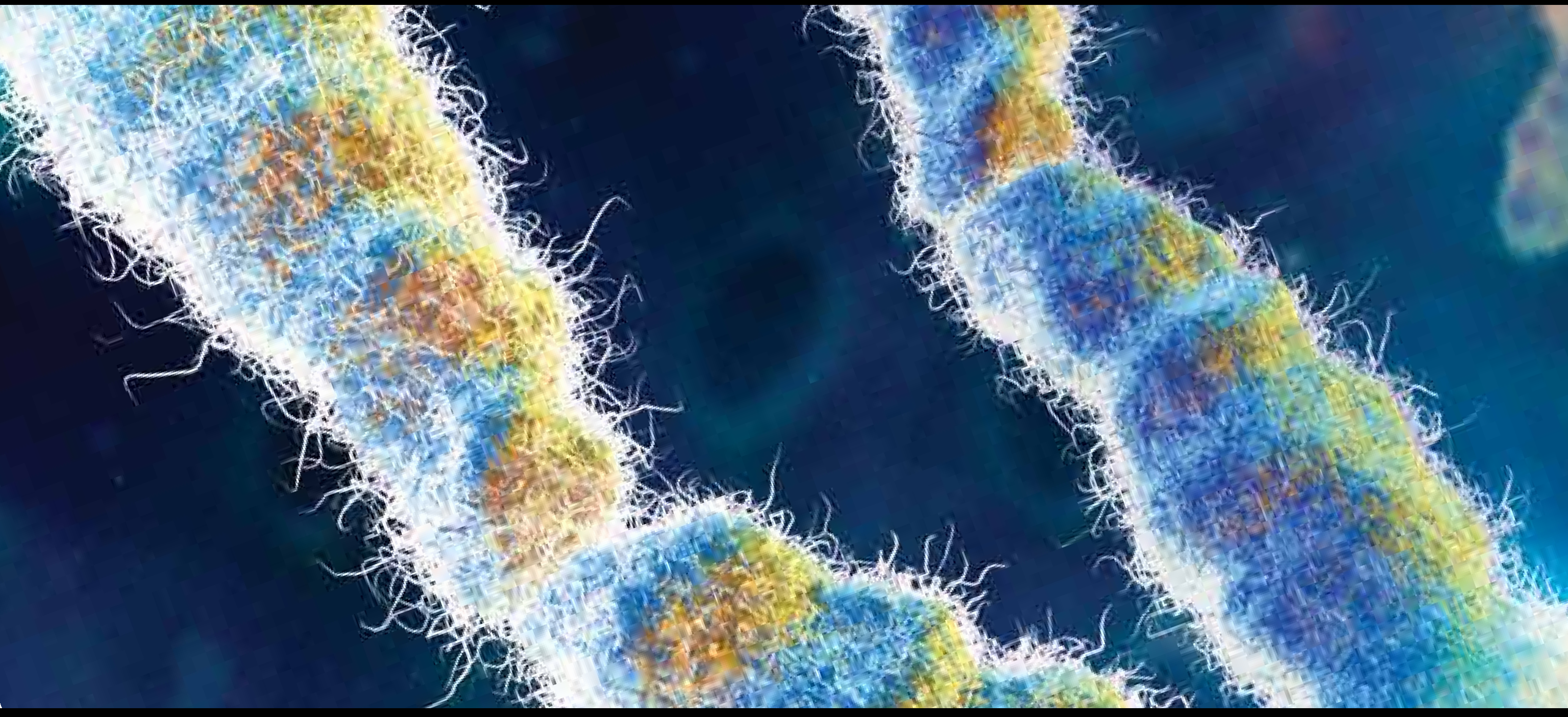
Journal of Aging Research

Successful Aging

Guest Editors: Loretta DiPietro, Maria Fiatarone Singh, Roger Fielding, and Hiroshi Nose



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Editorial Board

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Editorial

Successful Aging

Loretta DiPietro,[1] Maria Fiatarone Singh,[2] Roger Fielding,[3] and Hiroshi Nose[4]

[1] *School of Public Health and Health Services, The George Washington University, Washington, DC 20052, USA*
[2] *Faculty of Health Sciences, University of Sydney, Sydney, NSW 2000, Australia*
[3] *Nutrition, Exercise Physiology Laboratory, Jean Mayer USDA Human Nutrition Research Center on Aging at Tufts University, Boston, MA 02111, USA*
[4] *Department of Sports Medical Sciences, Institute of Pathogenesis and Disease Prevention, Shinshu University Graduate School of Medicine, 3-1-1 Asahi, Matsumoto, Nagano 390-8621, Japan*

Correspondence should be addressed to Loretta DiPietro, ldp1@gwu.edu

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Advances in public health and in health care are keeping people alive longer, and consequently, the proportion of older people in the global population is increasing rapidly. In the United States, persons aged 65 years and older comprise about 13% of the population, and their numbers are projected to reach 72.1 million (19% of the total) by the year 2030—a twofold increase over the older adult population in 2000 [1]. Perhaps of greatest interest in aging research is the rise in the "oldest old" segment of the population—those persons aged 85 years and older. Since 1930, this demographic subgroup has doubled in number every 30 years and is projected to be the fastest growing sector of the older population well into the 21st century [1]. This shifting demographic trend has substantial political, social, medical, and economic implications for most of the world.

Physiological function declines with aging, even among the most robust sectors of the older population. The degree to which this decline is attributable to true biological aging and the degree to which it is attributable to social or lifestyle factors that accompany older age is not entirely clear. Evidence suggests, however, that there is substantial heterogeneity in patterns of aging [2]. That is, while many older people continue to show expected patterns of decline in health and functional ability, others appear more resilient to various physiological (e.g., infection), emotional (e.g., bereavement), or environmental challenges. Thus, *resiliency* to various challenges or perturbations can be considered an underlying hallmark of "successful aging," which is the focus of this special issue.

Rowe and Kahn [3] first developed a model to characterize those very robust and independent older persons according to three domains: (1) disease risk; (2) physical or cognitive capacity; (3) engagement with life. Most newer models of successful aging now expand these domains to include additional measures of physical (e.g., self-rated health; days in bed; extremity strength; timed 15 ft walk; report of ADL or IADL limitations), cognitive (e.g., Minnesota Mini-Mental Status score), and psychosocial (e.g., Life Satisfaction score, CES-D score; Life View score; perceived economic status) function. Three of the papers in this special issue describe the prevalence of successful aging among various old and very old study populations according to one or more of these models. First, J. Cho et al. compared Rowe and Kahn's original model of successful aging with an alternative psychosocial model comprising aspects of subjective health, perceived economic status, and happiness. The authors observed a significantly greater proportion of octogenarians and centenarians to be characterized as "successful" according to the alternative model and argue that as people succeed into advanced older age (i.e., >80 years), additional criteria are necessary in order to capture the multidimensional aspects defining successful aging. Investigators on the Finnish vitality 90+ study (L. Nosraty et al.) observed that the prevalence of successful aging was greater in men than in women and was associated with being married and with higher level of educational attainment. Indeed, these findings also suggest that models emphasizing simply the absence of disease or disability may not be sensitive enough to capture more important attributes of very old age, such as autonomy, adaptation, or sense of purpose. Finally, using data from older participants in the Cardiovascular Health Study, S. Thielke and P. Diehr examined sex and age differences in the probability of remaining on a successful aging trajectory according to 12 different domains of successful aging. Not surprisingly, the probability of remaining "successful" in most of the domains studied declined significantly as participants aged, and similar to the findings among older Finns, men were more (not less) likely to remain "successful" on the majority of domains compared with women of the same age. Moreover, these same men were more likely than women to transition from "successful" to death, without transitioning to a state of sickness first. This latter finding reflects the "rectangularization" of the survival curve (i.e., compression of morbidity [4]) in successful aging and suggests that its prevalence is greater in men in advanced older age. A fourth study in this volume by G. K. Randall and colleagues is methodological in nature and proposes a shortened and valid version of the Duke Older Americans Resources and Services procedures (OARS) functional assessment tool, thereby reducing the respondent burden among the oldest old. In sum, these descriptive studies continue to challenge and expand our preconceptions of successful aging and, at the same time, provide even more evidence of the elusive and heterogeneous nature of growing really old.

The challenges of describing successful aging, notwithstanding those who study the oldest old, have to contend with the enormous methodological issue of selective survival. That is, those people most susceptible to putative risk factors for chronic disease and disability have not survived into their 8th decade, leaving only the most robust older people available to be studied. This issue becomes even more pronounced when performing research on those living past the age of 100 years—especially if they are men. Consequently, investigators often observe smaller effect sizes than what might be observed in younger people. The only experimental study in this issue, by L. DiPietro et al., examined the relation between stress reactivity and 24 h glycemic control in sedentary, but healthy older people. Peak cortisol responses to the stress challenge were significantly different compared with the control condition; however, the magnitude of response appeared blunted compared with what might be observed in middle-aged populations studied under the same conditions. Also, stress-related disruptions in glycemic control were minimal in this healthy older study sample. Continuous glucose monitoring over 24 h provided evidence that any subtle metabolic disruption (apparent only up to 6 h following the stress challenge) had completely dissipated by 24 h. Interestingly, the issue's only epidemiologic study, which analyzed data from the Canadian Community Health Survey-Healthy Aging supplement (S. Dogra and L. Stathokostas), is among the first to report a significantly elevated and potentially graded odds of successful aging among the least sedentary respondents compared with the most sedentary, independent of level of physical activity. These elevated odds were similar for men and women, and (contrary to several epidemiologic studies of aging in which estimates of relative risk attenuate as people age) the odds of successful aging due to lower amounts of sitting and higher amounts of physical activity were similar between middle-aged (45–65 years) and older (65+ years) respondents.

Finally, results from a systematic literature review on the use of robotics in geriatric care (A. J. Pearce et al.) provide ample evidence of the availability of robotic devices in allowing healthy older people and those with disabilities to remain independent, safe, and socially connected in their community setting. These findings have enormous public health implications as the Aging-in-Place movement gains momentum and as naturally occurring retirement communities (NORCs) continue to grow in the United States and globally. Again, as smart technology evolves and becomes accessible to growing numbers of very old people, our models to describe successful aging will need to evolve as well.

In sum, the papers included in this special volume on successful aging represent an exciting, insightful, and challenging view of this important interdisciplinary field. We hope that this special issue will attract readers with the same scientific and practice interests.

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Loretta DiPietro
Maria Fiatarone Singh
Roger Fielding
Hiroshi Nose

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Review Article

Robotics to Enable Older Adults to Remain Living at Home

Alan J. Pearce,[1,2] Brooke Adair,[2] Kimberly Miller,[2] Elizabeth Ozanne,[3] Catherine Said,[2] Nick Santamaria,[4] and Meg E. Morris[2,5]

[1] *Cognitive and Exercise Neuroscience Unit, School of Psychology, Deakin University, Melbourne, VIC, Australia*
[2] *Department of Physiotherapy, The University of Melbourne, Melbourne, VIC, Australia*
[3] *Department of Social Work, The University of Melbourne, Melbourne, VIC, Australia*
[4] *Department of Nursing, The University of Melbourne and Royal Melbourne Hospital, Melbourne, VIC, Australia*
[5] *School of Allied Health, La Trobe University, Melbourne, VIC, Australia*

Correspondence should be addressed to Meg E. Morris, m.morris@latrobe.edu.au

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Given the rapidly ageing population, interest is growing in robots to enable older people to remain living at home. We conducted a systematic review and critical evaluation of the scientific literature, from 1990 to the present, on the use of robots in aged care. The key research questions were as follows: (1) what is the range of robotic devices available to enable older people to remain mobile, independent, and safe? and, (2) what is the evidence demonstrating that robotic devices are effective in enabling independent living in community dwelling older people? Following database searches for relevant literature an initial yield of 161 articles was obtained. Titles and abstracts of articles were then reviewed by 2 independent people to determine suitability for inclusion. Forty-two articles met the criteria for question 1. Of these, 4 articles met the criteria for question 2. Results showed that robotics is currently available to assist older healthy people and people with disabilities to remain independent and to monitor their safety and social connectedness. Most studies were conducted in laboratories and hospital clinics. Currently limited evidence demonstrates that robots can be used to enable people to remain living at home, although this is an emerging smart technology that is rapidly evolving.

1. Introduction

Throughout the world rapid population ageing is occurring, with a large proportion of older adults preferring to stay living at home [1]. Most older people experience one to three chronic diseases [2] and, in very advanced age, frailty, disability, and social isolation are common. At the same time there are increasing demands on health service providers due to the low availability of home and community services, low uptake of e-health and smart technologies by healthcare professionals, and an ageing health workforce [3]. Although many older people express their desire to stay in the familiar social environment of their own home [4], many cannot do so due to impairments, immobility and social isolation. Many older people who live at home are at high risk of falls and injuries and report difficulty accessing health care services when they need them [5].

As previously discussed by Rowe and Kahn [6] the definition of successful aging requires three pillars. Firstly, there is a low probably of disease and/or disability from disease; secondly a high cognitive and physical functioning capacity; and three, the combination of the first two with an active engagement in life. In affecting successful aging, particularly with the nexus to an active engagement in life, there is a need for development of, and access to, smart technologies to monitor and maintain health and wellbeing, as well as to link older people with communities and health-care professionals. One area where technology is rapidly advancing is robotics. Robots are now available that provide services such as home cleaning, appliance operation, and safety monitoring. These "service robots" can be excellent for monitoring, surveillance, and basic tasks of everyday living yet they lack artificial intelligence. Morris et al. [3] argued the need for "smart" robotic technologies that not only respond to an individual's needs, but can also learn and modify their behaviour based upon their owner's requirements. This is particularly the case for older individuals who would need to interact with their robot to maintain mobility, health, safety, and social connectedness.

Service robots currently include commercialised domestic robots, such as self-navigating vacuum cleaners and mops, known as Roomba and Scooba respectively [7]. Service robots also include "pet" or sociable robots, such as the Aibo robotic pet dog, Paro the robotic pet seal, and similar robotic animals that use "pet therapy" to assist older people to maintain mobility, and to keep active [8]. Service robots have also been developed for hospital settings. One example of this is the iWARD project in Germany [9] where modular designed robots have been adapted for different roles for independent living, health, and safety. They can also act in a team to service the needs of medical and other health professional staff such as for remote consultations and communication between staff in different wards.

The literature reveals some misconceptions about the potential for robotic interaction with humans. For example, popular opinion holds that robotic technologies are only applied to individuals when they are disabled [10]. However, there is a small yet increasing awareness that robotic technologies can also complement current health care service provision by monitoring older people within their home environment [11] and assisting them to mobilise safely and prevent falls [12]. Narrative literature reviews on the role of robotics in health care [8, 11–13] or social assistance robots [14] have previously been completed mainly speculating about the future of robotics in health. The aim of this systematic review was to identify specific evidence-based research answering questions to address the potential of robotic technologies to monitor older individuals' health and wellbeing and to assist with activities of daily living. Another aim was to review the extent of robotic technologies currently tested and used in the home environment for older individuals.

2. Methods

We identified two key questions for the systematic review of the literature addressing robotics and ageing in the home environment.

(1) What is the range of robotic devices available to enable older people to remain mobile, independent and safe?

(2) What is the evidence demonstrating that robotic devices are effective in enabling independent living in community dwelling older people?

Where possible, in each database, searches for all topics were limited to peer-reviewed publications between January 1990–February 2012, published in English. We included human participants aged 45 years and older, as it is generally accepted that many chronic conditions may have their onset from approximately this age onwards. This broader definition of older individuals' was adopted by the authors, defined by MESH heading definitions of "middle-aged" 45–64 years, "aged" (65–79 years) and "aged 80+ years" with the understanding that "older individuals" were a heterogeneous group. The authors also accepted the definition of a "home" setting as the individual's place of residence [15]. This included establishments providing residence and care for special needs, such as retirement villages and aged care facilities providing low care services, service integrated housing, and supported accommodation.

To answer question 1, randomised controlled studies, quasi-experimental studies, and comparative studies with and without concurrent controls, case-series and feasibility studies, systematic and general review articles, and government reports (where relevant to topic area) were included to identify available technologies. The following publications were excluded from the paper: narrative reviews, descriptive or narrative papers without presentation of data, limited-review conference proceedings and abstracts, higher degree research theses (PhD/Masters), undergraduate research theses (Honours) and books.

To answer question 2, data extraction and quality assessments were predominantly performed on studies that met the criteria for question 1, however these studies were required to demonstrate that testing and/or data collection had been completed in a home (or simulated) environment.

Data base searches were limited to studies assessing humans and those published in English and included: Web of Science, Science Direct, MEDLINE, PSYCHINFO, SCOPUS, CINAHL, expanded version of the cumulative index to nursing and allied health by *EBSCO*, Australasian Medical Index, National Library for Health, Rehabilitation Research (USA), and TROVE.

Two independent, trained reviewers evaluated the title and abstracts of the yield articles against the decision rules inclusion criteria. The title of each article was scanned and the two reviewers independently excluded articles not related to the topic. The full texts of the articles were then obtained for data extraction, categorized according to National Health and Medical Research Council (NHMRC) guidelines on levels of evidence [16], and the quality of each article was assessed using the Downs and Black [52] quality appraisal tool. Downs and Black was specifically selected to assess the articles as it can be used for both experimental and quasi-experimental research designs. Two independent reviewers conducted data extraction and quality assessment for each article. Lack of agreement about inclusion of articles, data extracted, or grading against quality criteria was reconciled by mutual agreement.

3. Results

Figure 1 illustrates the breakdown of articles following the predetermined inclusion and exclusion criteria. The major reason for exclusion was that articles were descriptive and did not contain data providing evidence of effectiveness, feasibility, or validity. Table 1 shows the studies that have provided evidence of technologies assisting older people.

