps people alive (Woo 2013).

With engineering systems, safety analysis traditionally focuses on the risk of things going wrong. But a modern supplementary approach focuses instead on what keeps systems functional. This is resilience engineering (Hollnagel, Woods and Leveson 2006). Consider the paradigm of aviation risk. Flight safety is not just about flight pathology—what faults or accidents can bring a plane down. Flight safety is ultimately governed by the trained pilot who has the duty and responsibility to keep a plane in the air: Numerous air disasters have been averted through the professionalism, skill and dedication of the pilot. One of the most astonishing feats of resilience is the safe landing of an Israeli F-15 jet with only one wing in May 1983. Conversely, when the pilot loses control, as happened on a JetBlue passenger flight from New York to Las Vegas in March 2012, flight safety is endangered.

Resilience engineering is concerned not so much with the reliability of individual components but rather with understanding and facilitating a system's ability to actively ensure that things do not get out of control. A tenet of resilience engineering is that a system is safe if it can adjust its functioning prior to, during or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions. There are various definitions of resilience in the psychological literature; the ability to adapt positively to adversity is a core attribute (Zeng and Shen 2010).

In addressing individual differences in susceptibility to specific causes of death, Vaupel, Manton and Stallard (1979) introduced the concept of frailty as an age-independent factor of largely genetic origin. But Vaupel, a demographer, recognized that frailty is just one important component of an individual's complex makeup. Another important component, distinct from frailty, is comprised of reserves of various kinds to sustain life and maintain functionality under all manner of difficult testing situations. This may be expressed succinctly as resilience. Depending on resilience, the lifespan of two otherwise similar individuals may vary significantly. Faced with a life-threatening situation, resilience in coping with physical suffering, hardship and adversity can determine who survives and who does not.

It is established by gerontologists that, quite apart from disease avoidance, the criteria for successful aging include maintenance of high cognitive and physical function, sustained engagement in social and productive activities, and close personal relationships with family and friends. Much functional loss can be prevented through lifestyle factors that include not just diet, nonsmoking and exercise but also mental training and social support.

Human longevity is not then just a matter of pathology and frailty but is also driven by cognitive, psychological and social factors that keep people safe and advancing purposefully through life. Reason to get up in the morning is a trait of the long-lived population of Okinawa, Japan. These basic human resilience factors supplement the physical health factors that have been elucidated over more than the past half century starting with the Framingham Heart Study in the United States. Ignoring resilience as a human trait confounds attempts to forecast the abbreviated lifespan of individuals suffering from serious diseases.

Longitudinal studies of longevity inevitably take decades of diligence and patience to come to fruition. Thanks to the foresight of pioneering research psychologists around the world in the past few decades, the outcomes of a number of significant longitudinal studies of cognitive,

psychological and social factors have been published over the past few years. These provide the input data for the quantitative analysis presented here. As with all epidemiological studies, the scope for further exploration of these factors will engage demographers for many years to come. But sufficient understanding has now been achieved for these factors to be universally recognized in the actuarial pricing of mortality through a composite resiliency score.

1.1 Cognitive functioning

A clinical model, the cognitive reserve hypothesis, proposes that both increased brain volume and enhanced cognitive ability may contribute to healthy brain aging, reducing the likelihood of developing dementia. Selection for enlarged brain size and increased cognitive ability in hominid evolution may therefore have been important in selection for increased lifespan in the context of intergenerational social support networks (Allen, Bruss and Damasio 2005; Finch, Robine and Christen 2003). Study of Ashkenazi Jews with exceptional longevity indicates that the genetic component for longevity may predispose for improved cognitive function (Barzilai et al. 2006).

There is no health without mental health. Preservation of cognitive functioning is critical to successful aging, and rapid loss of cognitive faculties often indicates medical decline and heightened mortality risk. Many activities that influence longevity are very cognitively demanding. Better knowledge and reasoning help manage disease (Gottfredson and Dreary 2004). New treatments often require regular self-monitoring and complicated self-medication. Good health depends as much on preventing as on overcoming illness, injury and disability. Preventing some aspects of chronic disease is arguably no less cognitive a process than preventing accidents. Chronic disease patients must make many choices daily that have major implications for their health; indeed, some complex treatments require individual risk-benefit assessment (Slovic 2010) involving basic skills and numeracy lacking in many elderly people.