The yield of articles in response to question 1 showed that robotic technology is currently available to assist older

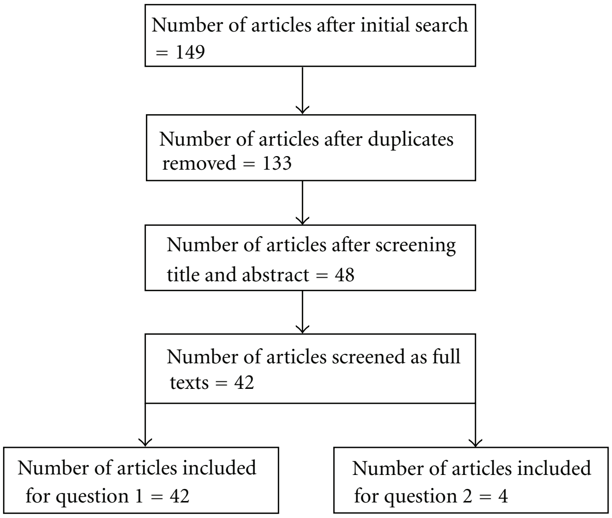

Figure 1: Yield of articles for the robotics literature.

people and people with physical disabilities. These were not "smart" robots per se, with no artificial intelligence interface, and the majority of these articles were lower limb "exoskeleton" technologies. Robotic exoskeletons are fitted to the outside of the limbs, rather than being internally fixed using surgical methods and supplies at the energy (or part of the energy) for limb movement. The "Lokomat" was the most widely tested robotic exoskeleton for the lower limbs [25, 27, 29, 33, 37, 48, 49] to trial its suitability as a supportive structure for walking. Other technologies to assist with walking and mobility included robotic walkers and robotic guidance systems [30, 38]. These systems, such as the "Guido", are extensions on the non-motorised walker frames, where the individual can control the speed of locomotion but also obtain environmental feedback, via sensors, to assist in obstacle avoidance and in navigating through doorways.

Upper limb technologies included both upper limb exoskeleton systems to guide arm movements and haptic visuomotor feedback systems to assist in compensation for disorders of sensation and visual impairment. The "MIT-MANUS", a visuomotor guidance system, was the most utilised of the upper limb robotic systems, particularly for people who were recovering from stroke [17, 19, 21, 24, 35]

Table 2 shows the articles that met the inclusion criteria for question 2. To date, four investigations have tested robots within a home, residential care setting, or simulated home environment. Generally, these studies demonstrated that robots are able to help older people with mobility issues around the home environment. However, this data presented was only low to moderate in terms of their level of evidence and research quality [52]. Shimada et al. [40] investigated the effectiveness of a lower limb exoskeleton device using a pre-post single group design in older healthy females within an independent home living facility. Unlike other lower limb robots, such as the Lokomat which is a relatively large driven gait orthosis that automates locomotion therapy, the exoskeleton technology in this study was smaller and more compact. This study reported improvements in walking speed and reduced energy expenditure (due to fitness gains) following 3 months of 2 sessions (90 minutes duration) per week of assisted walking using the exoskeleton technology with elderly females. Spenko et al. [28] investigated the effectiveness of a robotic personal mobility aid with sensors to guide elderly ambulatory individuals away from obstacles. Analysis of the effectiveness of the technology was difficult to interpret as only descriptive data were presented in the paper. Saeki et al. [32] presented a case study describing the use of an upper limb robotic trainer in an elderly woman two years post hemiparesis. Improvements in motor function were reported in musculature of the proximal arm compared to the distal hand and alterations in cortical representation maps of the affected area were suggestive of plastic adaptations. However, these cortical representation changes were not correlated with changes in movement performance of the hemi paretic upper limb. Finally, a recent study by Carlson and Demiris [51] demonstrated improvements in wheelchair mobility when combined with a robotic interface (collaborative control) compared to when participants had to control the wheelchair manually without robotic assistance. Moreover these authors showed, via self-reported questionnaire, that participants found manoeuvering the wheelchair less mentally demanding during collaborative control.

4. Discussion

This systematic review has highlighted that robotics is still an emerging field in terms of its application to health and rehabilitation for community dwelling older people. Despite these studies being of a lower design quality, the evidence to date shows that robotics research is used widely in engineering laboratories and, to a lesser extent, in clinical settings. Only a very small number of controlled clinical trials evaluated the effects of implementing robotic technology in the home for the purposes of potentially assisting with daily living activities, home care, home maintenance and housework, security, safety, falls detection, or social interaction. Moreover, none of the studies on robotics presented costing of the devices, discussed safety concerns to the user, whether the devices could be mass produced, or social issues such as acceptance by older people in their home environment.

It was also notable that the studies in this paper focussed on application of robotic technologies for purposes of movement rehabilitation in people who had impairments and disabilities arising from conditions such as arthritis, back pain, balance impairment, stroke, or spinal cord injury. To date no studies have objectively measured the potential application of robotic technologies as monitoring devices in the home setting. Potentially artificial intelligence could be used to measure the health status of their "owner," provide reminders for specific medications to be taken; or provide contingency procedures in the case of an adverse event such as a slip, trip, or fall.

One study in this paper demonstrated an increased exercise capacity when healthy older participants utilised a robotic exoskeleton for walking training in a "home" setting [40]; however as the study was limited to only

Table 1: Studies for question 1.

First Author/year	Study Design	Evidence Level	Duration	Setting	Country	Sample size	Age mean	Age range	Characteristics	Gender M	Gender F	Sampling	Technology	Description
		[16]												
Aisen [17] 1997	Intervention study	III-1	Overall duration not stated. Robot trained 4-5 hrs/wk on top of conventional training. Sham trained 1-2 sessions/wk	Hospital rehabilitation clinic	USA	20	§	Robot trained—45–68; Sham trained—38–72	Post-stroke, hemiplegia	11	9	Pseudorandomised	"MIT-MANUS"	Robotic upper limb exoskeleton.
Morvan [18] 1997	Qualitative study	IV	<1 mnth	§	France	28	§	§	Young with either tetraplegia, myopathies or spasticity	#		Not stated	"MASTER" robotic arm system	Psychological preparedness by older people for robots.
Krebs [19] 1998	Intervention study	III-1	Overall duration not stated. Robot trained 4-5 hrs/wk on top of conventional training. Sham trained 1 sessions/wk	Hospital rehabilitation clinic	USA	20	Robot trained—58.5; Sham trained—63	§	§	#		Pseudorandomised	"MIT-MANUS"	Robotic upper limb exoskeleton.
Cozens [20]1999	Intervention study	III-3	<1 d	Laboratory	England	10	§	47–69	Stroke or MS with upper limb weakness	#		Pseudorandomised	No name provided	Robotic upper limb apparatus.
Volpe [21] 1999	Intervention study	III-1	1 wk treatment, 3 yr follow-up	Hospital rehabilitation clinic	USA	20 total, 12 of 20 mea-sureat 3 yrs	Robot trained—54 ± 3 Sham trained—66 ± 2	§	Post-stroke	7	5	Pseudorandomised	"MIT-MANUS"	Robotic upper limb exoskeleton.
Reinkensmeyer [22] 1999	Intervention study	III-3	<1 d	§	USA	5	§	24–79	Brain injury (TBA/ABI)	#		Convenience	Robotic arm	Arm guidance system.
Burgar [23] 2000	Intervention study (x3)	III-2	1 wk–2 mnths	Laboratory	USA	24	§	21–80	Post-stroke hemiplegia	#		Convenience	MIME	Mirror Image Motion Enabler (MIME).
Volpe [24] 2000	Intervention study	III-1	25 × 1 hr sessions 5 d/wk	Hospital rehabilitation clinic	USA	56	64.5	27–83	Post-stroke hemiplegia	30	26	Randomised control	"MIT-MANUS"	Robotic upper limb exoskeleton.
Jezernik [25] 2003	Intervention study	III-3	2 × 1 hr sessions	Spinal cord injury clinic	Switzerland	6	§	38–73	Spinal cord	#		§	"Lokomat"	Robotic gait exoskeleton.
Loureiro [26] 2003	Intervention study	III-3	9 sessions over 3 wks	Hospital	England	30	§	§	Stroke hemiplegia	#		Randomised control	"GENTLE/S"	Haptic upper limb system.
Rentschler [13] 2003	Technical report	IV	<1 d	Laboratory	USA	1	29	29	Healthy	1	—	Case study	PAMA	Personal adaptive mobility aid (PAMA).
Winchester [27] 2005	Other	III-3	12 wks	Laboratory	USA	4	§	20–49	Spinal cord injury	4	—	Convenience	"Lokomat"	Robotic gait exoskeleton.
Spenko [28] 2006	Other	III-3	<1 d	Laboratory	USA	6	§	85–95	Healthy older	1	5	Convenience	"Smartcane" and "Smart walker"	Walking aid for mobility and monitoring.
Isreal [29] 2006	Other	III-3	5 sessions	Laboratory	USA	12	§	15–59	Spinal cord injury	#		Convenience	"Lokomat"	Robotic gait exoskeleton.

Table 1: Continued.

First Author/year	Study Design	Evidence Level	Duration	Setting	Country	Sample size	Age mean	Age range	Characteristics	Gender M	Gender F	Sampling	Technology	Description
Mehrholz [30] 2007	Systematic review	[16] I	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a		n/a	Assisted gait device	Robotic-assisted gait training.
Rocon [31] 2007	Other	III-3	<1 d	Laboratory	Spain	10	52.3	§	Tremor	7	3	Convenience	"WOTAS"	Robotic exoskeleton to reduce arm tremor.
Saeki [32] 2008	Other	IV	6 mnths	Laboratory	Japan	1	48	n/a	Neuro-logical	—	1	N/a	"Bi-Manu-Track"	Robotic arm trainer.
Hidler [33] 2008	Intervention study	III-2	6 mnths	Laboratory	USA	5	44.1	24–59	Spinal cord injury	#		Randomised control	"Lokomat"	Robotic gait exoskeleton.
Janssen and Pringle [34] 2008	Intervention study	III-3	6 wks	Laboratory	USA	12	36	20–70	Spinal cord injury	12	—	Convenience	"ERGYS 1"	Functional electrical stimulator leg ergometry.
Krebs [35] 2008	Intervention study	III-2	6 wks	Rehabilitation clinic	USA	47	57.5	27–79	Stroke	#		Pre-post single group	"MIT-MANUS"	Robotic hand visuomotorguidance system.
Patton [36] 2008	Other	n/a	n/a	n/a	USA	n/a	n/a	n/a	n/a	n/a		n/a	"KineAssist"	Discussion paper on robot to improve balance and gait.
Querry [37] 2008	Intervention study	III-2	<1 d	Laboratory	USA	26	35.5	§	Spinal cord injury	17	9	Non-randomised control	"Lokomat"	Robotic gait exoskeleton.
Rentschler [38] 2008	Intervention study	III-2	1 d	Laboratory	USA	17	85.3	§	Healthy	#		Pseudorandomised	"GUIDO"	Robotic walker.
Galluppi [39] 2009	Intervention study	IV	§	Hospital	Italy	§	§	§	§	#		§	Robotic wheelchair	Collaborative control robotic wheelchair.
Shimada [40] 2009	Intervention study	III-2	<6 mths	Retirement village	Japan	15	78.3	72–85	Healthy	0	15	Convenience	Stride assistance system	Robotic exoskeleton stride assistance system to assist with walking but provide resistance for physical improvement.
Flinn [41] 2009	Case study	IV	6 wks	Hospital	USA	1	48	n/a	Post-stroke	n/a		n/a	"InMotion2"	Upper limb visuomotor guidance system.
Zeng [42] 2009	Intervention study	IV	§	Hospital rehabilitation clinic	Singapore	3	§	16–48	Cerebral palsy/TBI	#		Convenience	Robotic wheelchair	Collaborative control robotic wheelchair.
Lo [43] 2010	Intervention study	II	12 weeks (total of 36 hours training)	Multi-rehabilitation centres	USA	127	64.6	§	>6 months post-stroke	122	5	Random control trial	Modular robotic system (no name) for upper arm guidance.	Modular robotic upper arm guidance system for shoulder, forearm, wrist, and grasping movements.
Frizera Neto [44] 2010	Intervention study	III-3	<1 d	Indoor installation	Spain	5	§	§	Healthy	#		Convenience	"SIMBIOSIS"	Robotic walker—upper body force interaction.
Sharma [45] 2010	Intervention study	III-3	<1 d	Laboratory	USA	19	38.5	§	Healthy	13	6	Convenience	"Drive Safe" smart wheelchairs	Joystick driven, sensor controlled wheelchairs.
Wolpaw [46] 2010	Expert opinion	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a		n/a	Brain-computer interfaces	Opinion based article on the progression in brain-computer interfaces and suggestions on where the technology paradigm should progress.
Galvez [47] 2011	Intervention study	III-3	n/a	Laboratory	USA	4	§	24–62	Spinal cord injury	#		Convenience	Sensor orthoses	Robotic body-weight support treadmill.
Turiel [48] 2011	Intervention study	III-3	1 hr/d, 5 d/wk, 30–45 mins/session	Laboratory	Italy	14	50.6	n/a	Spinal cord injury	10	4	Pre-post single group	"Lokomat"	Robotic gait exoskeleton.

Table 1: Continued.

First Author/year	Study Design	Evidence Level	Duration	Setting	Country	Sample size	Age mean	Age range	Characteristics	Gender M	Gender F	Sampling	Technology	Description
Schwartz [49] 2011	Intervention study	[16] III-3	2-3 times/wk, 30–45 mins/session	Rehabilitaion clinic	Israel	28	42	n/a	Spinal cord injury	18	10	Single group, matched historical control	"Lokomat"	Robotic gait exoskeleton.
Conroy [50] 2011	Intervention study	II	60 mins, 3 times/wk for 6 wks	Laboratory	USA	62	57.8	n/a	Stroke, hemiplegia upper limb	34	28	Random control trial	"InMotion2"	Upper limb visuomotor guidance system. 2D versus 3D including antigravity training, comparing the combination of vertical and planar robot with planar alone.
Carlson and Demiris [51] 2012	Intervention study	III-2	<1 d, 2 × 40 min sessions	Simulated home	England	21	§	17–47	Healthy	#		Convenience	No name	Collaborative controlled robotic wheelchair.

[#] No gender given, [§] Not given.

Table 2: Quality evaluation of data driven studies for question 2.

First Author/year	Design	Evidence Level [16]	Duration	Dosage	Setting	Country	Sample size	Age mean	Age range	Character-istics	Gender M	Gender F	Sampling	Key DV	Key measure	Results	Score (max27)* [15]
Spenko [28] 2006	Pilot Interven-tion study	IV	§	§	Residential care	USA	"several"	§	§	§	§	§	§	Distance from wall in meters before the smart-walker changed direction	Motor performance	Good performance outcome using both PAMM technologies. Subjective measures gave less confidence in robotic-controlled walkers to manually controlled walkers.	4
Saeki [32] 2008	Case study	IV	<6 mths	20 mins 2 d/wk for 4 mths	Home	Japan	1	48	§	Neurological	0	1	§	Oxygenated/deoxygenated/total haemoglobin level in motor cortex assessed by fMRI technique	Motor assessment scale (modified Ashworth Scale)	Improvement in modified Ashworth motor assessment scale (2 to 5); reduced score on modified Ashworth scale (3 to 2); no change in wrist and fine motor tasks; direct activation of motor area in affected hemisphere.	4
Shimada [40] 2009	Intervention study	III-2	<6 mths	2 × 90 mins/wk for 3 mths	Retirement village	Japan	15	78.3	72–85	Healthy	0	15	Conven-ience	Walking speed	5 m walk test	Increase in walking speed; reduction in energy consumption (lower glucose metabolism)	12
Carlson and Demiris [51] 2012	Intervention study	III-2	<1 d	2 × 40 mins	Simulated "home" environment	England	21	§	17–47	Healthy	§	§	Conven-ience	Wheel-chair control around a simulated home environment	Collision and cognitive perception	Less collisions with robotic assistance and lower scores on perceptions of concentration	13

§ Not given.

*The last question of the Downs and Black assessment tool was excluded due to ambiguity of the question. This meant that the maximum score possible was 27.

one group, with no direct comparison to an age-matched control group who participated in the walking program without the exoskeleton, it is difficult to rigorously evaluate the effectiveness of the use of the robotic exoskeleton in this study. Moreover, follow-up data measures were not taken, therefore it is not possible to ascertain the long-term effectiveness of the technology in assisting in maintaining independence.

However, this paper has demonstrated that applications of robotic technologies have progressed much further than what the general public perceive robots are capable of undertaking. Robotic technology studies, despite being methodologically weak [52], have demonstrated capability of functional improvements following loss of function in upper and lower limbs, or to assist with mobility in indoor environments. The range of the robotic technologies presented in in Table 2 show that the technology is now progressing to the point that that home trials of these different robotic technologies will be undertaken in the near future.

A limitation of this review was that non-English language studies were excluded. Therefore it is possible that studies of testing robotics in the home environment have been completed, but were not included in this paper as they were published in languages other than English. A second limitation of this review was the decision by the authors to exclude robotic interventions for uses relating to cognitive decline/successful brain aging. Indeed, recent reviews have discussed the use of robotics for cognitive healthcare in the elderly [3]; however, the primary aim of this paper was to review evidence for robotics in addressing physical mobility to reduce disability and loss of independence in the home. Further, although outside the scope of this review and thus also excluded was the emergence of nanotechnology. It is plausible to suggest that progress in nanotechnology research (also known as nanorobotics) [53] could potentially reduce hazards in the home. Robotics will improve, in a number of different directions, to the point of assisting older people to live independently and safely in their homes, and enjoy excellent quality of life in their communities.

The recently released (April 2012) Living Longer. Living Better Report from the Australian Federal Government [54] in response to the Productivity Commission's Report on Care of Older Australians [55] recommends the major expansion of home care supportive services, although these are largely conceptualized as intensive case management services. However, the aged housing and care industry in Australia is moving ahead with the rapid take up of new technologies to assist older people to live more independently at home and in supported accommodation in association with the rollout of a new broadband network nationally [55].

Robotics are perhaps one of the newest technology areas to have entered the home care market, being previously largely developed for application in heavy industry and acute health. Looking forward, however, the potential for robotic application in the home is wide open. Some of the major barriers relate to cost of development, the incorporation of artificial intelligence in new design applications, and the encouragement of greater interdisciplinary convergence between the many research fields now involved in the development of new robotic technologies. At this point in time in Australia, progress on home grown robotic applications is limited, given the substantial infrastructure required in the start-up phase [56].

In light of the research reviewed, a number of key recommendations can be provided as follows:

4.1. Applying Research into Home Environments. The evidence from the current systematic review has clearly demonstrated that robotics research needs to be conducted in the home environment. To date, only four studies have attempted to conduct research within the home environment [28, 32, 40, 51]. These studies have demonstrated positive outcomes, providing a good rationale to take robotics into environments outside of laboratories or hospital clinics.

4.2. Diversifying Robotics. The majority of robotic technology studies found in the current review were directed at movement rehabilitation. However, for the elderly population, healthy living includes prompting and reminding for effective monitoring. Development of robotic technologies should include technologies that can provide gentle reminders for medications, continually scan the environment to ensure no falls have taken place, and have a protocol in place to advise relevant authorities if an incident has occurred. Similarly, robotics has the potential to allow for social connectedness by providing company for elderly people living alone, or to serve as interfaces for connecting with family and friends using existing technologies (e.g., Skype).

4.3. Reducing Costs. The final recommendation would be to investigate ways of reducing the costs of technologies. As shown in this paper, robotic technologies are still in development and trial phases. It would be anticipated that with commercial development and mass production, these costs would reduce significantly. However, at the present time costs appear to be a barrier towards broad adoption of robots in the home environment.

In conclusion, this systematic review has shown that robotic technologies have the potential to assist older people and people with disabilities to remain mobile and to live safe and healthy lives at home. Further research and training of the heath and disability workforces is needed to the adoption of robotics as an effective, routine, and practical option within the home environment. The evidence demonstrates that robots already exist to assist with movements, obstacle-avoidance, and functional rehabilitation, but require further development to realise their full potential for safety monitoring, falls, and social connectedness. Future robot design needs to consider development from a different perspective, considering not only assisted mobility, but also interfacing artificial intelligence for interaction with older individuals, to monitor their health, provide medication prompts, encourage exercise, and provide them with confidence to maintain independent living.

Conflict of Interests

The authors declare that they have no conflict of interests.

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Research Article

Transitions among Health States Using 12 Measures of Successful Aging in Men and Women: Results from the Cardiovascular Health Study

Stephen Thielke[1,2] and Paula Diehr[3]

[1] *Department of Psychiatry, University of Washington, Seattle, WA 98195, USA*
[2] *Geriatrics Research, Education, and Clinical Center, Puget Sound VA Medical Center and Psychiatry and Behavioral Sciences, University of Washington, P.O. Box 356560, Seattle, WA 98195, USA*
[3] *Departments of Biostastitics and Health Services, University of Washington, Seattle, WA 98195, USA*

Correspondence should be addressed to Stephen Thielke, sthielke@u.washington.edu

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Introduction. Successful aging has many dimensions, which may manifest differently in men and women at different ages. *Methods*. We characterized one-year transitions among health states in 12 measures of successful aging among adults in the Cardiovascular Health Study. The measures included self-rated health, ADLs, IADLs, depression, cognition, timed walk, number of days spent in bed, number of blocks walked, extremity strength, recent hospitalizations, feelings about life as a whole, and life satisfaction. We dichotomized variables into "healthy" or "sick," states, and estimated the prevalence of the healthy state and the probability of transitioning from one state to another, or dying, during yearly intervals. We compared men and women and three age groups (65–74, 75–84, and 85–94). *Findings*. Measures of successful aging showed similar results by gender. Most participants remained healthy even into advanced ages, although health declined for all measures. Recuperation, although less common with age, still occurred frequently. Men had a higher death rate than women regardless of health status, and were also more likely to remain in the healthy state. *Discussion.* The results suggest a qualitatively different experience of successful aging between men and women. Men did not simply "age faster" than women.

1. Introduction

Changes in health status, symptoms, and functioning during aging defy simple description. Despite the inevitability of death, no orchestrated or predictable decrements in health or types of sickness uniformly precede it, and individuals vary widely in how and how successfully they age. Certain groups may experience aging and health differently from others. The most obvious instance is gender: older men and women have been observed to have different lifespans [1, 2], functional trajectories [3], risk factors for disease [4], chronic and acute diseases [5, 6], and use of medical treatments [7]. There is practical and theoretical importance in understanding health changes during aging, especially the maintenance of health and the ability to recuperate from sickness, differ between men and women.

Successful aging is a multidimensional construct, which initially centered on absence of disease and objective physical and social functioning [8]. Recent research has deemphasized medical disease and concentrated more on self-identified successful aging, psychological health, well-being, mobility, and the absence of frailty [9–12]. There is no canonical definition for successful aging, and no single domain or variable captures all of its facets. Most previous analyses of age and gender effects on health status have examined health transitions for single health measures such as disability, depression, self-rated health, body mass index, ADL, or IADLs [13–21]. Because these studies generally focus on a single aspect of successful aging, and they inconsistently examine gender and age as predictors, they offer somewhat limited perspectives and generally cannot be compared.

There is utility in systematically scrutinizing the changes in different aspects of health status that occur with advancing age among men and women. First, evidence from research can help to counter ageist or sexist stereotypes about health during the aging process, which may influence social expectations, clinical care, and patient decision making [22]. Second, interventions to reduce morbidity and mortality can be better targeted by understanding the prevalence, persistence, and resolution of sickness in different populations. Third, observational results can inform both the theory of successful aging and research into the biology of aging. For instance, research has suggested that men "age faster" than women [23], yet this observation has not received much scrutiny in observational studies.

We sought to characterize a variety of measures of successful aging among a group of older adults, with particular attention to the differences between men and women of different ages. To explore changes in health systematically, and to allow age and gender comparisons, we analyzed transition probabilities for 12 different health variables which capture different aspects of psychological, physical, cognitive, and functional status. We hypothesized, for these 12 different domains of successful aging, that (1) the prevalence of health decreases because both the probability of remaining healthy and the probability of returning to a healthy state decline with increasing age, and (2) the prevalence and transition probabilities are different for men and women.

2. Methods

2.1. Data. Data came from the Cardiovascular Health Study (CHS), a population-based longitudinal study of risk factors for heart disease and stroke in 5888 adults aged 65 and older at baseline [24]. Participants were recruited from a random sample of Medicare eligible adults in four US communities, and extensive data were collected during annual clinic visits and telephone calls. The original cohort of 5201 participants, recruited in 1989 and 1990, had up to ten annual clinic examinations. A second cohort of 687 African Americans, enrolled in 1993 and 1994, had up to seven annual examinations.

The 12 variables used in this study were measures of health based on self-report or observation. They were selected in order to capture various aspects of psychological, physical, cognitive, and functional status. All were measured annually. Each value was dichotomized into "Healthy" and "Sick", as shown in Table 1, using either previously published cutoffs or logical thresholds [27]. Some of the domains involved responses inherently suggestive of sickness. For hospitalization (HOSP), bed days (BED), ADL limitations (ADL), IADL limitations (IADL), and poor extremity strength (EXSTR), participants who endorsed the presence of any difficulty or one or more impairments were considered to be sick in that domain. For feelings that life is worthwhile (FLW), answers of "delighted," "pleased," and "mostly satisfied" were considered healthy; those of "mostly dissatisfied," "unhappy," and "terrible" were considered sick. For satisfaction with the purpose of life (SPL), using a 10-point scale between "extremely satisfied" (1) and "not at all satisfied" (10), answers better than "neither satisfied nor unsatisfied" (<4) were used to characterize health. For depression (DEP), a score of less than 10 on the CES-D depression scale was used to characterize health [20, 28]. For self-rated health (SRH), self-reported "excellent," "very good," or "good" general health were defined as healthy, and "fair" or "poor" as sick [29]. Healthy cognitive status (COG) was defined as above 89 points on a 100-point scale, corresponding to 26 or higher on the MMSE, which is suggestive of intact cognition [30]. The sick state for ambulation (TWLK) was defined by a velocity of less than 0.66 feet per second (10 seconds) in a 15-foot walk, which is a marker for low speed [31]. Blocks walked during the last week (BLK) were dichotomized at 28 blocks or more to signify the healthy state [32]. Because the analyses compared age and gender groups within each domain rather than the domains to each other, the variability in the prevalence of healthy and sick states as a result of different cutoffs were unlikely to influence the main results significantly.

In order to simplify comparisons, age was divided into three categories—65–74, 75–84, and 85–94—in accordance with the common definitions of "young old," "old old," and "oldest old". Persons could contribute data to more than one age category, depending on their age at the start of each transition.

Missing data were imputed, after a transformation to recode death as zero health, by interpolating over time between existing data points for each person. Any data that remained missing at the end of a sequence were extrapolated as an average of the last observed value and of transformed self-rated health (which was measured every 6 months and is thus well characterized) [33, 34]. No imputation across participants was performed. All available observations were used, including those that were imputed.

2.2. Statistical Approach. In order to represent and compare prevalence and incidence of healthy and sick states in various domains, and to account for death, we used a transition probability approach. This technique has been used to examine other changes in health among older adults, including self-rated health [13], obesity [14], depression [20], and pain [35]. Transition probability models make the simple assumption that health status measures can be categorized into discrete states, among which individuals can move. The ovals in Figure 1 represent discrete health states, and the arrows show the likelihood of transitioning from one state to another during a single time interval, one year. The number of individuals in each of the states (shown by the ovals) is the relative prevalence of health or sickness in the total population.

When evaluated at two time points, there are thus six possible transitions among these states: remaining healthy (P(HtoH)), becoming sick (P(HtoS)), remaining sick (P(StoS)), becoming healthy (P(StoH)), dying from a state of health (P(HtoD)), and dying from a state of sickness (P(StoD)). Persons move among those states with certain

Table 1: 12 Measures of successful aging.

Category	Abbreviation	Question	Definition of healthy
Not hospitalized	HOSP	"Did you stay overnight in the hospital in the last 6 months?"	No report of being hospitalized
No bed days	BED	"During the past two weeks, how many days have you stayed in bed all or most of the day because of illness or injury?"	No days in bed reported
Life satisfaction	SPL	"How satisfied are you with the meaning and purpose of your life? on a scale of 1–10, with 1 being extremely and 10 being not at all"	Score of 1 to 4
Life as a whole	FLW	"How do you feel about life as a whole?" (1: delighted; 3: mostly satisfied; 6: terrible)	Score of 1–3
Not depressed	DEP	10 questions of the center for epidemiologic studies short depression scale [25], each ranked 0–3	Score < 10, out of a possible 30 points
No limitations in activities of daily living	ADL	"Do you have any difficulty performing this activity?" from a list of walking, transferring, eating, dressing, bathing, or toileting	No difficulties reported
No limitations in independent activities of daily living	IADL	"Do you have any difficulty performing this activity?" from a list of heavy or light housework, shopping, meal preparation, money management, or telephoning	No difficulties reported
Intact extremity strength	EXSTR	"Do you have any difficulty with this activity" from a list of lifting, reaching, or gripping	No difficulty reported
Self-rated health	SRH	"How would you rate your health in general: excellent, very good, good, fair, or poor?"	Excellent, very good, or good self-reported health
Intact cognition	COG	Modified minimental state examination [26], scored from 0 to 100	Score above 89
Ability to ambulate	TWLK	Timed 15 foot walk	Less than 10 seconds
Frequent ambulation	BLK	"During the last week, how many city blocks did you walk?"	>4 blocks per day, on average

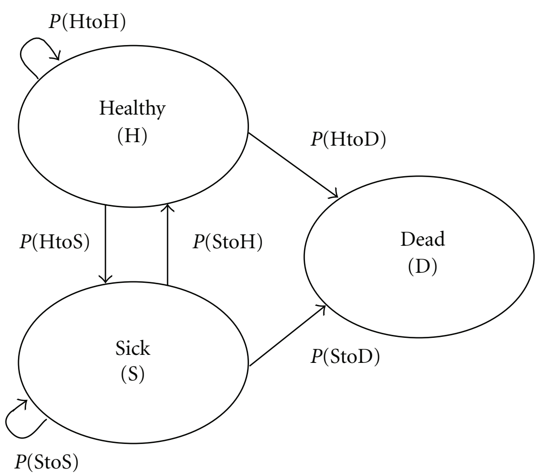

Figure 1: Transition probability model, showing the probability of remaining in a state or moving to another state during specific time intervals (such as one year).

probabilities, which may vary by age, gender, or other characteristics. The equilibrium—or steady state—prevalence of a system can be calculated directly from the transition probabilities [36].

2.3. Analysis. The prevalence of the healthy state of each variable in each wave was calculated as the percentage of living persons who were healthy. The one-year probabilities of transitioning from state to state were estimated from crosstabulation of data collected one-year apart. All cases where a beginning state and a starting state were available were used, for all 5888 participants. General patterns by age and gender groups were described. We estimated one-year transition probabilities for participants starting in each health state (sick or healthy). These transition probabilities, shown in Figure 1, were constructed as a simple fraction: number of moving to other state or remaining in state/ number in the state at the starting time point. Calculations were performed separately for each age and gender grouping. The associations of the estimated transition probabilities with age and gender were tested using cross-sectional time series logistic regression (the xtlogit command in Stata). This form of generalized estimating equation accounts for participants contributing multiple observations. We carried out separate analyses for men and women of the same age group and estimated the statistical significance of the difference using generalized estimating equations.

The level of significance for individual comparisons was set at $P < 0.05$, two tailed, and differences between men and women in the same age group at this degree are shown in bold in the tables. The differences by age are described in the text. We summarize the significant findings across variables, with the reminder that 5% of all significant differences could be due to chance. There was no explicit adjustment for multiple comparisons, because all of the results were shown (i.e., we did not select only the significant results after running multiple models and because of the large number of potential combined hypotheses.)

Analyses were conducted in Stata (StataCorp, College Station, Texas, version 11.2).

3. Findings

45,297 transition pairs (starting and ending state, separated by one year) from the 5888 participants were analyzed. During the study, 1684 participants died. For the whole sample, 13.5% of observations were missing and imputed, with some variability across the 12 domains of health. In the year prior to death, 7% of all observations were missing, which were part of the imputed fraction. The median number of imputed observations per participant was one.

As an illustration of the analytic approach, the prevalences and selected transition probabilities for ADL are shown in Figure 2. "Healthy" was defined as having no difficulties with activities of daily living, and "sick" as having one or more difficulties. The third and fourth lines from the top represent the healthy prevalence (proportion of the living who had no ADL difficulties), with a solid line for males and a dotted line for females. The prevalence is quite high for the youngest group (about 90%) and declines over time. The healthy prevalence is higher for men than for women, and the difference becomes larger with age. The lowermost two lines represent the probability of recovering from the sick state (having ADL difficulties) by transitioning into the healthy state (no ADL difficulties) one year later, labeled as P(StoH). The probability is initially near 0.4 and is higher for women than for men. The two topmost lines in the graph represent the probability of staying in the healthy state, P(HtoH). This probability is initially about 0.9 and is higher for men than for women. This figure shows how transitions and prevalence both change over time and differ between men and women, and also how relatively small differences in transitions accumulate into more pronounced differences in prevalence.

3.1. Prevalence of the Healthy State. The first two lines of Table 2 show the number of observations (transition pairs) in each group, and the mean age, by age category and gender. Mean age did not differ significantly in each category for men and women. The next 12 lines show the prevalence of a healthy state for each variable. For example, for HOSP, 91.3% of the women aged 65–74 were "healthy," defined as "having no hospital days." For men in the same age range, the prevalence of a healthy state was 88.0%. Over the three age groups, women's prevalence for HOSP declined from 91.3% to 87.8% to 84.9%.

Prevalence by Age and Gender. All of the prevalence values in Table 2 declined with age; the prevalence values were significantly lower at each subsequent age group compared with the younger one. The bolded entries in Table 2 show the situations where women or men had a significantly higher prevalence of a healthy state. Women were significantly healthier than men only for HOSP and COG. Men had a significantly higher prevalence of a healthy state than women for all the 33 other domains and age groups, except for three where there was no significant difference.

3.2. Transitions Probabilities for Healthy Persons. Table 3 shows the transition probabilities for persons who were initially in the healthy state. For instance, for HOSP, age 65–74, women who were healthy (without a hospital stay in the first year) had a 0.92 probability of remaining healthy (not having a hospital stay in the next year), a 0.08 probability of becoming sick (having a hospital stay), and a 0.01 probability of dying. The bold entries in the upper and lower tables represent probabilities where women or men became or remained significantly healthier. More than half of the comparisons were found to be statistically significant.

In all three comparisons (remaining healthy, becoming sick, and dying from a healthy state), there was a significant decline with advancing age for almost all the domains of health. Men were more likely than women to remain healthy and less likely to become sick in the majority of comparisons, and men were more likely to die.

3.3. Transition Probabilities for Sick Persons. Table 4 shows the transition probabilities for persons who were initially in the sick state. The bolded entries indicate probabilities of remaining in or recovery from sickness, or probability of death, that were significantly healthier in women (in the top of the table) or in men (in the bottom). For convenience we considered P(StoS), remaining sick, as an unfavorable transition, because the person did not recover, but it could also be considered as favorable because the person did not die.

In almost all domains of health, the probability of recovery from a sick state declined significantly with age, while the probability of dying from a sick state increased with age. Women were significantly more likely than men to recover from a sick state in six of 36 total groups; men were more likely to recover in 12. Men were less likely to remain in a sick state than women in 23 of the 36 groups; in no cases were women significantly less likely than men to remain sick. For every health variable, men were significantly more likely to die from a state of sickness than women were.

4. Discussion

4.1. Overview. This analysis, unlike previous approaches that have focused on one or a few domains of health, examined the prevalence of and transitions in 12 measures of successful aging among a cohort of older adults. The 12 health-related variables, while related, were diverse and included measures of physical and mental health, quality of life, and health behaviors. Some were self-reported and some were measured through objective tests. Some were subjective single item questions while others were based on structured

Table 2: Prevalence of a healthy state among men and women, with health defined separately for each domain. Bolded entries represent significantly higher prevalence of health in women (left columns) or men (right columns). The differences between groups based on age are described in the text.

	Female			Male		
	65–74	75–84	85–94	65–74	75–84	85–94
Number of observations	12261	12433	2183	7801	8867	1752
Mean age	71.0	78.6	87.5	71.1	78.6	87.7
HOSP: no hospital days	**91.3**	**87.8**	**84.9**	88.0	85.6	81.7
BED: no bed days	94.3	92.3	89.3	**95.9**	**94.6**	**91.3**
SPL: Satisfied with purpose of life	75.7	69.8	59.6	**80.7**	**75.2**	**67.4**
DEP: not depressed	80.2	73.8	64.3	**87.6**	**81.4**	**70.9**
ADL: no ADL difficulties	86.3	76.1	56.7	**90.2**	**82.7**	**67.6**
FLW: feel life is worthwhile	94.4	91.0	83.6	**95.3**	91.7	85.6
EXSTR: good extremity strength	67.6	57.6	42.1	**84.6**	**78.8**	**65.4**
SRH: high self-rated health	79.0	70.8	60.7	80.0	**73.6**	**64.7**
TWLK: walk 10 feet < 10 seconds	64.3	44.5	16.9	**73.8**	**58.6**	**30.0**
IADL: no IADL difficulties	71.8	58.7	39.5	**80.9**	**70.5**	**50.7**
COG: 3 MSE > 90	**70.9**	**54.6**	**27.6**	67.2	53.1	25.7
BLK: walked 4+ blocks per day	33.3	20.9	8.5	**47.7**	**37.8**	**22.3**

Table 3: One-year transition probabilities for those starting in a healthy state for 12 different variables. Bolded entries indicate a significantly healthier transition (more likely remaining healthy, less likely remaining sick, or less likely dying) among women compared to men (top half) or men compared to women (bottom half). The differences between groups based on age are described in the text.