Active mental stimulation is important for maintaining cognitive function. Other than mental exercises, reading and conversation provide regular opportunities for mental stimulation. Landau et al. (2012) showed that individuals with greater early and middle life cognitive activity had lower β -amyloid deposition, which accompanies Alzheimer's disease in later life. Furthermore, in a study of sisters in a Bavarian religious order, which largely excludes lifestyle and environmental factors, Bickel and Kurz (2009) found a strong association between low educational and occupational attainment and dementia. Indeed, a large meta-analysis undertaken by Meng and D'Arcy (2012) was able to demonstrate robust evidence that a high level education in early life is related with a significant reduction both in the prevalence and incidence of dementia.

Cognitive brain training studies show it is possible for the cognitive biological age of an individual to be lowered compared with chronological age. Keeping fit through mental activities, even video gaming, leads to better cognitive health in old age (Anguera et al. 2013). Brain plasticity research by Michael Merzenich (Doidge 2008) has demonstrated that for older people with mild cognitive impairment, a cognitive age reduction is achievable for some mental tests. The Improvement in Memory with Plasticity-based Adaptive Cognitive Training (IMPACT) study was a cognitive training program based on principles of brain plasticity. Participants in the active group who used the brain fitness program increased their auditory processing speed by 130 percent and experienced an improvement in memory equivalent to approximately 10 years.

1.2 Positive psychology

Positive psychology is the study of human flourishing, and focuses on personal traits such as well-being and happiness, rather than on problems. Martin Seligman was among those to introduce the term in the late 1990s. While it is clear that happiness is a good predictor of

longevity, research is ongoing to explain the causal biological connection linking well-being with longevity. From an evolutionary psychology perspective, Fredrickson (2001) has sought to demonstrate that positive emotions have a higher purpose in evolution, through broadening thought-action repertoires. Researchers of positive psychology have demonstrated that positive characteristics or feelings help people live longer, and even endure terrible suffering. In his harrowing memoir of survival, and search for meaning at Auschwitz, Frankl (1959) quoted the philosopher Nietzsche: “He who has a *why* to live for can bear almost any *how*.”

Positive feelings are especially beneficial for the longevity of pensioners. Significant cardiovascular protection seems to be achieved by satisfaction with life. People who are stressed over long periods tend to look haggard, and it is commonly thought that psychological stress and distress lead to premature aging, and the earlier onset of diseases of aging (Russ et al. 2012). Stress has a marked socio-economic gradient. At work, lower grade staff are more stressed, as shown by the Whitehall studies of civil servants first conducted more than 40 years ago in the United Kingdom. At home, those living in poorer cramped accommodation are more stressed, and liable to have higher blood pressure and other health problems. Studies of centenarians show the way people cope with stress is a longevity factor. People may live through difficult situations yet not view their lives as especially stressful.

As a personality trait, conscientiousness is a predictor of longevity. This is a finding of personality psychologists. Conscientiousness refers to dutifulness, organization and responsibility, and is the antithesis of carelessness. Individuals who are conscientious tend to follow standards of healthy living more than others. To the extent that people who are conscientious tend to be socially upwardly mobile, this may also be a factor in the socio-economic longevity divide.

An optimistic person may be more likely to have habits that enhance health or a recovery process, and be more compliant with medical treatment demands. Optimistic people tend to have lower blood pressure and better immune systems. Optimistic people tend to interpret their troubles as transient and controllable, while pessimistic people may believe their troubles last forever and are uncontrollable. Optimism is an aspect of well-being: having times of happiness to look forward to, and having a social network for people to engage.

1.3 Social functioning

Isolation is a powerful risk factor for poor health. In their influential MacArthur Foundation study of successful aging, Rowe and Kahn (1998) report that friendship is a key factor in keeping older people active and emotionally secure, even in advanced old age. Using data collected through the Framingham Heart Study, Christakis and Fowler (2011) have shed new light on the importance of not just the quality and quantity of independent friendships, but the influence of the interconnectedness of entire networks. Sustained engagement in social and productive activities is central to healthy aging, and is ingrained in the most long-lived communities.

Loneliness is a common source of suffering in older people. Perissinotto, Cenzer and Covinsky (2012) have shown it is also a risk factor for poor health outcomes, including death and functional decline. Consequently, there is a degree of coupling between the longevity of any older person and that of his or her peers, including a partner of similar age. The mortality of any older individual is contingent to some extent on the survival of at least one peer. Members of communities noted for their longevity both work and socialize together in a close-knit tribal fashion, reinforcing good habits and behavior. This social contagion aspect of longevity implies that a single life annuity has some characteristics of a joint life annuity. Social cohort survival may contribute to the nonlinear rise in the number of those 85 or older.

Social support can buffer or reduce some health-related effects of aging. There are two main kinds of social support: emotional social support and hands-on care. The latter can be essential for basic survival among the infirm or incapacitated, unable to look after themselves adequately. Emotional social support encourages a sense of being cared for, being esteemed by others and being of value to others. It is especially needed to get through serious illness and prolonged difficult treatments.

Volunteering is one way of being of value to others that brings longevity benefits. This was shown in a longitudinal study of American community-dwellers age 70+. Doing some form of charity work is a common middle-class activity, and may contribute to the socio-economic longevity divide. Also, active membership of recreational clubs or religious communities, and access to hands-on care tends to have a Socio Economic Classification (SEC) gradient. Low SEC is associated with a smaller social network, less emotional support, lower feelings of mastery and lower self-efficacy compared with high SEC people. Having a superior social support network may be one of the reasons women tend to live longer than men (Buettner 2008). Women have better and stronger systems of support than men, and are more engaged and helpful.

2. ANALYSIS OF LONGEVITY DRIVERS

Having financial reserves to call upon in times of need is a key part of prudent financial planning and maintaining financial health. For maintaining personal health, monetary resources to pay for health care, medical treatment and nursing assistance are valuable, but so also are other types of reserves: cognitive, psychological and social. Depending on the state of his or her reserves, each of these three human factors may raise or lower an individual's mortality rate for different diseases, relative to the average for a population. Models for quantifying these incremental changes are described.

2.1 Cognitive longevity driver

Cognitive reserve describes an individual's resistance to impairment in cognitive processes such as memory, reasoning and attention, which may arise as a consequence of brain pathology caused by injury, disease or the normal aging process. Cognitive reserve can be thought of as an asset that can be accumulated throughout life, through education, work and leisure activities involving physical or cognitive exertion. This asset can be used throughout life to take advantage of opportunities and to maintain well-being in response to stress and other environmental challenges. Nonetheless, most evidence for its utility comes from circumstances where the brain is required to function beyond its maximum capacity. Whether limitations are reached because of aging, illness or injury, cognitive reserve can then be drawn upon to minimize functional impairment (Barnett and Sahakian 2008). A surrogate measure of cognitive reserve is based on information supplied on educational records and cognitive lifestyle. A unique experimental study in Sweden showed a causal effect of additional education in reducing all-cause mortality after age 40 (Lager and Torssander 2012).

Long educational history associates with less post-stroke cognitive deficit, dementia and favorable long-term survival, independent of age, gender, marital status and stroke severity. This supports the hypothesis that educational history as a proxy indicator of cognitive reserve protects against deficits induced by acute stroke (Ojala-Oksala et al. 2012). The risk of stroke is robustly associated with cognitive function, reflecting differences in subclinical cerebrovascular pathology (Llewellyn et al. 2008). Apart from these benefits, cognitive reserve moderates the association between heart failure and cognitive impairment (Alosco et al. 2011).

A cognitive skills test provides a direct means of assessing current cognitive ability and signs of potential impairment. Various tests have been used, including the Mini-Mental State Exam

(MMSE), Enhanced Mental Skills Test (EMST) and Digit Symbol Substitution Test (DSST). The latter was used in a study linking telomere length with cognitive aging (Yaffe et al. 2011).