	Age 65–74			Age 75–84			Age 85–94		
	P(HtoH)	P(HtoS)	P(HtoD)	P(HtoH)	P(HtoS)	P(HtoD)	P(HtoH)	P(HtoS)	P(HtoD)
Female									
HOSP	**0.92**	**0.08**	**0.01**	**0.88**	**0.10**	**0.02**	**0.80**	**0.13**	**0.07**
BED	0.95	0.05	**0.01**	0.92	0.06	**0.02**	0.86	0.08	**0.06**
SPL	0.85	0.15	**0.01**	0.80	0.18	**0.02**	0.70	0.27	**0.04**
DEP	0.88	0.11	**0.01**	0.84	0.14	**0.02**	0.77	0.19	**0.04**
ADL	0.90	0.09	**0.01**	0.85	0.14	**0.02**	0.72	0.24	**0.04**
FLW	**0.96**	0.04	**0.01**	0.92	0.06	**0.02**	**0.85**	0.11	**0.05**
EXSTR	0.83	0.17	**0.01**	0.77	0.21	**0.02**	0.66	0.30	**0.03**
SRH	**0.90**	**0.30**	**0.01**	0.85	0.37	**0.01**	0.73	**0.40**	**0.04**
TWLK	0.83	0.17	**0.00**	0.72	0.27	**0.01**	0.54	0.45	**0.01**
IADL	0.85	0.15	**0.01**	0.77	0.21	**0.02**	0.61	0.35	0.05
COG	**0.86**	**0.13**	**0.01**	**0.81**	**0.18**	**0.01**	0.67	0.30	0.04
BLK	0.65	0.01	**0.00**	0.55	**0.01**	**0.01**	0.49	0.03	0.03
Male									
HOSP	0.88	0.10	0.02	0.85	0.12	0.03	0.76	0.15	0.09
BED	0.95	**0.03**	0.02	0.92	**0.04**	0.04	0.84	0.07	0.10
SPL	**0.86**	**0.12**	0.02	**0.82**	**0.16**	0.03	0.71	**0.21**	0.08
DEP	**0.91**	**0.08**	0.02	**0.86**	**0.11**	0.03	0.76	**0.16**	0.07
ADL	**0.92**	**0.06**	0.02	**0.87**	**0.11**	0.03	0.75	**0.18**	0.07
FLW	0.95	**0.03**	0.02	0.92	0.05	0.03	0.82	0.10	0.08
EXSTR	**0.90**	**0.08**	0.02	**0.85**	**0.12**	0.03	0.74	**0.20**	0.06
SRH	0.89	0.35	0.01	0.84	**0.34**	0.03	0.75	0.45	0.06
TWLK	**0.85**	**0.13**	0.02	**0.76**	**0.22**	0.02	0.61	**0.34**	0.05
IADL	**0.88**	**0.11**	0.01	**0.81**	**0.17**	0.02	0.64	**0.30**	0.06
COG	0.83	0.15	0.02	0.78	0.20	0.03	0.62	0.33	0.05
BLK	**0.72**	0.02	0.01	**0.63**	0.02	0.02	0.54	0.04	0.03

Table 4: One-year transition probabilities for those starting in a sick state for 12 different variables. Bolded entries indicate a significantly healthier transition (more likely becoming healthy, less likely remaining sick, or less likely dying) among women compared to men (top half) or men compared to women (bottom half). The differences between groups based on age are described in the text.

	Age 65–74			Age 75–84			Age 85–94		
	P(StoH)	P(StoS)	P(StoD)	P(StoH)	P(StoS)	P(StoD)	P(StoH)	P(StoS)	P(StoD)
Female									
HOSP	0.68	0.26	0.06	**0.61**	0.29	**0.11**	0.54	0.27	**0.20**
BED	0.55	0.37	**0.08**	**0.44**	0.41	**0.15**	0.34	0.37	**0.30**
SPL	0.37	0.60	**0.03**	0.30	0.64	**0.06**	0.24	0.61	**0.16**
DEP	0.35	0.62	**0.03**	0.29	0.64	**0.07**	0.20	0.63	**0.17**
ADL	**0.36**	0.59	**0.05**	0.25	0.67	**0.08**	0.15	0.70	**0.15**
FLW	**0.37**	0.54	**0.09**	**0.29**	0.56	**0.15**	0.18	0.53	**0.29**
EXSTR	0.31	0.66	**0.03**	0.23	0.72	**0.05**	0.14	0.74	**0.12**
SRH	0.31	0.64	**0.04**	0.25	0.67	**0.07**	**0.24**	0.61	**0.15**
TWLK	0.29	0.68	**0.03**	0.16	0.80	**0.05**	0.06	0.84	**0.10**
IADL	0.30	0.67	**0.03**	0.22	0.73	**0.05**	0.16	0.73	**0.11**
COG	0.27	0.70	**0.03**	0.17	0.78	**0.05**	0.07	0.83	**0.11**
BLK	0.14	0.84	**0.02**	0.08	0.88	**0.04**	0.03	0.88	**0.09**
Male									
HOSP	0.63	0.29	0.08	0.56	0.28	0.16	0.49	0.23	0.28
BED	0.49	0.35	0.15	0.33	0.36	0.32	0.26	0.33	0.41
SPL	**0.41**	**0.53**	0.06	0.32	**0.56**	0.12	0.24	**0.54**	0.22
DEP	0.37	**0.54**	0.08	0.27	**0.57**	0.16	0.18	0.58	0.25
ADL	0.31	0.59	0.10	0.23	**0.60**	0.17	0.13	**0.63**	0.24
FLW	0.29	0.55	0.16	0.20	0.52	0.28	0.15	0.46	0.39
EXSTR	**0.37**	**0.57**	0.07	**0.31**	**0.56**	0.14	**0.20**	**0.56**	0.24
SRH	0.32	**0.60**	0.08	0.25	**0.62**	0.13	0.18	0.59	0.24
TWLK	**0.34**	**0.61**	0.05	**0.21**	**0.70**	0.09	**0.08**	**0.76**	0.16
IADL	**0.34**	**0.59**	0.08	**0.24**	**0.64**	0.12	0.17	**0.64**	0.19
COG	0.27	0.69	0.04	0.18	**0.74**	0.08	0.07	**0.78**	0.15
BLK	**0.21**	**0.76**	0.04	**0.14**	**0.79**	0.07	**0.08**	**0.77**	0.15

responses. Despite these differences, most of the measures of successful aging performed in very similar ways with regard to their associations with age and gender.

4.2. Age Trends. Overall, the trends in prevalence suggest both high initial rates of health and consistent incremental declines in health with advancing age. First, the prevalence of emotional and functional health shown in Table 2 remained quite high, even at advanced ages. For instance, about 85% of 85–94-year-old individuals expressed the belief that life is worthwhile. Second, health declined with advancing age across all the domains: there were no areas that were spared the effects of aging. Some aspects declined more dramatically, especially the functional measures of cognition, timed walk, and blocks walked. In these domains, the proportion of participants who were healthy in the oldest group was less than half the proportion of who were healthy in the youngest group. Nevertheless, the majority of men and women aged 85–94 in this community cohort had no hospital days, no bed days, no ADL difficulties, were not depressed, had high self-rated health, and felt that life was worthwhile. These findings are a testament to overall successful aging among the old old and oldest old, and challenge stereotypes about the high prevalence of sickness and disability in these groups.

4.3. Prevalence and Incidence by Gender and Age. Men were observed to have a higher prevalence of a healthy state except for hospitalization and cognitive status. In Table 4, P(HtoS) is consistently higher for men than for women only for these domains of health; Table 3 shows smaller and less consistent differences in P(StoH). Most of the gender difference is thus driven by difference in incidence of sickness rather than difference in recovery from it. In other words, men seem to be healthier because they are less likely to transition *into* sick states, while men and women show roughly the same return to health. This implies an aging process for men in which the sickest persons are consistently removed by recovery or death, while for women the sickest persons are less likely to be removed. A different trend is seen for the age effects: with increasing age, the probability of staying healthy becomes lower than the probability of staying sick, which decreases the prevalence of health. Older adults are thus less healthy than younger adults mainly as a result of less likely recovery from sickness combined with higher probability of death. These findings may have some implications for disease prevention and treatment programs [37].

4.4. Patterns of Aging in Men and Women. We found several key differences in aging based on gender. Men died more often than women from a state of either sickness or health, remained more healthy than women while alive, and were more likely to recover from being sick. These differences were not characterized by similar transitions offset by a period of years, as might happen if men's health trajectories were simply premature or accelerated versions of women'strajectories. Comparing the adjacent age categories for men and women (for instance, 65–7-year-old men compared to 75–84-year-old women) shows that younger men's transitions were more similar to older women'stransitions than younger women's transitions to older men's transitions for 58 (60%) of the 96 possible comparisons. This is seen graphically for ADL status in Figure 2, where the transition probabilities for men are consistently higher for P(HtoH) but lower for P(StoH), and there is no transformation of the women's transitions (as by moving the lines for women to the left, or by compressing the curves) that would make them match those for men.

These results demonstrate qualitative differences in health transitions between men and women during aging, not just that men "age faster", as has been suggested [23]. If this had been the case, men would have developed sickness sooner than women, remained sick as much as women, and had equal likelihood of dying from a state of sickness as women. Not only was this effect not seen but also in many cases opposite effects were observed. The findings suggest that men may show more compression or squaring of mortality than women [38]. Put another way, the occurrence of sickness—regardless of the operational definition—does not seem to be the key intermediary which makes men die sooner than women, and no other factor associated with gender well accounts for this effect.

The observed differences in incidence and prevalence of health between men and women encourage speculation about their etiology in human gender dimorphism and argue for fundamental differences between how men and women age. Historical analyses suggest that the environmental pressures of infectious disease and resource availability have caused women to live longer [39]. Some research suggests that lower mortality among women could be attributable to a low-risk, healthy lifestyle [40, 41], or to lack of male hormones such as testosterone [42]. Other factors include the unequal distribution of chronic conditions, health behaviors like smoking, and differential effects of diseases on mortality [40]. Women may assess their health differently, for instance by applying different anchoring points to define sick and healthy states, or by being more willing to assume the sick role. [43, 44]. This latter possibility is supported by the fact that hospitalization and cognitive status, the only variables where women were healthier than men, are relatively objective measures. Nonetheless, timed walk, another objective measure of health, favored men. In order to understand the underlying factors behind these gender differences better, it might be useful to repeat these analyses using other variables, datasets, and age groups, with attention to differences in self-reported and performance measures.

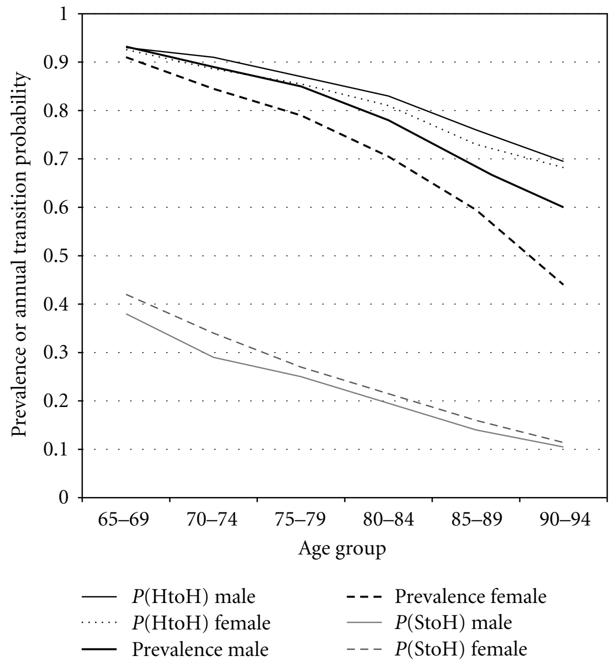

Figure 2: Prevalence, maintenance, and recovery for ADL Health by age and sex. The prevalence estimates are the proportion with no ADL difficulties. The transition probability estimates are the likelihoods of remaining healthy (P(HtoH)) and of returning to health (P(HtoS)) over one-year intervals.

4.5. Limitations. First, about one-tenth of the data were missing and had to be imputed. The ascertainment of death, however, was essentially complete. The approach we used for imputation, using interpolation and extrapolation, may have minimized changes by assuming that the missing health status was mainly consistent with the data before and after the missing measurement and declined close to death. There was no difference in missingness between men and women, and it is unlikely that this imputation method would intensify group differences. Second, the individual significance tests that are reported here should be considered as descriptive rather than definitive, due to the large number of comparisons that were made in this analysis. Third, the category of "healthy" in the various outcome measures should not be interpreted literally, since the cutoffs for healthy and sick states were assigned by categorizing each variable individually, and not by cross-validating them with other metrics for subjective or objective health. Most of the cutoffs have face validity as markers of health. Fourth, in the interests of generating straightforward descriptive results, we did not adjust for other patient-level health or sociodemographic characteristics which might confound the associations between age, gender, and health. Investigating these could help understand how men and women differ in the aging process.

5. Summary and Conclusion

Transition probabilities among various states of health during aging, and separately for men and women, are rarely reported in ways that can be compared. We calculated the gender-specific transition probabilities for 12 health-related variables across different domains of health and believe that these have utility for organizing future research and for characterizing the changes that happen during aging. In general, the 12 variables all behaved similarly. Recuperation from sickness declined with age, but still occurred frequently. Men and women experienced different types of change in health over time, with men showing more health and less sickness, but greater likelihood of dying. Men did not simply age faster compared to women. They exhibited a more "square" pattern of health status over time, with dropoff at younger ages than women. There is no simple explanation for the differences observed between men and women; they may partly relate to women's health-related behaviors or perceptions of health, or to more biologically fundamental gender dimorphisms. Future study can help to clarify how health is constructed and changes in different groups during aging.

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Research Article

Is There Successful Aging for Nonagenarians? The Vitality 90+ Study

Lily Nosraty,[1] Tytti Sarkeala,[2] Antti Hervonen,[1] and Marja Jylhä[1]

[1] *Gerontology Research Center and School of Health Sciences, 33014 University of Tampere, Tampere, Finland*
[2] *Finnish Cancer Registry, Institute of Statical and Epidemiological Cancer Research, Pieni Roobertinkatu 9, 00130 Helsinki, Finland*

Correspondence should be addressed to Lily Nosraty, lily.nosraty@uta.fi

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Objectives. This study was designed (1) to estimate the prevalence of successful aging among nonagenarians based on six different models and (2) to investigate whether successful aging is associated with socio-demographic factors. *Methods*. A mailed survey was conducted with people aged 90+ in Tampere in 2010. Responses were received from 1283 people. The prevalence of successful aging was measured by six multidimensional models including physical, social, and psychological components. Age, sex, marital status, level of education, and place of living were studied as factors associated with successful aging. *Results*. The prevalence of successful aging varied from 1.6% to 18.3% depending on the model applied. Successful aging was more prevalent in men, and also more prevalent among community-living people. In most models, successful aging was also associated with younger age, being married, and a higher level of education. *Discussion*. Models which emphasize the absence of disease and activity as criteria for successful aging may not be the most relevant and applicable in oldest old. Instead, preference should be given to models that focus more on autonomy, adaptation and sense of purpose. Age-sensitive approaches would help us better understand the potential of successful aging among individuals who already have success in longevity.

1. Introduction

Increasing longevity is one of the great achievements of our civilization, but it has also given rise to discussion about good and successful aging. The concept of successful aging has attracted much debate, but there is still no universally accepted definition or standard measurement tool for it. The Encyclopedia of Aging defines successful aging as survival (longevity), health (lack of disabilities), and life satisfaction (happiness) [1]. It appears that the main sources of difficulty lay in the ambiguity of the meaning of "success," in the complexity of the aging process, the rapid changes taking place in society, and the changing characteristics of the older population.

Discussions on successful aging have taken two main perspectives: one defines successful aging as a state of being, while the other understands it as a process of adaptation, described as doing the best with what one has [2]. Studies taking the adaptation approach have often found that older people themselves feel they are aging successfully, even though traditional quantitative models say otherwise [3, 4]. Successful aging as a state of being, then, is an objective measurable condition at a certain point in time, demonstrating the positive extreme of normal aging. The most influential model of successful aging as a state of being was introduced by Rowe and Kahn [5–8], who characterize "success" as absence of disease and disability, maintained physical and mental functioning, and active engagement with life. Many studies and definitions take the view that successful aging is possible only among individuals without disease and impairment. Obviously such categorizations are likely to exclude most older people, typically the oldest-old, from the possibility of successful aging [9].

Successful aging is of course impossible in the absence of aging. Still, according to Bowling [3], longevity is only rarely mentioned in lay or biomedical definitions. In studies using quantitative measures, younger age is one of the most regular predictors of successful aging [10, 11], and the rate of "success" drops dramatically in very old age. This may largely be due to the usual focus on physical deficits.

Indeed, several researchers have emphasized the need to use multidimensional models and to adopt different conceptual approaches to studying different age groups [3, 12]. Recently, Young et al. [13] suggested that successful aging may coexist with diseases and functional limitations if compensatory psychological and social mechanisms are used. Their model considers three important principles: the heterogeneity of aging, multiple pathways to successful aging, and individual compensation mechanisms to adjust for age-related changes.

The oldest-old group of nonagenarians meets the key biomedical criterion of successful aging that is longevity. They are also a rapidly growing age group that is heterogeneous in terms of health and functioning: a large majority have some health problems but are independent in basic everyday activities [14].

In this study, we investigate successful aging in an unselected population of nonagenarians, applying several different models that include physical, social, and psychological dimensions. The models differ with respect to the threshold for "success" on the physical, social, and psychological dimensions. Our aim is not to introduce an ideal or universal model, but rather to demonstrate the variation in the prevalence of successful aging by applying different criteria. The first objective of this study was to construct six different models of successful aging and to use these models to estimate the prevalence of successful aging among nonagenarians. The second objective was to investigate whether successful aging in nonagenarians, defined in several different ways, is associated with sociodemographic factors.

2. Methods

2.1. Data. The Vitality 90+ study is a population-based multidisciplinary research program on nonagenarians in the city of Tampere, Finland. In the context of this program, mailed surveys were conducted with all community-dwelling people in 1996 and 1998, and with both community-dwelling and institutionalized people four times since 2001. This study used the data from the mailed survey in 2010. A questionnaire was sent to all individuals aged 90 or over in Tampere ($N = 1630$). Responses were received from 1283 people, giving a response rate of 79%. Proxy responses were obtained from 22% of the subjects who were themselves unable to answer the questions. For additional 20%, the respondent chose the answers but someone else helped in reading the questions or writing down the answers.

The research protocol was approved by the City of Tampere Ethics Committee. Informed consent was obtained from all respondents or their legal representatives.

2.2. Independent Variables. We explored the associations of five sociodemographic factors with successful aging: age, sex, marital status, level of education, and place of living. Age was categorized into three groups: 90-91, 92-93, and 94–107. Marital status was classified as currently married and currently unmarried, including never married, divorced, and widowed. Education was categorized into four groups as low (no more than elementary schooling), middle (lower secondary school), high (vocational school, folk high school, or upper secondary school), and highest (college and academic education). Place of living was dichotomized as community (private and service housing) and institution (residential care, service housing with 24-hour assistance, and hospitals).

2.3. Components of Successful Aging. Our dependent variable was successful aging. It was described by six different models that were constructed using psychical, social, and psychological indicators.

The physical component included three elements: diseases, functioning, and senses. The participants were asked whether they had been told by a doctor that they had (1) a heart problem, (2) stroke, (3) circulatory problems in the brain, (4) diabetes, (5) arthritis, (6) Parkinson's diseases, (7) hip fracture, or (8) dementia or memory problems. For the measurement of functional ability, the participants were asked whether they were able to perform independently (a) three mobility activities: moving about indoors, walking 400 meters, using stairs and (b) two ADL activities: getting in and out of bed and dressing and undressing. The response options, (1) yes, without difficulty; (2) yes, with difficulty; (3) only with help; (4) not at all, were categorized as independent (1 + 2) and dependent (3 + 4). The participants were also asked whether they were able to read the newspaper, with glasses if they used glasses (vision), and to hear what another person was saying when they were alone with them, with hearing aid if they used a hearing aid (hearing).

The psychological component was described by three variables. The participants were asked whether they suffered from depression or had depressive feelings (yes, no). Present self-rated health was categorized as average or good (very good, fairly good, and average) and poor (fairly poor and poor). Self-rated health was included in the psychological components because it is a subjective measure with no predetermined criteria: it reflects not only the more objective components of health, but also and importantly the age-related way in which the individual adjusts and adapts to different health problems [15]. The participants were also asked whether they thought it was good for people to live to be 100 years (yes, no).

The social component was measured by two questions: the frequency of meetings with children (six categories from today or yesterday to several years ago) and the frequency of talking on the phone with family members or friends (six categories from today or yesterday to several years ago). One-fifth (20.1%) of the respondents had no children. If these participants had had telephone contacts during the past two weeks, they were categorized as having had contact with children.

The percentage of missing data varied between the different variables. The highest figures were recorded for two psychological variables. Part of the reason for this was that these questions were not asked of proxy respondents. Most of these participants lived in institutions and had multiple health problems. To avoid reducing the number of participants in the analyses, we categorized both proxy responses and other missing values in these two variables at the negative extreme (poor self-rated health and thinking

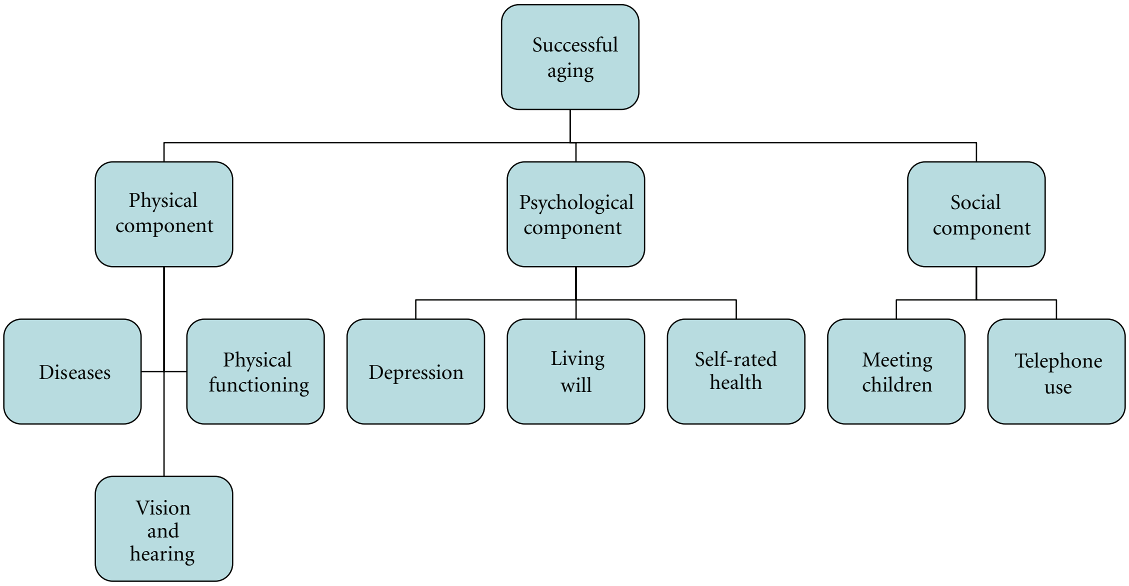

Figure 1: Three components of successful aging.

that it is not good to live to be 100). This imputation was done to avoid overestimation of the prevalence of successful aging, which would happen if the frailest participants were lost from the analyses.

2.4. Constructing Six Models of Successful Aging. Following Rowe and Kahn [6] and Young et al. [13], we defined successful aging as consisting of three components as shown in Figure 1. Six different models were constructed with different thresholds. The main differences between the models are in the physical component, where we defined four alternative criteria for "success," ranging from most to least demanding as follows:

Criterion 1: absence of disease + good vision and hearing + independence in all five activities.

Criterion 2: less than three diseases, no dementia, good vision and hearing, and independence in ADL and moving about indoors (independent in 3 easier activities).

Criterion 3: no dementia, good vision and hearing, and independence in all five activities.

Criterion 4: good vision and hearing, and independence in all five activities.

In the psychological component, "success" was defined as absence of depressiveness, average or good self-rated health, and agreement with the view that it is good to live to be 100. In the social component, "success" was defined as having met one's children and having talked on the phone with family members or friends during the past two weeks.

The six models of successful aging were constructed as follows:

Model 1: Physical component criterion 1 and psychological component & social component.

Model 2: Physical component criterion 2 and psychological component & social component.

Model 3: Physical component criterion 3 and psychological component & social component.

Model 4: Physical component criterion 4 and psychological component & social component.

Model 5: Physical component criterion 3 and psychological component.

Model 6: Physical component criterion 3 and social component.

2.5. Analysis. The prevalence of successful aging in different sociodemographic categories was compared by cross tabulation using the Chi-square test. Logistic regression models were used to assess the independent associations of different models of successful aging with sociodemographic factors. Odds ratios (ORs) and 95% confidence intervals (95% CI) were calculated. These analyses were performed using the SPSS Package 16.

3. Results

Most of the participants (85.9%) were under 95 years of age, and more than 80% were women. These figures well reflect the distributions in the general population. Only 12.1% were still married and 37.5% lived in an institution. The majority had no more than elementary schooling (Table 1). Heart problems, arthritis, and dementia were the most frequent diseases, and only 14.7% of men and 10.2% of women did not have any of the eight conditions listed in the questionnaire. Four in ten respondents were independent in all five activities, and seven in ten were independent in ADL and moving about indoors. According to different criteria, 5.3 to 25.2% were aging successfully if only the physical

Table 1: Population characteristics.

Characteristic	Frequency %
Age	(N = 1283)
90–91	44.5
92–93	25.5
94+	30.0
Gender	(N = 1283)
Women	81.2
Men	18.8
Marital status	(N = 1267, missing 16)
Unmarried	87.9
Married	12.1
Education	(N = 1234, missing 49)
Low	56.4
Middle	9.9
High	22.7
Higher	11.0
Place of living	(N = 1278, missing 5)
Community	62.5
Institution	37.5

component was considered. In the psychological component, the prevalence of successful aging was 20%, in the social component the figure was markedly higher at 75%. Men had better scores than women in both the physical component (most criteria) and the psychological component (Table 2).

The prevalence of successful aging varied between the six models (Table 3). It was lowest (1.6%) for Model 1, which required absence of all diseases, independence in all five activities, and good vision and hearing, in addition to the psychological and social components, and highest (18.3%) for Model 6, which differed from Model 1 in that diseases other than dementia were allowed, and the psychological component was not included. Successful aging was significantly more prevalent in men than women and among community-living than institutionalized individuals, regardless of the model. According to most models, successful aging was more frequent among those aged 90–93 than those aged 94+, among married people, and among those with a higher education.

Finally, logistic regression models were calculated to examine the independent association of different sociodemographic indicators with the six models of successful aging (Table 4).

In four models, higher age was independently associated with less successful aging. Gender was another predictive variable, and in all models except model 6, men were significantly more successful in aging than women. Higher education was a significant predictor in two models, and in Model 6 both those with a high and the highest educational level differed significantly from those with the lowest level of education. Marital status did not play an independent role, but place of living was a significant determinant of successful aging in all but Model 1.

4. Discussion

This paper examined one the most prominent concepts in aging research, successful aging, by constructing six different models to measure it among nonagenarians. The models were based on work by Rowe and Kahn, Rowe, and Young et al. [6–8, 13, 16], although not the exact same indicators were used. According to Young et al. [13] and Rowe and Khan [6], successful aging is typically understood as comprising three main domains: physical (in Young et al.: physiological), psychological, and social (in Young et al.: sociological). The results showed that the prevalence of successful aging varies markedly from one model to another, standing at 1.6% for Model 1 that required the absence of any disease, independence in functioning, and the ability to hear and read, as well as meeting the psychological and social criteria, and at 18.3% for Model 6, which required the absence of dementia, independence in functioning, the ability to hear and read, and meeting the social criteria. However, the main socioeconomic predictors remained largely the same across the models.

It is obvious that the absence of disease is the most demanding criterion for measuring successful aging. Disease and at least some functional deterioration are almost inevitable in very old age. Only 11% of the nonagenarians in our study had no major disease, and only 5.3% were both free of disease, able to hear and see, and independent in five daily activities (physical dimension criterion 1). Very few earlier studies have attempted to estimate the prevalence of successful aging in nonagenarians or in very old age in general. von Faber et al. [2] classified only 10% of community-dwelling and 1.9% of institutionalized participants aged 85 or over as successful agers. In the NonaSantfeliu study by Formiga et al. [17], the figure was 12% with community-dwelling nonagenarians. These studies emphasized the role of health and physical functioning, but also included some social or quality-of-life measures. It is clear that especially when the focus is on the physical dimension, successful aging will be very rare among people experiencing longevity.

Rowe and Kahn [6] included productive activities in their model of successful aging but these can hardly be expected from nonagenarians. Horgas et al. [18] showed that the daily activities of individuals aged 90 or over differed from other age groups, and in all categories this age group was engaged in significantly less activity than others. This implies that the social dimension of successful aging among the oldest old should be measured using different criteria and against different activities than in the case of the younger old and should be seen in relation to the situation of the best performers in the same age group.

In cross-sectional analysis, we limited our examination to socioeconomic predictors that at least potentially have played a role in the lives of the individuals for a longer time, and, with the exception of place of living, are not supposed to be influenced by factors that were thought to be components of successful aging. In most studies age has emerged as one of the strongest predictors of successful aging [18]. In our study, persons aged 94 or over were less likely to meet the successful aging criteria than the younger age groups. The difference

Table 2: Frequency (%) of the variables composing three components of successful aging in men and women.

Variables	Men (N = 226–238) %	Women (N = 1006–1038) %	P value	All (N = 1227–1283) %
Physical component				
No heart problem	42.4	47.1	0.192	46.2
No stroke	96.2	94.4	0.250	94.7
No circulatory problems in brain	78.6	79.3	0.798	79.2
No diabetes	85.7	88.8	0.178	88.2
No arthritis	69.7	54.3	<0.001	57.2
No Parkinson's disease	99.6	98.3	0.148	98.6
No hip fracture	89.2	81.3	0.003	82.8
No dementia	66.4	59.2	0.033	60.6
No disease	14.7	10.2	0.045	11.0
2 or less diseases with no dementia	39.5	29.8	0.004	31.6
Able to see	72.8	59.9	<0.001	62.3
Able to hear	68.1	71.5	0.299	70.9
Able to see and hear	53.2	48.2	0.170	49.2
Independent in five activities	58.3	34.9	<0.001	39.2
Independent in 3 easier activities	83.0	72.5	<0.001	74.5
Criterion 1*	7.7	4.8	<0.001	5.3
Criterion 2*	28.3	26.1	0.500	26.5
Criterion 3*	24.8	19.1	0.050	20.2
Criterion 4*	33.9	23.2	<0.001	25.2
Psychological				
No depressiveness	87.8	79.6	0.004	81.2
Self-rated health average or good	72.3	61.4	0.002	63.4
Willing to live up to 100 years	42.4	24.8	<0.001	28.1
Psychological component	34.0	16.7	<0.001	20.0
Social engagement				
Met children during past 2 weeks	92.7	93.5	0.644	93.4
Phone contacts	84.6	79.4	0.070	80.4
Social component	78.8	74.4	0.166	75.2

*Criterions. Criterion 1: No disease, and able to hear and read, and independent in all five activities. Criterion 2: Less than 3 diseases, no dementia, able to hear and read, and independent in three easier activities. Criterion 3: No dementia, able to hear and read, and independent in 5 activities. Criterion 4: Able to hear and read, independent in 5 activities.

Table 3: Prevalence of successful aging (%) according to the six models in different socioeconomic categories.

	Models of successful aging*					
	1	2	3	4	5	6
Total prevalence	1.6	6.3	5.7	6.8	6.3	18.3
Age						
90–91	1.9	7.9	6.5	7.5	7.5	23.8
92–93	2.5	6.8	7.1	8.6	7.7	21.2
94+	0.5	3.4	3.2	4.2	3.4	7.8
P value	0.104	0.021	0.042	0.048	0.022	<0.001
Gender						
Men	4.7	12.4	11.1	13.2	12.4	22.3
Women	1	5	4.5	5.5	5.1	17.5
P value	<0.001	<0.001	<0.001	<0.001	<0.001	0.095
Marital status						
Married	3.3	11.8	11.8	14.5	12.5	24.2
Not married	1.4	5.6	4.9	5.9	5.6	17.6
P value	0.095	0.003	0.001	<0.001	0.001	0.03
Place of living						
Community	2.3	8.4	7.6	9.1	8.2	25.9
Institution	0.6	2.9	2.5	3.1	2.5	6.1
P value	0.026	<0.001	<0.001	<0.001	<0.001	<0.001
Education						
Low	1.3	4.7	4.6	6	5.8	14.4
Middle	1.6	7.4	4.9	4.9	5.7	20.5
High	2.1	7.5	7.1	8.2	7.2	22.6
Higher	3	12.5	9.6	11.9	9.6	29.1
P value	0.51	0.005	0.093	0.058	0.377	<0.001

* Models of successful aging. Model 1. Health and functioning criterion 1 + psychological + social. Model 2. Health and functioning criterion 2 + psychological + social. Model 3. Health and functioning criterion 3 + psychological + social. Model 4. Health and functioning criterion 4 + psychological + social. Model 5. Health and functioning criterion 3 + psychological. Model 6. Health and functioning criterion 3 + social.

between the age groups was significant for all except Model 1, and it was greatest in Model 6 where the overall prevalence of successful aging was highest. After adjusting for other sociodemographic variables, a significant age difference still persisted in four models.

In our study, the prevalence of successful aging was consistently higher for men, and in all except the last model the differences were also significant after the adjustments. Earlier studies [10] show no consistent patterns of gender differences, but the results seem to be dependent on the model used. McLaughlin et al. [11] found no gender difference in prevalence, but higher odds of successful aging in women after controlling for sociodemographic variables. Our findings among nonagenarians are only partly explained by the high prevalence of disabilities and disease in women, as men had clearly better scores in the psychological component as well. These disparities are likely to reflect differential survival, lifelong differences in biological, health, and social conditions.

Marital status was associated with successful aging in unadjusted analysis but not in the adjusted models, where the uneven age and gender distribution of the variable was controlled for.

Education is known to have an impact on health and life style, and it reflects socioeconomic status; therefore, it can also be considered a potential predictor of successful aging. Most of the studies reviewed by Depp and Jeste [10] found no differences according to educational level, but the analysis by McLaughlin et al. [11] in the Health and Retirement Study showed that the prevalence of successful aging was higher in groups with a higher education and household income. The study of Pruchno et al. [19] revealed that a higher level of formal education is associated with successful aging. Our findings with an older group than in these studies showed a graded increase in the prevalence of successful aging with higher education, although the difference was not significant for all models. The discrepancy between the findings may at least partly be due to sampling bias. In several studies institutionalized people and those of lower social position were less likely to participate [10], while our study represents the whole age group in the region.

Place of living is not usually considered a predictor of successful aging and in many (but not all, see e.g., von Faber et al. [2]) studies samples only include community-dwelling individuals. In our study, we wanted to take account of the possibility of successful aging even in an institution.

Table 4: Associations of successful aging, according to the six models, with socioeconomic characteristics. A multivariate logistic regression model, all the predictors included in the model simultaneously. Odds ratios (OR) and 95% confidence intervals (CI).