Consider a coarse five-grade population segmentation, such that those with the least cognitive function (without actually suffering from a medically diagnosed cognitive disorder such as dementia or Alzheimer's) are assigned Grade 5, and those with the most cognitive function are assigned Grade 1. Those with intermediate levels of cognitive reserve are assigned grades 2, 3 or 4 according to table 1. The choice of five grades for segmentation allows the possible range to be spanned, without having more grades than could be reasonably assigned with the information likely to be available.

Table 1. Grading of cognitive function

Grade 1	Excellent mental health and cognitive reserve; extended length of education; continued daily brain exercise and training
Grade 2	Very good mental health and cognitive reserve; many intellectually stimulating pursuits
Grade 3	Good MMSE test score (29 or 30); regular engagement of mental faculties
Grade 4	Inferior MMSE test score (26–28); mental distress; prone to anxiety and depression
Grade 5	Poor MMSE test score (25 or less), indicative of incipient mild cognitive impairment

Using the Mini-Mental State Examination, Sampson, Bulpitt and Fletcher (2009) found a hazard ratio for the mildly cognitively impaired of 0.76 for community-dwelling people age 75 or older. Using the simpler and more basic 10-question Short Portable Mental Status

Questionnaire (SPMSQ), and adjusting for other risk factors such as age, gender and smoking status, Sachs et al. (2011) obtained a hazard ratio for the mildly cognitively impaired of 0.85 for a population age 60 or older. This latter figure is taken to be a conservatively moderate value applicable for those age 60+.

For the j th disease, the maximum cognitive functioning variation $\kappa_{\max}(j)$ is defined as the logarithm of the hazard ratios for Grade 1 compared with highest Grade 5. An estimate of the mortality risk mitigation factor associated with best and worst cognitive function, adjusted for other risk factors such as age, gender, lifestyle and socio-economic status, is $\exp[\kappa_{\max}(j)] = 0.85$. Mortality risk mitigation factors for the various intermediate grades can be obtained approximately by log-linear interpolation.

2.2 Psychological longevity driver

Positive psychological well-being has a protective effect on healthy populations, as well as promotes increased adherence to medical regimens in disease populations. Various direct physiological pathways have been suggested as ways in which positive psychological well-being could contribute to the association with reduced mortality. Seligman, the leading advocate of positive psychology, has offered the following signs of well-being (Seligman, 2012): rapid wound healing, low blood pressure, high heart rate variability and longer telomere length (age-adjusted). Psychological well-being and high blood pressure are thought by clinicians to be inversely correlated (Blanchflower and Oswald 2007). Positive emotions can reduce the physiological damage on the cardiovascular system sustained by negative emotions.

Psychological research indicates that increasing resilience to life stress, and promoting well-being, will be beneficial. Evidence connects major stressful events to physiological changes. Stress induces cellular resistance to cortisol, reducing the body's ability to regulate inflammation. Work stress has been related to systematic differences in cortisol. Nobel laureate

Elizabeth Blackburn has investigated the hypothesis that stress impacts health by modulating the rate of cellular aging. Evidence has been found that psychological stress is significantly associated with higher oxidative stress, lower telomerase activity and shorter telomere length, which are known determinants of cell senescence and longevity (Blackburn et al. 2004). A University of California San Francisco (UCSF) study of telomere length in the immune cells of older women showed that pessimists have poorer immune system functioning and shorter telomeres (O'Donovan et al. 2009).

2.2.1 Grading of mortality risk mitigation

There is a substantial volume of research attesting to the longevity benefits of psychological well-being. A Mayo clinic study of 839 patients who were referred for medical care showed that optimists had 19 percent greater expected life span (Manuta et al. 2000). A Dutch study of almost 1,000 people between ages 65 and 85 showed that most causes of mortality were reduced among optimists (Deeg and von Zonnefeld 1989). For two years, 2,282 Mexican-Americans from the southwest United States, age 65+, were tracked. After controlling for age, income, education, weight, smoking, drinking and disease, researchers found that happy people were much less likely to die (Seligman 2002). An Ohio study of 660 people over 50 showed that, after 23 years, those who viewed aging as a positive experience lived on average 7.5 years longer (Levy et al. 2002). In a Danish study of 3,966 twins age 70 or older, subjective well-being, as rated on a three-point affective scale, predicted increased longevity, controlling for shared genes and environment (Sadler et al. 2011).