	Models of successful aging					
	1	2	3	4	5	6
Age						
90–91	2.74 (0.59–12.76)	1.93 (0.99–3.78)	1.68 (0.83–3.4)	1.43 (0.76–2.66)	1.82 (0.93–3.57)	2.85 (1.81–4.49)
92–93	3.93 (0.82–18.89)	2.15 (1.02–4.53)	1.76 (0.91–3.42)	1.93 (1.0–3.73)	2.14 (1.05–4.40)	2.90 (1.79–4.73)
94+	1	1	1	1	1	1
Gender						
Men	1	1	1	1	1	1
Women	0.20 (0.07–0.54)	0.46 (0.26–0.82)	0.53 (0.29–0.96)	0.54 (0.31–0.94)	0.47 (0.27–0.83)	0.98 (0.06–1.50)
Marital status						
Unmarried	1	1	1	1	1	1
Married	0.85 (0.26–2.73)	1.17 (0.61–2.26)	1.60 (0.82–3.12)	1.71 (0.92– 3.16)	1.42 (0.74–2.7)	1.11 (0.69–1.81)
Education						
Low	1	1	1	1	1	1
Middle	1.64 (0.34–7.88)	1.77 (0.81–3.85)	1.16 (0.47–2.87)	0.89 (0.37–2.18)	1.10 (0.47–2.54)	1.57 (0.94–2.63)
High	1.14 (0.39–3.33)	1.28 (0.72–2.3)	1.23 (0.68–2.22)	1.10 (0.64–1.91)	0.95 (0.54–1.69)	1.45 (1.00–2.11)
Higher	1.35 (0.38–4.6)	2.03 (1.06–3.89)	1.48 (0.73–2.99)	1.45 (0.76–2.76)	1.14 (0.57–2.28)	2.00 (1.26–3.17)
Place of living						
Community	3.11 (0.89–10.8)	2.48 (1.36–4.53)	2.66 (1.39–5.05)	2.64 (1.48–4.72)	3.18 (1.68–6.0)	4.30 (2.83–6.53)
Institution	1	1	1	1	1	1

However, the results showed that the prevalence of successful aging was clearly lower for those living in institutions, and this was also true for the adjusted models. Our earlier analyses (not shown here) indicated that disease, disability, and problems with hearing and seeing are more prevalent in institutions, as is self-rated health, which partly explains this finding.

4.1. Strengths and Limitations. The major strength of this study is that it covers the whole population aged 90 or over in the area concerned, including institutionalized people as well as proxy responses. The response rate was high. Our earlier and ongoing analyses suggest that the information on health and functioning collected by mailed questionnaires among nonagenarians is sufficiently valid and reliable [20, 21]; particularly as for a majority for those suffering from dementia, the answers were given by a proxy respondent.

In order to gain a broad and thorough understanding of successful aging, we included both physical, psychological, and social components in our analyses. Unlike most other studies, we also included the ability to see and hear as an important contributing factor to independence and quality of life. The main limitations of our study have to do with the measures used to assess the social and psychological components. Our only information about meeting with other people concerned meetings with children; no data were available about other family members or friends. One fifth of the respondents had no children, and we decided to give them a positive score for social contacts if they had made or received any telephone calls during the past two weeks. One-fifth of our responses were from proxies, who were not asked about self-rated health or living to be 100. Therefore, we had a high percentage of missing or proxy answers to two questions regarding the psychological dimension of successful aging. In order not to overestimate the prevalence of successful aging, we scored this missing data and proxy answers as negative. These kinds of problems are unavoidable in unselected samples of very old people, but they nonetheless add some uncertainty to our findings. Another obvious limitation of our study is that we had no direct questions designed to capture our respondents' self-evaluations of their life.

4.2. Implications. Our study in a nonselected population of persons aged 90 or over supports earlier findings that the prevalence of successful aging is highly dependent on the model applied, but in every case successful aging is associated with age, gender, and socioeconomic status. However, it is apparent that with any model that defines successful aging as a state of being and that uses criteria commonly used for younger age groups, successful aging remains a rare situation among the oldest old. An increased likelihood of health and functional problems, often followed by reduced opportunities for active social engagement, is normative consequences of biological aging and typical of extreme longevity. Therefore, in very old age, rather than models emphasizing the absence of disease and activity, emphasis should be given to approaches focusing on autonomy, adaptation, and sense of purpose [3, 22, 23]. These age-sensitive approaches would help us better understand the potential of successful aging among those individuals who have already had success in longevity.

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Research Article

Sedentary Behavior and Physical Activity Are Independent Predictors of Successful Aging in Middle-Aged and Older Adults

Shilpa Dogra[1] and Liza Stathokostas[2]

[1] *School of Recreation Management and Kinesiology, Acadia University, Wolfville, NS, Canada B4P 2R6*
[2] *Centre for Activity and Aging, University of Western Ontario, London, ON, Canada N6G 2M3*

Correspondence should be addressed to Shilpa Dogra, shilpa.dogra@acadiau.ca

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Background. Sedentary behavior is emerging as an important risk factor for poor health. Physical activity has proven to be important in determining overall successful aging (SA) among older adults; however, no data exists on the influence of sedentary behavior on SA. The purpose of this analysis was to determine whether there is an association between sedentary behavior and successful aging, independent of physical activity levels. *Methods*. 9,478 older (M = 4,245; F = 5,233) and 10,060 middle-aged (M = 4.621; F = 5,439) adults from the Healthy Aging cycle of the Canadian Community Health Survey were analyzed. Multivariate logistic regressions were conducted with SA and its three components as outcomes while physical activity and sedentary behavior were entered as main exposures. *Results*. Among older adults, compared to those who were sedentary (4 hours or more/day), those who were moderately (2–4 hours/day) and least sedentary (<2 hours/day) were 38% (OR: 1.38; CI: 1.12–1.69) and 43% (OR: 1.43; CI: 1.23–1.67) more likely to age successfully, respectively. Among middle-aged adults, those who were least sedentary were 43% (OR: 1.43; CI: 1.25–1.63) more likely to age successfully. *Conclusions*. These novel findings suggest that sedentary activities are significantly associated with lower odds of SA among middle-aged and older adults, potentially in a dose-dependent manner.

1. Introduction

Recent research suggests that despite meeting the minimum physical activity recommendations, sitting for prolonged periods (i.e., sedentary behavior) can compromise the health of adults [1]. Literature has established that a physically inactive lifestyle and low levels of cardiorespiratory fitness lead to an increase in the risk of developing numerous chronic diseases as well as all-cause mortality [2]. Interestingly, sedentary behavior is emerging as a potentially important independent contributor to the relationship between lifestyle and health [3, 4].

Sedentary behavior is defined as any waking behavior characterized by an energy expenditure ≤1.5 METs and a sitting or reclining posture [5]. Accumulating evidence shows that, independent of physical activity levels, sedentary time is associated with an increased risk of cardiometabolic disease and all-cause mortality in children and adults [6–8]. Similar evidence is emerging for the older adult population. Katzmarzyk et al. [8] reported that all-cause death rates increased across daily sitting time categories in a dose-response manner in groups of adults under the age of 59 years and over 60 years. It has also been demonstrated that individuals greater than 60 years of age with metabolic syndrome spend a greater percentage of waking hours in sedentary time versus those with no metabolic disease [3]. Unfortunately, according to the 2007 Canadian Community Health Survey (CCHS), television viewing time increases steadily with age such that 36% of those aged from 55 to 64, 47% of adults from 65 to 74 years and 52% of adults 75 years and older spend 15 or more hours per week viewing television [6].

Beyond the influence on health, sedentary behavior may also influence overall successful aging (SA); a term used to represent the physical, psychological, and social success with which adults age. The relationship between physical activity and SA is already well established [9]. Unfortunately, there is limited data on the relationship between sedentary behavior and SA or the components of SA. There is also a dearth of data available on SA and physical activity in middle-aged adults. This information is critical as lifestyle behaviors have been shown to persist once they are developed [10–13]. For example, using a modified Rowe and Kahn [14] definition of SA, Sun et al. [15] showed that participants of the Nurse's Health Study surviving to age 70 who had higher levels of midlife physical activity had higher odds of "successful survival." Similarly, in a 17-year longitudinal study, Britton et al. [11] found early-life exercise (mean age 44 years) to be a predictor of SA (free from major disease, good physical and mental function). No data exists on the relationship between overall SA and sedentary behavior in middle-aged adults.

Recent reports indicate that 69% of waking hours of middle-aged and older adults are spent performing sedentary activities [16]. Given the strong relationship between physical activity and SA, an investigation between sedentary behavior and SA is warranted in this population. Clearly, if sedentary behavior is related to SA, middle-aged and older adult populations are at high risk of poor physical, psychological, and social health. The purpose of the present study therefore was to determine whether there is an association between sedentary behavior and SA, independent of physical activity, in a Canadian population of middle-aged and older adults.

2. Methods

2.1. Sample. The Healthy Aging cycle of the Canadian Community Health Survey (CCHS-HA) was used for the current analysis. The objective of the CCHS-HA is to provide information on SA, examine healthy aging from a multidisciplinary approach, examine the effects of lifestyle on age, and better understand the aging process in those aged 45 years and older. All data contained in this survey were self-reported and all participants provided informed consent prior to participation. The total sample size of the CCHS-HA is 30,865. For purposes of the current analysis the sample was restricted to those who had complete data for all variables of interest as outlined below ($n = 19{,}538$). Detailed information on data collection methods and data weighting can be found in the CCHS user guide [17].

2.2. Main Outcome. SA variables were created for all three components of SA, that is, physical, psychological, and sociological. Young et al. [18] recently outlined the required variables to assess each of the components of SA based on Rowe and Kahn's model of SA [14]. Each SA component for the current analysis was based on this outline within the limitations of the database.

2.2.1. Physical Component of SA. The physical component of SA generally includes both the presence of chronic disease and functional impairments; however, Strawbridge et al. [19] showed that SA is not dependent on the presence or absence of disease and that many older adults were being misclassified based on this variable. Recent evidence using data in the CCHS indicates that self-perceived health is a better indicator of physical activity levels than the presence of chronic disease [20]. As such, the current analysis limited the definition of physical SA to those with functional impairment only. Participants were classified as having no mobility problems, having a problem but not requiring any aids, requiring mechanical support, or requiring help from others or cannot walk as per their responses to five separate questions in the CCHS-HA. Those in the first two groups were categorized as aging successfully and those in the latter two groups were categorized as aging poorly.

2.2.2. Psychological Component of SA. As per Young et al. [18] the psychological component should include data on cognitive function, emotional vitality, and depression. The CCHS-HA collected data on all three of these variables. Using two questions participants were classified into one of six categories for cognitive function: (1) able to remember most things, think clearly, and solve day-to-day problems, (2) able to remember most things but have a little difficulty when trying to think and solve day-to-day problems, (3) somewhat forgetful but able to think clearly and solve day-to-day problems, (4) somewhat forgetful and have a little difficulty when trying to think or solve day-to-day problems, (5) very forgetful and have great difficulty when trying to think or solve day-to-day problems, or (6) unable to remember anything at all and unable to think or solve day-to-day problems. Emotional vitality was based on a single question which classified participants as either (1) happy and interested in life, (2) somewhat happy, (3) somewhat unhappy, (4) very unhappy, or (5) so unhappy that life is not worthwhile. Finally, depression was assessed using a single question on the presence or absence of depression. Those in the first three categories of cognitive function and the first 2 categories of emotional vitality who did not have depression were classified as aging successfully in the psychological domain; all other were classified as aging poorly.

2.2.3. Sociological Component of SA. Engagement with life, social support, and spirituality are the main variables used to assess the sociological component of SA. Unfortunately there were no data pertaining to spirituality in the CCHS-HA. Two variables were used to classify participants as aging successfully and aging poorly, sense of belonging to the local community and the loneliness scale. Sense of belonging was a single question that classified participants as very strong, somewhat strong, somewhat weak, or very weak. The loneliness scale was based on three items: lack of companionship, feeling left out, and feeling isolated. Participants responded with either hardly ever, sometimes, or often. These scores were summed to create the loneliness scale. Those who had a strong sense of belonging and a loneliness scale score of ≤ 6 were classified as aging successfully, all other were classified as aging poorly.

2.2.4. Overall SA. Those who were classified as aging successfully in the physical, psychological, and sociological domains were classified as aging successfully. All other were classified as aging poorly.

2.3. Main Exposures

2.3.1. Physical Activity. Unlike the other CCHS cycles, the CCHS-HA does not contain data on energy expenditure. The PA variable for the current analysis was therefore based on the number of hours the participant walked each week. Participants who spent 1 hour or more/day walking were classified as active, those who spent 30–60 minutes/day walking were classified as moderately active and those who spent <30 minutes/day walking were classified as inactive.

2.3.2. Sedentary Behavior. The number of hours spent sitting per day were used to classify participants as sedentary (4 hours or more/day), moderately sedentary (2–4 hours/day), or least sedentary (<2 hours/day).

2.4. Covariates. Middle-aged adults were those between the ages of 45 and 64 years, and older adults were those between the ages of 65 years and more. The CCHS-HA public access file does not contain age as a continuous variable for maintenance of confidentiality; therefore these data are presented in categories. Participants were classified as male or female based on self-reported biological sex. Marital status was categorized as either married/common-law, widowed/separated/divorced, or single/never married. Income was used as a proxy for socioeconomic status and was categorized as <20,000, \$20–39,000, \$40–59,000, \$60–79,000, or >\$80,000. These covariates were chosen based on previous literature [8, 19]. Marital status was additionally included as it is related to SA in older adults [20].

2.5. Statistical Analysis. Pearson chi-square analyses and standardized adjusted residuals that denote deviations from a normal distribution were [21] calculated to determine differences in all sample characteristics with the exception of age. Bivariate associations between each SA outcome and physical activity or sedentary behavior were conducted using logistic regression analysis for each sex and age group. Multivariate logistic regressions controlling for age, marital status, and income were conducted for each SA outcome with both physical activity and sedentary behavior entered in the model. These models were created for each sex and age group (middle-aged and older adults). All analyses were conducted using SPSS version 17.0 with statistical significance set at alpha < 0.05. In order to compensate for the deliberate over-sampling of particular groups, population weights supplied by Statistics Canada were applied to the entire dataset to ensure accurate population estimates. To estimate variance, the sample population weights were rescaled, standardized, and reapplied to the dataset.

3. Results

Sample characteristics are described in Table 1. Overall there were significant differences between older and middle-aged adults for all covariates investigated. Interestingly there were no differences between overall SA between age groups, nor were there for the psychological component of SA for either of both sexes combined or for females.

Bivariate associations (Table 2) indicated a consistent trend for both physical activity and sedentary behavior such that those who were active and moderately active were significantly more likely to be aging successfully compared to those who were inactive. Similarly, those who were moderately sedentary and least sedentary were significantly more likely to be aging successfully compared to those who were sedentary. This trend was true for both sexes combined and for males and females separately. Additionally, in most cases there was a dose-response relationship such that those who were active or least sedentary had greater odds of SA than those who were moderately active or moderately sedentary, respectively.

Regressions adjusted for age, income, and marital status showed similar trends as bivariate regression (Table 3). Compared to inactive older adults, moderately active and active older adults were 41% (OR: 1.41; CI: 1.19–1.67) and 42% (OR: 1.42; CI: 1.20–1.69) more likely to be aging successfully overall, respectively. Similarly, compared to sedentary older adults, moderately sedentary and least sedentary older adults were 38% (OR: 1.38; CI: 1.12–1.69) and 43% (OR: 1.43; CI: 1.23–1.67) more likely to be aging successfully overall, respectively. This was similar to the results seen in middle-aged adults except that moderately sedentary adults were not more likely to be aging successfully overall compared to sedentary adults (OR: 1.08; CI: 0.96–1.21).

4. Discussion

Using a sample of middle-aged and older adults from the CCHS-HA, we analyzed the relationship of SA with physical activity and sedentary behavior. Similar to previous research, we found that physical activity is strongly related to SA and each of its components. The novel findings of this study pertain to the association between sedentary behavior and SA. Our primary finding is that sedentary behavior is associated with SA such that those who spend less time in sedentary activities are more likely to age successfully, regardless of their physical activity levels. Our secondary finding is that the relationship between the physical component of SA with physical activity and sedentary behavior was stronger and occurred in a dose-response manner. Finally, for the psychological and sociological components of SA, it seems that sedentary behavior lasting <2 hours/day is required for SA. The present study is one of the first to highlight the adverse role of sedentary behavior in SA. These findings have implications for the development of sedentary guidelines for middle-aged and older adults.

Our finding that there is a strong association between physical activity and SA was as expected based on research pertaining to physical activity and SA. A direct association between SA and physical activity was noted by Baker et al. [9] using data from the CCHS (cycle 2.1, $n = 12{,}042$). They reported that only 11% of Canadians were aging successfully and that older adults who were physically active were 2.26 (estimate = 0.817, CI: 0.703–0.931) times more likely to

Table 1: Characteristics of the sample by age group and sex.

			Older adults			Middle-aged adults		
			Both sexes	Males	Females	Both sexes	Males	Females
	n (unweighted sample size)		9,478	4,245	5,233	10,060	4,621	5,439
Age	65–69 y	45–49 y	26.9	30.1	24.5	26.6	25.1	28.0
	70–74 y	50–54 y	19.8	21.2	18.6	30.8	34.3	27.5
	75–79 y	55–59 y	17.2	16.9	17.4	22.2	20.9	23.4
	80–84 y	60–64 y	12.8	9.9	15.0	20.4	19.6	21.0
	>80 y		23.3	21.8	24.4			
Income	>$20,000		24.1	13.7	32.2	8.3*	7.1*	9.5*
	$20,000–39,000		37.8	37.9	37.7	13.4*	11.3*	15.4*
	$40,000–59,000		18.3	21.3	15.9	17.2	15.5*	18.9*
	$60,000–79,000		8.9	11.1	7.2	18.6*	18.6*	18.7*
	>$80,000		10.9	16.0	7.0	42.4*	47.5*	37.5*
Marital status	Married/common law		48.7	67.0	34.4	74.9*	78.3*	71.8*
	Widowed		38.0	19.7	52.3	3.5*	1.5*	5.3*
	Separated/divorced		8.4	8.0	8.7	12.7*	10.6*	14.6*
	Single/never married		4.9	5.2	4.6	8.9*	9.6*	8.3*
Physical activity levels	Active		33.3	36.4	30.9	39.3*	42.7*	36.2*
	Moderately active		35.3	35.6	35.2	37.9*	35.7	40.1*
	Inactive		31.3	28.0	33.9	22.7*	21.6*	23.8*
Sedentary behaviour	Least sedentary		14.9	15.7	14.3	25.2*	25.6*	24.9*
	Moderately sedentary		33.8	34.4	33.3	34.0	33.2	34.7
	Sedentary		51.3	49.9	52.4	40.8*	41.2*	40.4*
	Overall SA		56.8	58.0	55.8	56.9	58.1	55.6
	Physical SA		87.6	90.4	85.5	98.4*	98.8*	98.1*
	Psychological SA		85.3	84.9	85.7	86.6	89.2*	84.1
	Sociological SA		70.5	70.8	70.2	63.2*	63.3*	63.2*

* significant differences between older and middle-aged adults within sex category.
n: sample size; SA: successful aging.
All data are weighted unless otherwise stated.
All data are a percent of the sample.

age successfully compared to those who were physically inactive. In a follow-up study, Meisner et al. [21] showed that physical activity influences each component of SA, such that greater levels of physical inactivity were associated with an increased likelihood of reporting disease and disablement, low functional capacities, and being socially disengaged with life. While the results of these two studies imply that sedentary behavior would be associated with SA, no specific analyses to this effect were conducted. A study published by Ko et al. [22] showed that engaging in a greater number of activities (physical and nonphysical in nature) was significantly associated with several indicators of SA. Therefore this study shows that those who did not engage in activities (i.e., sedentary individuals) were less likely to age successfully. This is in direct line with the findings of our study.