Will to live is a strong predictor of survival among older people, and has a degree of self-fulfillment (Karppinen et al. 2012). The finding that purpose in life is related to longevity in older people suggests that aspects of human flourishing, particularly the tendency to derive meaning from life's experiences and possess a sense of intentionality and goal-directedness,

contribute to successful aging. For those living in U.S. retirement communities, possessing a greater purpose in life is associated with low hazard ratio of about 0.6 (Boyle et al. 2009). But a dull retirement community environment may amplify the need for purpose in life; indeed, some U.K. care homes have been described as little more than waiting rooms for death (Wolpert 2011).

In Japanese culture, having a sense of life worth living, *ikigai*, is the most commonly used indicator of subjective well-being. It is an important Japanese contribution to positive psychology (Petersen 2008), and a salient factor in Japanese longevity, e.g., in the blue zone of Okinawa. The blue zone was introduced by Buettner (2004) to identify pockets around the world where people lived measurably longer. Sone et al. (2008) have shown that the mortality of those age 65+ was significantly lower among those with a sense of *ikigai* by a hazard ratio of about 2-to-3. They concluded that the association between the negative psychological factors and the mortality risk was independent of socioeconomic factors, other psychological factors, physical function, lifestyle habits and a history of illness.

This notable Japanese experience suggests a five-grade segmentation of the population of pensionable age, such that those with the most positive psychological outlook, with a strong purpose in life (or sense of *ikigai*) are assigned Grade 1, and those with the least positive psychological outlook are assigned Grade 5. Those with intermediate levels of psychological outlook are assigned intermediate grades 2, 3 or 4 according to table 2.

Table 2. Grading of psychological outlook

Grade 1	Thriving sense of well-being; very happy, smiling and highly optimistic; with purpose and direction in life, and a strong sense of <i>ikigai</i>
Grade 2	Good sense of well-being; contented and optimistic; enjoying making plans for a purposeful future
Grade 3	Moderately happy, with some sense of direction in life; but not too optimistic about the future
Grade 4	Struggling, stressed, unhappy and pessimistic; wandering aimlessly in life with little purpose
Grade 5	Suffering, highly stressed and very dejected, with no goal or meaning in life

For the j th disease, the maximum psychological well-being variation $\psi_{\max}(j)$ is defined as the logarithm of the hazard ratios for Grade 1 compared with highest Grade 5. An estimate of the mortality risk mitigation factor associated with best and worst psychological well-being, adjusted for other risk factors such as age, gender, lifestyle and socio-economic status, is taken to be $\exp[\psi_{\max}(j)] = 2/3$. This applies for most diseases, but not for cancer, which seems to be rather impervious to positive psychology or *ikigai* (Sone et al. 2008), even though they may boost the immune system. Mortality risk mitigation factors for the various intermediate grades can be obtained approximately via log-linear interpolation.

2.3 Social longevity driver

It is clear that social networks may affect health behavior by encouraging and prompting individuals at risk to seek health care, attend scheduled appointments and adhere to treatment regimes. In addition, there are physical mechanisms by which the effects of a social network may be biologically mediated through neuroendocrine and neuroimmune pathways. More transparently, patients with higher levels of support may be more likely to receive assistance in getting to the pharmacy, surgery or hospital, and cope with more vigorous and aggressive treatment. This applies especially to cancer treatment such as chemotherapy. Pinqart and Duberstein (2010) conducted a large meta-analysis of 87 cancer studies, and found a reduced mortality risk ratio of 0.75 for cancer survival of patients with high levels of social support.

In Japan, relative risks for all circulatory system disease, ischemic heart disease and cerebrovascular disease have been shown to be high among single, divorced and widowed men (Iwasaki et al. 2002). In all countries, the greatest sense of social loneliness occurs when a spouse dies. Quantifying the corresponding mortality impact in a robust way is complicated by potential selection effects. By controlling for a range of individual and household-level characteristics, researchers at St. Andrews University have managed to quantify the widowhood effect, using a large dataset from the Scottish Longitudinal Study (Boyle, Feng and Raab 2011). Studying the mortality statistics of 58,000 married couples, they found hazard ratios of 1.40 for men and 1.36 for women. The risk is highest shortly after widowhood but remains raised for at least 10 years. There was little evidence that these hazard ratios differed by any classification of the cause of death of the spouse.