Physical activity is an established determinant of SA [23]. Moreover, the master athlete has been suggested as a model of SA given that this group of middle-aged and older adults is healthier and has a better quality of life than age-matched peers [24]. It is not surprising then that the strongest association in our study was found between sedentary behavior and the physical component of SA, that is, functional limitations. Several studies have shown that functional dependence is more likely to develop in older adults who are not physically active, or who were not physically active in middle age. Patel et al. [25] found that sedentary behavior in middle age had a significant impact on functional autonomy in older age using a population-based study. Similarly, Huang et al. [26] showed that middle-aged adults who were physically active and fit were less likely to have functional impairments in older age. These studies support our findings that middle-aged and older adults who were physically active and not sedentary were most likely to be aging successfully in the physical domain, that is, to maintain functional autonomy.

In addition to a strong association between the physical component of SA and sedentary behavior, we also noted a dose-response relationship, that is, less time spent in sedentary activities was associated with higher odds of SA. In a recent review conducted on physical activity and functional limitations, a similar dose-response relationship was displayed such that those with higher levels of physical activity were less likely to develop functional limitations as compared to a sedentary group [27]. Spirduso and Cronin

Table 2: Bivariate associations of successful aging with physical activity and sedentary behaviour.

		Older adults						Middle-aged adults					
Overall SA		Both sexes		Males		Females		Both sexes		Males		Females	
		OR	CI	OR	CI	OR	CI	OR	CI	OR	CI	OR	CI
Physical activity	Inactive	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.
	Moderately active	1.60	1.36–1.89	1.34	1.08–1.57	1.39	1.16–1.67	1.37	1.20–1.56	1.34	1.08–1.57	1.39	1.16–1.67
	Active	1.69	1.43–1.99	1.30	1.08–1.57	1.58	1.31–1.90	1.44	1.27–1.65	1.30	1.08–1.57	1.58	1.31–1.90
Sedentary behaviour	Sedentary	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.
	Moderately sedentary	1.58	1.36–1.84	0.91	0.77–1.07	1.31	1.11–1.54	1.09	0.97–1.23	0.91	0.77–1.07	1.31	1.11–1.54
	Least sedentary	1.60	1.31–1.95	1.22	1.02–1.46	1.63	1.36–1.94	1.41	1.24–1.61	1.22	1.02–1.46	1.63	1.36–1.94
		Older adults						Middle-aged adults					
Physical SA		Both sexes		Males		Females		Both sexes		Males		Females	
		OR	CI	OR	CI	OR	CI	OR	CI	OR	CI	OR	CI
Physical activity	Inactive	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.
	Moderately active	2.64	1.66–4.17	3.22	1.51–6.84	2.34	1.30–4.19	2.64	1.66–4.17	3.22	1.51–6.84	2.34	1.30–4.19
	Active	4.03	2.4–6.78	5.81	2.44–13.86	3.07	1.60–5.90	4.03	2.4–6.78	5.81	2.44–13.86	3.07	1.60–5.90
Sedentary behaviour	Sedentary	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.
	Moderately sedentary	1.91	1.20–3.05	2.83	1.19–6.73	1.61	0.92–2.82	1.91	1.20–3.05	2.83	1.19–6.73	1.61	0.92–2.82
	Least sedentary	2.61	1.45–4.68	1.90	0.83–4.34	3.44	1.48–7.97	2.61	1.45–4.68	1.90	0.83–4.34	3.44	1.48–7.97
		Older adults						Middle-aged adults					
Psychological SA		Both sexes		Males		Females		Both sexes		Males		Females	
		OR	CI	OR	CI	OR	CI	OR	CI	OR	CI	OR	CI
Physical activity	Inactive	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.
	Moderately active	1.47	1.23–1.75	1.30	0.98–1.72	1.59	1.27–200	1.47	1.23–1.75	1.30	0.98–1.72	1.59	1.27–200
	Active	2.18	1.81–2.63	2.13	1.58–2.86	2.13	1.66–2.72	2.18	1.81–2.63	2.13	1.58–2.86	2.13	1.66–2.72
Sedentary behaviour	Sedentary	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.
	Moderately sedentary	1.08	0.92–1.27	0.90	0.69–1.97	1.24	1.00–1.53	1.08	0.92–1.27	0.90	0.69–1.97	1.24	1.00–1.53
	Least sedentary	1.53	1.26–1.86	1.44	1.06–1.97	1.59	1.24–2.05	1.53	1.26–1.86	1.44	1.06–1.97	1.59	1.24–2.05
		Older adults						Middle-aged adults					
Sociological SA		Both sexes		Males		Females		Both sexes		Males		Females	
		OR	CI	OR	CI	OR	CI	OR	CI	OR	CI	OR	CI
Physical activity	Inactive	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.
	Moderately active	1.32	1.15–1.51	1.19	0.98–1.46	1.44	1.20–1.73	1.32	1.15–1.51	1.19	0.98–1.46	1.44	1.20–1.73
	Active	1.32	1.15–1.51	1.14	0.94–1.38	1.51	1.25–1.83	1.32	1.15–1.51	1.14	0.94–1.38	1.51	1.25–1.83
Sedentary behaviour	Sedentary	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.
	Moderately sedentary	1.03	0.92–1.16	0.89	0.75–1.05	1.19	1.01–1.41	1.03	0.92–1.16	0.89	0.75–1.05	1.19	1.01–1.41
	Least sedentary	1.37	1.20–1.56	1.25	1.03–1.51	1.50	1.24–1.80	1.37	1.20–1.56	1.25	1.03–1.51	1.50	1.24–1.80

SA: successful aging; OR: odds ratio; CI: confidence interval.

Table 3: Adjusted regressions of successful aging with physical activity and sedentary behaviour.

		Older adults						Middle-aged adults					
Overall SA		Both sexes		Males		Females		Both sexes		Males		Females	
		OR	CI	OR	CI	OR	CI	OR	CI	OR	CI	OR	CI
Physical activity	Inactive	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.
	Moderately active	1.41*	1.19–1.67	1.62*	1.24–2.10	1.27*	1.02–1.58	1.35*	1.18–1.54	1.36*	1.11–1.66	1.33*	1.10–1.59
	Active	1.42*	1.20–1.69	1.57*	1.21–2.05	1.33*	1.06–1.68	1.45*	1.27–1.66	1.35*	1.12–1.64	1.54*	1.28–1.86
Sedentary behaviour	Sedentary	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.
	Moderately sedentary	1.38*	1.12–1.69	1.36*	1.08–1.72	1.49*	1.22–1.83	1.08	0.96–1.21	0.90	0.76–1.07	1.27*	1.08–1.50
	Least sedentary	1.43*	1.23–1.67	1.20	0.88–1.62	1.56*	1.18–2.07	1.43*	1.25–1.63	1.23*	1.01–1.48	1.65*	1.37–1.98
		Older adults						Middle-aged adults					
Physical SA		Both sexes		Males		Females		Both sexes		Males		Females	
		OR	CI	OR	CI	OR	CI	OR	CI	OR	CI	OR	CI
Physical activity	Inactive	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.
	Moderately active	1.62*	1.26–1.08	1.65*	1.09–2.51	1.61*	1.18–2.21	2.46*	1.53–3.94	2.90*	1.34–6.30	2.24*	1.35–7.55
	Active	1.80*	1.37–2.37	1.96*	1.25–3.07	1.75*	1.24–2.48	3.87*	2.28–6.58	5.63*	2.33–13.63	3.18*	1.62–6.22
Sedentary behaviour	Sedentary	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.
	Moderately sedentary	1.75*	1.37–2.24	1.85*	1.22–2.79	1.69*	1.24–2.31	1.68*	1.04–2.72	2.28	0.93–5.56	1.50	0.84–2.66
	Least sedentary	2.44*	1.64–3.65	2.48*	1.28–4.79	2.45*	1.47–4.07	2.15*	1.18–3.92	1.27*	0.54–3.02	3.20*	1.62–6.22
		Older adults						Middle-aged adults					
Psychological SA		Both sexes		Males		Females		Both sexes		Males		Females	
		OR	CI	OR	CI	OR	CI	OR	CI	OR	CI	OR	CI
Physical activity	Inactive	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.
	Moderately active	1.53*	1.22–1.91	1.96*	1.40–2.76	1.26	0.93–1.70	1.40*	1.17–1.68	1.27	0.95–1.71	1.46*	1.15–1.85
	Active	1.74*	1.37–2.21	2.47*	1.73–3.54	1.33	0.96–1.83	2.16*	1.78–2.63	2.29*	1.69–3.12	2.03*	1.58–2.62
Sedentary behaviour	Sedentary	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.
	Moderately sedentary	1.08	0.82–1.44	1.03	0.75–1.42	1.40*	1.05–1.88	1.02	0.86–1.21	0.82	0.62–1.07	1.15	0.92–1.44
	Least sedentary	1.21	0.98–1.50	0.89	0.59–1.35	1.28	0.86–1.91	1.51*	1.23–1.85	1.30*	0.94–1.80	1.60*	1.23–2.08
		Older adults						Middle-aged adults					
Sociological SA		Both sexes		Males		Females		Both sexes		Males		Females	
		OR	CI	OR	CI	OR	CI	OR	CI	OR	CI	OR	CI
Physical activity	Inactive	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.
	Moderately active	1.19*	1.00–1.43	1.30	0.98–1.72	1.11	0.88–1.40	1.30*	1.14–1.49	1.21	0.99–1.48	1.39*	1.15–1.67
	Active	1.21*	1.01–1.46	1.23	0.93–1.63	1.21	0.94–1.55	1.33*	1.16–1.52	1.17	0.96–1.43	1.49*	1.23–1.80
Sedentary behaviour	Sedentary	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.	1.00	Ref.
	Moderately sedentary	1.32*	1.12–1.56	1.17	0.85–1.62	1.30*	1.04–1.61	1.03	0.91–1.16	0.90	0.76–1.08	1.17	0.99–1.38
	Least sedentary	1.25*	1.00–1.55	1.35*	1.05–1.74	1.32	0.98–1.78	1.39*	1.22–1.59	1.28*	1.05–1.55	1.52*	1.26–1.84

SA: successful aging; OR: odds ratio; CI: confidence interval.
Adjusted for age, marital status, and income.

[28] conducted a review on the effect of the exercise dose response on SA using functional autonomy as a main outcome. The authors found that long-term physical activity was closely related to delaying disability and independent living in older adults. They also found that evidence for a dose response or a "threshold" between physical activity and physical functioning exists. It is difficult to assess a true dose response in the current analysis given the categorical nature of the variables in the data set. Whether there is indeed a threshold or a dose-response relationship should be determined in the future in order to develop optimal sedentary guidelines.

The possibility of a threshold for sedentary behavior was also observed for the psychological and sociological components of SA. Among older adults, the psychological component was not influenced by sedentary behavior whereas the sociological component was only influenced by sedentary behavior lasting less than two hours. Among the middle-aged adults, only those who were sedentary for less than two hours per day were more likely to age successfully, that is, those engaging in sedentary activities for 2–4 hours per day were not more likely to age successfully in these domains than those sedentary for 4 hours or more per day. In other words, less than two hours of sedentary activity per day may serve as a minimum duration (threshold) that must be achieved in order to age successfully in these two domains. This idea of a dose-dependent relationship or a threshold has been assessed in studies using physical inactivity and the psychological component of SA. Pietrelli et al. [29] found a dose-dependent effect of exercise on cognitive function and anxiety in an animal study using aerobic exercise in middle-aged and older rats. In the area of depression, a recent randomized control trial among adults aged 18–70 with depression found that the group who was assigned a higher dose of exercise had greater benefit than a group assigned a lower dose of exercise; however, both had clinically meaningful improvements with exercise participation [30]. There are also cross-sectional studies on the relationship between sedentary behavior and depression or hopelessness that support our findings. de Wit et al. [31] found that those who had depression and anxiety disorders were more likely to engage in sedentary activities such as television watching and computer use in a sample of adults aged 18–65. Similarly, among a group of middle-aged men, a negative association between engaging in physical activity and developing hopelessness was found such that those who engaged in higher volumes of physical activity were less likely to develop feelings of hopelessness [32]. With regards to the sociological component of SA, factors such as satisfaction with life [33], sense of belonging to community [34], and loneliness [35] are associated with physical inactivity, but again, little data exist on sedentary behavior. Future research should assess the dose-response relationship between sedentary activity and each component of SA. Furthermore, a consensus on the definition of SA should be reached.

4.1. Limitations. The current analysis has two limitations that are noteworthy. First, the CCHS-HA uses self-reported data; as such it is difficult to truly know how much time participants were spending in sedentary activities or being physically active. Therefore some participants may have been misclassified. Social desirability would dictate that physical activity was overreported and sedentary behavior was underreported. Given the broad categories used in the current analysis, it is less likely that such misclassification occurred. Second, the CCHS is a cross-sectional data set, so reverse causality cannot be ruled out. In other words, it cannot be said with certainty that sedentary behavior is causing poor outcomes as it is possible that poor outcomes are leading to sedentary lifestyles.

In conclusion, using a large database of middle-aged and older adults we found that similar to previous research, physical activity is strongly associated with SA. The novel finding of the current study is that sedentary behavior is significantly associated with lower odds of SA independent of physical activity levels, that is, sedentary behavior and physical activity may be independent risk factors for poor health among aging populations. We also found evidence for a dose-dependent relationship between sedentary behavior and each of the components of SA. Results of the present analysis are novel and have implications for the development of sedentary guidelines for middle-aged and older adults.

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Research Article

The Older They Are, the Less Successful They Become? Findings from the Georgia Centenarian Study

Jinmyoung Cho,[1,2] Peter Martin,[3] and Leonard W. Poon[4]

[1] *Center for Applied Health Research, Scott and White Healthcare, Temple, TX 76508, USA*
[2] *School of Rural Public Health, Texas A&M Health Science Center, College Station, TX 77845, USA*
[3] *Human Development and Family Studies, Iowa State University, Ames, IA 50011, USA*
[4] *Institute of Gerontology, University of Georgia, Athens, GA 30602, USA*

Correspondence should be addressed to Jinmyoung Cho, chojm85@gmail.com

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This study examined whether oldest-old adults are successful agers. Three hundred and six octogenarians and centenarians of Phase III of the Georgia Centenarian Study participated in this study. A first model examined Rowe and Kahn's successful aging model (Rowe and Khan (1997 and 1998)) including the probability of disease, physical or cognitive capacity, and engagement with life. All three components were applied to assess how many oldest-old adults satisfied all three criteria. The result showed about 15% of octogenarians (15.1%), and none of centenarians satisfied all three components of successful aging. Consequently, a second alternative model focused on psychosocial aspects including three different components: subjective health, perceived economic status, and happiness. Different from Rowe and Kahn's successful aging model, a total of 62.3% of octogenarians and 47.5% of centenarians satisfied all three components of the alternative model of successful aging. The results suggest that additional criteria of successful aging should be considered thereby expanding the concepts and multidimensional aspects of successful aging among oldest-old adults.

1. Introduction

There is an oriental word—"*bullojangsaeng*"—which means physical immortality or external life in several Asian countries (e.g., Korea). The desire to live longer and healthy has been an aspiration of humankind for all ages and in all countries. The advancement of science has resulted in lower mortality. A consequence of lower mortality in the United States from 17.2 to 8.2 per 1,000 population and increases in life expectancy from 47 years in 1900 to 74 for men and 79 years for women [1] is that most people in the United States can expect to live longer. As the population of centenarians, another important segment of the older population, is expected to grow from 37,000 in 1990 to 850,000 in 2050 [2], it is important for oldest-old adults to understand successful aging when compared to relatively younger old adults. Even though increased longevity has been achieved, it is not clear whether increasing longevity is directly connected with successful aging.

Since Rowe and Kahn [3, 4] proposed three indicators for successful aging (i.e., low probability of disease and disease-related disability, high cognitive and physical functional capacity, and active engagement with life), a number of studies have conceptualized successful aging indicators and examined older adults as successful agers based on the three criteria. However, many older adults have rarely satisfied these criteria because of the presence of disabilities and chronic diseases [5–8]. Moreover, oldest-old adults may easily fail to be categorized as successful agers when these criteria are applied. Kahn admitted that successful aging models should be complementary with other models [9], and successful aging model should encompass the criteria especially for oldest-old adults. For example, subjective health has been significantly correlated with functioning and mortality among oldest-old adults [10–14]. As subjective health has been generally viewed as a comprehensive single indicator of successful aging [15, 16], it is included as an alternative criterion instead of the physical health component of successful aging models in this study.

Several critical viewpoints of Rowe and Kahn's model have also suggested alternative indicators for successful aging models. George [17], for example, argued that the components of successful aging primarily focus on physical aspects and addressed an important question: "Is an older adult successfully aging if he/she is disability-free, physically and cognitive intact, and generally active, but rates the quality of life as poor or not good?" [17, page 322]. Although the majority of successful aging studies have included physical aspect as an essential factor for successful aging, psychological factors including emotional well-being have been identified as significant factors, especially in studies including very old adults [18, 19]. Thus, happiness, as a construct of life satisfaction or quality of life, in this study included "achievement of successful adaptation and expert survivorship in aging" ([13, page 3] and [20]).