Earlier research supports these findings. Indeed, even if a spouse is sick, the impact on the partner's mortality may be significant. Christakis and Allison (2006) studied more than half a million U.S. couples 65 and older who were enrolled in Medicare from 1993 through 2001.

Over that period, their study found that, overall, having a sick spouse is about one-quarter as bad for a partner's health as having a spouse actually die. Some spousal diseases, such as hip fracture or psychiatric conditions, were nearly as bad for partners as if the spouse had actually died. Thus poor health of a spouse is a risk factor for the partner.

A grading of social reserve can be constructed with those fortunate to have the most social reserve being assigned Grade 1, and those having the least social reserve being assigned Grade 5. Those with intermediate levels of social reserve are assigned grades 2, 3 or 4 according to table 3. Human beings are social creatures, and there is a massive potential variation in the tangible and emotional support provided to a person in a close-knit tribe in Grade 1 compared with a lonesome soul in Grade 5. This is one of the salient reasons for the extreme longevity of blue zone communities (Buettner 2008).

Table 3. Grading of social reserve

Grade 1	Very extensive supportive social network of family and friends; strong sense of community; well connected with close-knit long-lived tribe
Grade 2	Large extended family and numerous supportive and helpful friends; family prioritized
Grade 3	Some family and confidantes, and a circle of other friends
Grade 4	Moderately lonely, with very few close friends, and no close family
Grade 5	Recently bereaved of partner; lacking a practical social support network; severely lonely

For the j th disease, the maximum social reserve variation $\pi_{\max}(j)$ is defined as the logarithm of the hazard ratios for Grade 1 compared with highest Grade 5. Across 148 studies of social

relationships and mortality risk, Holt-Lunstad, Smith and Layton (2010) found a large hazard ratio between those with high and low social support. These findings remain consistent across a number of factors, including age, gender, initial health status and cause of death. The striking results are also encompassed by the grades of loneliness introduced for a U.S. health and retirement study for adults older than 60 (Perissinotto, Cenzer and Covinsky 2012).

From the meta-analyses, the maximum mortality risk reduction factor associated with best and worst social support is estimated from Holt-Lunstad, Smith and Layton (2010) to be $\exp[\pi_{\max}(j)] = 0.53$. This applies across the range of diseases; the practical networking mechanisms for delivering social support assistance serve all disease categories. Mortality risk mitigation factors for the various intermediate grades can be obtained approximately via log-linear interpolation.

3. RESILIENT AGING

In the 1960s, a disengagement theory was propounded that regarded successful aging as the desire and ability of older people to disengage from active life in order to prepare themselves for death (Ouweland, De Ridder and Bensing 2007). Disengagement reflected a negative and passive societal attitude toward aging, which is exhibited in the prevailing high mortality rates for the elderly. There is an element of reflexivity in any theory of successful aging. If the elderly are expected to be passive as they await death, they will tend to die earlier than if they are encouraged and motivated to be active. The stark increase in longevity in the past half century, and the rising prospects of living to 100, reflect in part the medical acceptance and public adoption of more enlightened active theories of successful aging, which are promoted not just in gerontology journals but also on numerous healthy aging websites.

Theories of successful aging have been typically applicable to a proportion of age ranges, but not the entire aging process from 60 to 100 years old, which is of relevance to annuity

providers. Recognizing Japan's premier world ranking in life expectancy, theories emanating from Japanese experience are especially noteworthy. Yasuyuki Gondo, a Japanese geriatric psychologist, has proposed a theory of successful aging, emphasizing psychological development in old age (2012). This modifies a single overall model into a multiple shift model, covering the three distinctive periods of old age: the young old (64–74), the old old (75–84) and the oldest old (85+).

Maintenance of health and functional capacity is a primary goal for the physical function of those in young old age (65–74). A biomedical model takes as the basis of successful aging the avoidance of physical or psychological decline and disability, and focuses on the consequences of the aging process. But the elderly gradually shift their priorities, strategies and concerns, from those in keeping with a biomedical model to those described by a model of psychological well-being. This shift remains to be quantitatively addressed for annuity pricing, which has a strong biomedical model focus.

In fact, psychological factors have turned out to be more important for successful aging than traditionally considered. A psychological well-being model clarifies the mechanisms enabling the elderly to adapt and maintain psychological well-being. Gondo has suggested the complex interrelationships between demography and psychology should be considered within a broader domain of research to meet the needs of an aging society.

Based on the psychological mechanisms underlying the adaptation process, Gondo (2012) has classified models of psychological well-being into two distinct domains: logical and “nonlogical.” A logical model indicates the need for cognitive resources to maintain psychological and emotional well-being, suggesting that intentional logical thought is necessary for the successful operation of adaptive approaches to aging. By contrast, a nonlogical model applies where function and cognitive capacity have declined considerably,

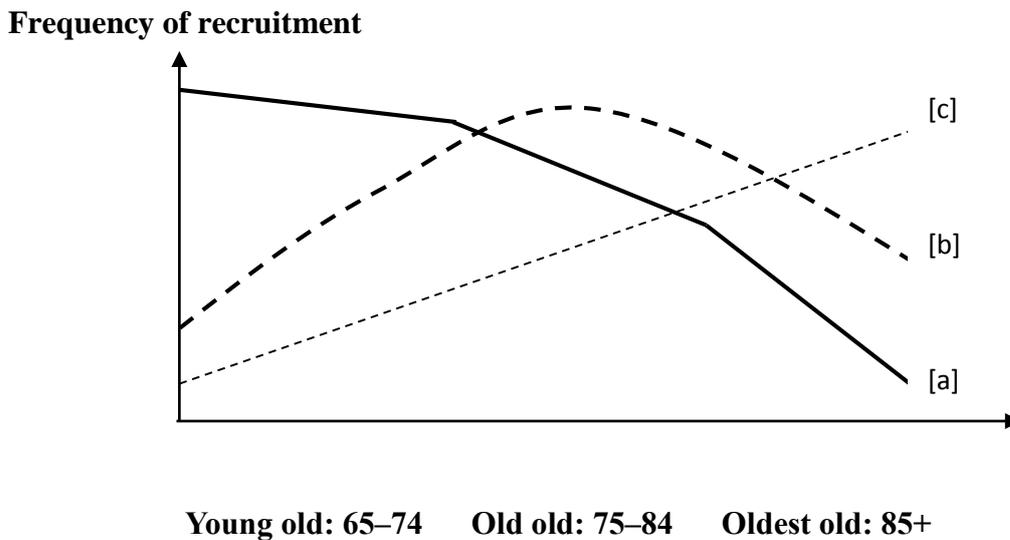
and the capability of an individual to make logical decisions is severely diminished. Often care is then needed; in Tokyo, for example, 42 percent of the oldest old have required others to take care of them. Accordingly, a nonlogical model provides special insights for the survival of the oldest old.

Cognitive, psychological and social factors matter at all old ages. But past the first stage of young old age, i.e., 75, they become crucial to understanding and modeling mortality, as the standard medical risk factors become rather less predictive of mortality. Rizzuto et al. (2012) have shown that biomedical efforts at mortality modeling beyond 75 are improved with the inclusion of social factors, which are the most significant of the three factors.

Cognitive function is vital for navigating through the old old stage (75–84); once this declines, *ikigai* and social support are vital for surviving in the oldest old stage. Gondo (2012) has quoted a Japanese woman, age 105, who was asked if she sometimes felt life was not worth living. Her response captured the spirit of *ikigai* and her close dependable social support: “I can still talk and be a companion for my daughter.”

Gradual and natural changes in behavior and thought, according to age, are an adaptive mechanism through which the elderly can maintain psychological well-being. This process, which has been termed *gerotranscendence*, is illustrated in figure 1. Three curves are drawn to convey understanding of Gondo’s shift model of successful aging. Curve [a] represents the biomedical model; curve [b] represents the logical psychological model; and curve [c] represents the nonlogical psychological model. Each model differs in its relevance for each age range. Clearly, at age 75+, modeling of cognitive, psychological and social factors becomes essential.

Figure 1. Gondo's shift model (2012) of successful aging



3.1 Resiliency Score

The analysis presented here highlights the importance of accounting for the cognitive, psychological and social drivers of longevity risk, which are integral to 21st century interdisciplinary understanding of successful aging. Actuaries and demographers cannot expect to fathom the mortality of the very old without the assistance of geriatric psychologists.

The cognitive, psychological and social reserve grades $(G_{\kappa}, G_{\psi}, G_{\pi})$ constitute a three-component composite resiliency vector. Each grade maps into a corresponding mortality risk mitigation factor, appropriate for the disease state of the individual, and the product of the three mitigation factors yields a first order composite resiliency score. As a refinement to the score, allowance might be made for some degree of overlap between cognitive functioning and the capability for social networking, and having a positive attitude toward life (e.g., Kato et al. 2013).

Whatever the health state of an individual, some combination of cognitive, psychological and social factors will influence his or her longevity prospects. Each of these factors is associated with a probability distribution, which varies from one population segment to another. Relative to the middle Grade 3, mortality reduction factors are less than unity for the better grades 1 and 2, and greater than unity for the worse grades 4 and 5. For a population of individuals purchasing annuities, the probability distribution for each of the three resiliency vector components may well be weighted toward the better grades.

As an illustration, table 4 shows a composite resiliency score matrix of risk mitigation factors for the top Social Grade 1. The mortality reductions shown here are for death by diseases other than cancer. This matrix covers the 5×5 array of possible combinations of cognitive and psychological grades. The largest mortality rate reduction of 0.55 is achievable for an individual in the top cognitive and psychological grades. The profile of an individual with top cognitive, psychological and social reserve grades would be familiar to residents of the blue zone longevity hot spots (Buettner 2008).

Table 4. Resiliency score matrix for Social Grade 1

		Psychological Grade				
		1	2	3	4	5
Cognitive Grade	1	0.55	0.61	0.67	0.74	0.82
	2	0.57	0.63	0.70	0.77	0.86
	3	0.59	0.66	0.73	0.81	0.89
	4	0.62	0.69	0.76	0.84	0.93
	5	0.64	0.71	0.79	0.87	0.97

3.2 Conclusions

Recent pioneering biomedical research on the hypothalamus indicates the brain may exert fundamental control over aging (Zhang et al. 2013). This finding adds further weight to the suggestion that more information relating to salient “above-the-neck” personal human factors should be sought from applicants for life and health policies. To rely predominantly on physical medical factors, without taking human resilience into insurance consideration, is to treat humans rather like their inarticulate pets.

A sense of an individual’s resilience can be gained from information such as years of education, foreign languages, hobbies involving mental and physical exercise, club memberships and voluntary work, sense of well-being, extended family and social networks, and especially their purpose in life and reason for getting up in the morning—*ikigai* for the long-lived Japanese.

Particularly as individuals progress beyond young old age (65–74), this supplementary information becomes increasingly important relative to reliance just on standard biomedical data. To understand the mortality of those age 75+, it is not enough to gather and analyze data from physical medical examinations. Lessons need to be learned from geriatric psychology, which has been under-represented as a health discipline of significance to mortality modeling.

Based on the information made available about an individual, a multivariate probability distribution may be assigned for the underlying cognitive, psychological and social reserve factors to map into a probability distribution for the composite resiliency score. This makes explicit the epistemic uncertainty in the pricing of human resilience, which is a classic risk problem of decision-making under uncertainty. To illustrate how this would impact underwriting annuities, if there were a 25 percent chance an individual is highly resilient (e.g.,

a blue zone type), a risk-averse annuities underwriter would be less enthusiastic over seeking this business than if there were only a 5 percent chance.

Over a period of time, the accumulation of experience data, augmented by such resilience information, would allow for the refinement and improved segmentation of actuarial pricing of policies involving the elderly. Even if specific information of this social psychological kind has not hitherto been explicitly acquired for annuitants, it may be actuarially instructive and rewarding for risk managers to undertake a retrospective resiliency score analysis of actual mortality experience.

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