Furthermore, Rowe and Kahn [3, 4] overlooked important aspects of aging such as financial resources, which directly or indirectly influence later life such as access to attain services for basic needs, physical health, living arrangement, and quality of life [21–25]. Since many oldest-old adults rely on family members' assistance, Social Security benefits, and the Medicaid program [26], perception or satisfaction of economic status may explain overall quality of life among older adults instead of objective income measures [27, 28].

The purpose of this study is to investigate Rowe and Kahn's [3, 4] "successful aging" model using data from the Georgia Centenarian Study. The overall objectives are to explore whether oldest-old adults are successful agers or not, to explore whether oldest-old adults are satisfied based on the criteria of successful aging, and to expand the psychological concept of successful aging among oldest-old adults. The following research questions are examined.

(1) Will oldest-old adults satisfy the components of successful aging (i.e., physical health, cognitive/physical functioning, and engagement with life)?

(2) Based on previous research, will oldest-old adults satisfy alternative criteria of successful aging (i.e., subjective health, financial resources, and happiness)?

2. Methods

2.1. Participants. As discussed in our previous work [29], the sampling frame of the Georgia Centenarian Study (GCS, Phase III) [30], which provides data for this study, had two components. The first one was to identify the proportion of all residents of skilled nursing facilities (SNFs) and personal care homes (PCHs) in a 44-county area in northern Georgia. Based on census proportions, the project recruited residents of SNFs and PCHs as well as community-dwelling residents. A second recruiting strategy was to use date-of-birth information in voter registration files. Based on these two components and five different characteristics (geographic, age, gender, ethnicity, and type of residence) a sample of octogenarians and centenarians was drawn for this study [30]. Information was collected through four sequential sessions, and information regarding resources and adaptation of older adults was the focus of this study.

Among 375 octogenarians and centenarians, three hundred and six participants (72 octogenarians and 234 centenarians) were left due to missing data and several proxies who had marginal mental status scores (proxy's MMSE $<$ 23). The majority of octogenarians (69.4%) and centenarians (82.5%) were female. Over two-thirds of octogenarians (86.6%) lived in their own homes, whereas less than half of the centenarians (45.5%) lived in their own homes. As expected, most participants were widowed (centenarians: 86.3% and octogenarians: 53.7%). More octogenarians had an education beyond a high school degree than centenarians (octogenarians: 59.6% and centenarians: 40.4%). More octogenarians (86.1%) had high levels (MMSE $\geq$ 23) of cognition status functioning than centenarians (32.7%). In addition, in terms of the excluded 69 participants' information, they had similar characteristics when compared with samples used in this study. Most of them were female (73.9%), Caucasians (78.3%), widowed (77.9%), and over half of them (52.2%) lived in private home/apartments. There was no significant difference between the excluded and the remaining sample in mental status. A summary of demographic characteristics of the remaining sample of 306 can be found in Table 1.

2.2. Measures of Rowe and Kahn's Successful Aging Model. The criteria suggested by Rowe and Kahn [3, 4] were applied to oldest-old adults and included low probability of disease, physical or cognitive capacity, and engagement with life. Even though there is little agreement about the operationalization and definition of successful aging nor its measurement [31–34], each definition will follow the most often used operationalization as reviewed by Depp and Jeste [16]. Furthermore, the data used in this study were collected from proxy informants. It is not always easy nor feasible to obtain information from oldest-old adults. Many studies have shown a significant relationship between self and proxies or between self and physicians' reports [35] and that there was no potential bias such as disagreements between proxies and participants [36–40] or mean differences on mental health ratings between proxies and participants [41]. Therefore, we included data from proxy informants for several measures in this study.

2.2.1. Low Probability of Disease. Rowe and Kahn [3, 4] defined "probability of disease" not only as the absence or presence of disease itself but also the absence, presence, or severity of risk factors for disease. Following this definition and based on Strawbridge et al. [8], absence of congestive heart failure, cancer, high blood pressure, Parkinson's disease, chronic pulmonary disease, and diabetes mellitus was used for low probability of disease. The reports were used based on centenarians' reports, proxy reports, medical reports, care facility's reports, or other available resources for best available information.

Table 1: Summary of semographic characteristics.

Demographic characteristics	Octogenarians (n = 72) n	%	Centenarians (n = 234) n	%	χ^2
Gender					5.72*
Female	50	69.4	193	82.5	
Male	22	30.6	41	17.5	
Type of residence					35.52***
Private home/Apartment	58	86.6	97	45.5	
Personal care (Assisted Living)	1	1.5	41	19.2	
Nursing home	8	11.9	75	35.2	
Ethnicity					2.02
White/Caucasian	61	84.7	179	76.5	
Black/African American	11	15.3	55	23.5	
Education					22.58**
0–4 years	1	1.5	11	4.9	
5–8 years	2	3.0	53	23.8	
Some high school	6	9.0	26	11.7	
High school diploma	18	26.9	43	19.3	
Trade school or vocational degree	8	11.9	28	12.6	
Some college	9	13.4	22	9.9	
College degree	13	19.4	19	8.5	
Graduate degree	10	14.9	21	9.4	
Marital status					54.15***
Never married	1	1.5	9	4.3	
Married	26	38.8	10	4.7	
Widowed	36	53.7	182	86.3	
Divorced	4	6.0	9	4.3	
Separated	0	0.0	1	0.5	
Cognitive status					63.59***
Low (MMSE ≤ 17)	9	12.5	112	48.3	
Mid (18 ≤ MMSE ≤ 22)	1	1.4	44	19.0	
High (MMSE ≥ 23)	62	86.1	76	32.7	

*$P < 0.05$. **$P < 0.01$. ***$P < 0.001$.

2.2.2. High Cognitive/Physical Capacity. As the second component of successful aging, physical/cognitive capacity was defined as potential for activities [3, 4]. *Physical capacity* was examined with instrumental activities of daily living (IADLs; seven items), and physical activities of daily living (PADLs; seven items) comprise the self-care capacity assessment [42] with coefficient $\alpha = .92$ and $\alpha = .88$, respectively. In addition, internal consistency of all 14 items was $\alpha = 0.94$. All 14 items were scaled so that 2 = without help (e.g., can clean floors, etc.); 1 = with some help (e.g., can prepare some things but unable to cook full meals yourself); or 0 = completely unable to prepare any meals. Those who had no help with PADL were coded as high physical capacity (= 1), and the remains were coded as low physical capacity (= 0) [43]. *Cognitive capacity* was examined with the Mini-Mental Status Examination (MMSE) [44]. The MMSE is commonly used for evaluation of cognitive impairment. The MMSE is composed of five sections: orientation, registration, attention and calculation, recall, and language. The reliability is 0.98 for older adults, and concurrent validity with the Wechsler Adult Intelligence Scale was 0.78 in the original study [44]. The performance ranged from 0 to 30, and the thirty items yielded a reliability of $\alpha = 0.87$ for this study. MMSE scores of 23 or higher were coded as high cognitive capacity (= 1), and the remaining scores were coded as low cognitive capacity (= 0) [45]. Taking high physical capacity and high cognitive capacity together was used as the second definition of Rowe and Kahn's model in this study [19].

2.2.3. Active Engagement with Life. Engagement with life, the final component of successful aging, was defined as interpersonal relations and productive activities [3, 4]. Active engagement with life was examined with two constructs, interpersonal relations and productive activity. For interpersonal relations, two questions of social support developed by Fillenbaum [42] were used: "How many people do you know well enough to visit with in his/her home or in their homes?" and "About how many times did you talk to someone—friends, relatives, or others on the telephone in the past week?" Those who had been spending time with family and/or friends at least once a week and having three or more people to visit were coded as active interpersonal relations (= 1), and the remaining were coded as inactive relations (= 0) [6]. For productive activity, experience of volunteer work was coded as "1" and the remaining were coded as "0" [46]. Both interpersonal relations and productive activity were considered together.

2.3. Measures of Alternative Successful Aging Model. The criteria for alternative successful aging model follow the most frequently used operationalization as reviewed by Depp and Jeste [16] as well.

2.3.1. Subjective Health. Subjective health was used as a criterion instead of low probability of disease. Health status rated as either "good" or "excellent" was coded as good health (= 1) and "fair" or "poor" was coded as poor health (= 0) [47].

2.3.2. Perceived Economic Status. Perceived economic status, which was neglected by Rowe and Kahn [3, 4], was included. Perceived economic status was measured with three items: the capacity to meet emergencies, to take care of needs, and to buy small luxuries [42]. Among the three items, those who were able to meet emergencies, to buy small luxuries, and to take care of needs fairly or very well were coded as better economic status (= 1), and the remaining were coded as poor status (= 0).

2.3.3. Happiness. The last indicator for successful aging included psychological aspects in later life, happiness. The top third of the summary scores of three items ("I am just as happy now as when I was younger," "My life could be happier than it is now" (reversed), "These are the best years of my life") was used for happiness [19]. Those who had scores 1 to 3 on the summary scores of the three items were coded as happy (= 1), and those who had scored −3 to 0 on the summary scores of the three items were coded as unhappy (= 0).

2.4. Data Analysis. Pearson's Chi-squared tests were performed to identify study participants to achieve the criteria of original successful aging model and the alternative successful aging model. Data were analyzed using the SPSS Statistical Software Package (version 19.0; SPSS).

3. Results

The results are separated into two sections. First, Rowe and Kahn's successful aging model was examined with octogenarians and centenarians. Three components were investigated separately and aggregately by age groups. Second, an alternative successful aging model with three criteria (i.e., subjective health, perceived economic status, and happiness) was analyzed in the same manner as in the first section.

3.1. Oldest-Old Adults and Rowe and Kahn's Successful Aging Model. Each component was applied to octogenarians and centenarians, and how many octogenarians and centenarians satisfied each component was investigated. For "low probability of disease," 28.8% of octogenarians and 29.5% of centenarians satisfied this criterion. Over half of octogenarians (58%) and 4.4% of centenarians satisfied the physical and cognitive capacity criteria. There was a significant difference in association between age and physical/cognitive capacity among octogenarians and centenarians, $\chi^2(1, N = 295) = 107.67$, $P < 0.001$. For engagement with life, 63.5% of octogenarians and 57.5% of centenarians met the third criterion (Table 2). Therefore, we can argue that physical and cognitive capacities are critical factors distinguishing octogenarians and centenarians.

Table 2: Proportion of successful aging criteria.

	Octogenarians	Centenarians	χ^2
Low probability of disease	28.8%	29.5%	.01
High physical and cognitive capacity	58.0%	4.4%	107.67***
Active engagement with life	63.5%	57.5%	.72

*** $P < 0.001$.

Next, all three components were applied to investigate how many octogenarians and centenarians satisfied all criteria. Figure 1 shows the combined proportion of participants, octogenarians, and centenarians, who satisfied three components of successful aging. Over 15% of octogenarians (15.1%) and none of centenarians satisfied all three components of successful aging. In addition, 15.1% of octogenarians and 27.3% of centenarians did not achieve any of the three components of successful aging. One-third (34%) of octogenarians and 18% of centenarians met two of the three components. Over one-third of octogenarians (35.9%) and 54.6% of the centenarians achieved only one component of successful aging. Specifically, it might be worthy to note that although centenarians had a high probability of disease and lower potential capacities, 39.1% of them had a high level of life engagement. Therefore, based on Rowe and Kahn's [3, 4] criteria of low probability of disease, high physical and cognitive capacity, and engaged lifestyle, we could argue that living longer does not necessarily imply successful aging.

3.2. Oldest-Old Adults and Alternative Successful Aging Model. However, are these three criteria the only viable aspects of successful aging among oldest-old adults? The three criteria have been commonly used to examine successful aging but, as Kahn [9] suggested, the successful aging model should be complemented with other models. Hence, it might also be necessary to expand the definition of successful aging. An alternative model for successful aging with three criteria (i.e., subjective health, perceived economic status, and happiness) is explored in this section.

Each component was applied to octogenarians and centenarians, and how many octogenarians and centenarians were satisfied with each component was investigated. For "subjective health," 77.5% of octogenarians and 73.0% of

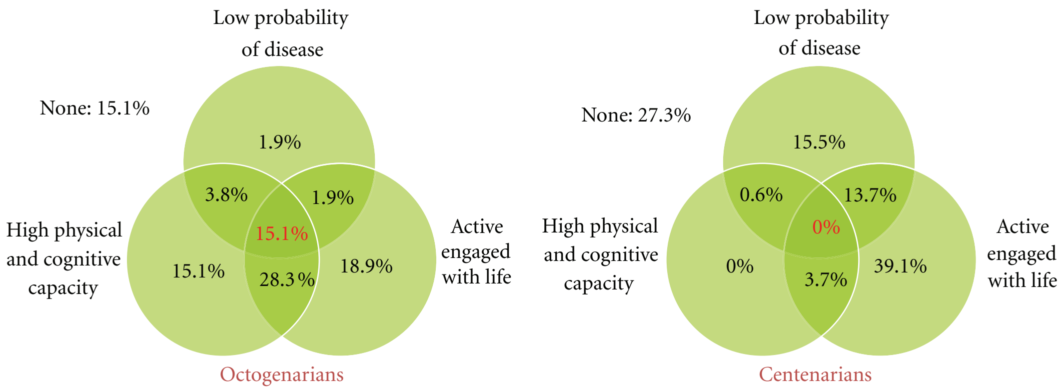

Figure 1: Drawings of age group comparisons for original successful aging model between octogenarians and centenarians. Numbers represent the proportion of each age group satisfied with components of the successful aging model.

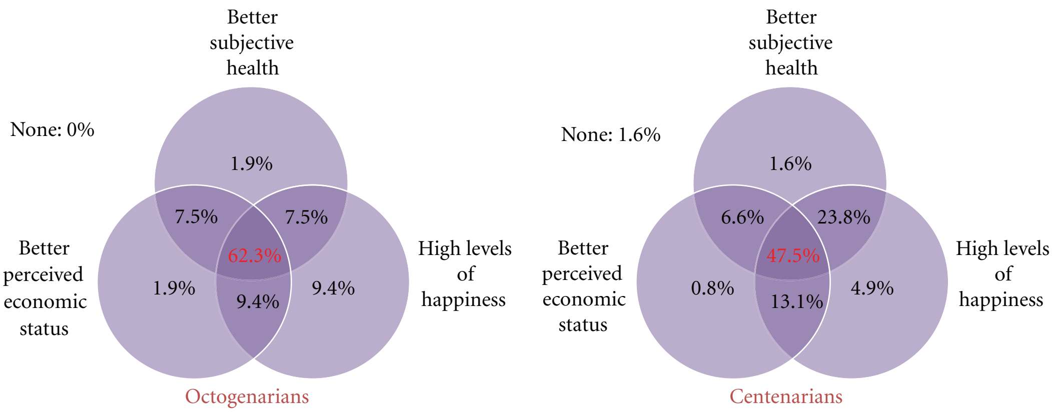

Figure 2: Drawings of age group comparisons for alternative successful aging model between octogenarians and centenarians. Numbers represent the proportion of each age group satisfied with components of the alternative successful aging model.

Table 3: Proportion of alternative successful aging criteria.

	Octogenarians	Centenarians	χ^2
Better subjective health	77.5%	73.0%	.57
Better perceived economic status	78.8%	61.8%	6.49*
High level of happiness	89.8%	89.7%	.00

$^*P < 0.05$.

centenarians satisfied this criterion. Over three quarters of octogenarians (78.8%) and 61.8% of centenarians satisfied the perceived economic status criterion. There was a significant difference in association between age and perceived economic status among octogenarians and centenarians, $\chi^2(1, N = 286) = 6.49$, $P < 0.05$. This indicates a larger proportion of octogenarians satisfied the perceived economic status criterion compared to centenarians. For happiness, 89.8% of octogenarians and 89.7% of centenarians met the third criterion (Table 3). Therefore, compared to Rowe and Kahn's [3, 4] criteria, more oldest-old adults satisfied these alternative aspects of successful aging criteria.

As was done with Rowe and Kahn's [3, 4] successful aging criteria, all three components for the alternative model were applied to investigate how many octogenarians and centenarians satisfied all criteria. Figure 2 shows the combined proportion of participants, octogenarians and centenarians, who satisfied the three components of successful aging. A total of 62.3% of octogenarians and 47.5% of centenarians satisfied all three components of the alternative model of successful aging. Less than 25% of octogenarians (24.4%) and less than half of centenarians (43.5%) met two of the three components. Over 10% of octogenarians (13.2%) and 7.3% of centenarians achieved only one component of successful aging. In addition, no octogenarian and only 1.6% of centenarians did not achieve any of the three components of the alternative successful aging model.

4. Discussion

Rowe and Kahn's successful aging model was applied to oldest-old adults in this study. The components of the successful aging model included low probability of disease, high cognitive/physical functional capacity, and active engagement in life. The first research question was whether oldest-old adults would satisfy all three components of the successful aging model. Only 15.1% of octogenarians and none of the centenarians satisfied all three components.

There is one obvious reason why oldest-old adults did not maintain all three components of the successful aging model. The participants used in the Rowe and Kahn study were 70 to 79 years old [3, 4]. The participants in this study were over 80 years of age, and most of them were centenarians. Physical health, which is a critical factor in Rowe and Kahn's aging model defined as the absence of disease and disability, shows dramatic decline after the age of 80 [48]. This might be the primary reason that our participants, especially centenarians, did not satisfy the criteria of Rowe and Kahn's successful aging model.

Because this research question was not supportive of Rowe and Kahn's model with oldest-old adults, an alternative successful aging model was suggested (Research Question 2). The reason to suggest an alternative successful aging model is that successful aging should not be limited to a few concepts and variables. Kahn [9] agreed that the successful aging model should be complemented by other models or have a broader definition to adjust for the limitation that only a significant number of people could reach advanced age free of age-associated disease and without appreciable functional deterioration [8]. Consistent with other centenarian studies, this study confirmed the fact that it is naturally difficult, if not impossible, to reach advanced age free of diseases and disability [49–52].

The alternative successful aging model provided us with a different picture of successful aging for advanced old age. Instead of low probability of disease, high cognitive/physical functional capacity, and active engagement in life, subjective health, perceived economic status, and happiness were included. The results showed that 62.3% of octogenarians and 47.5% of centenarians met the criteria of the alternative successful aging model. Perhaps the results can best be interpreted with the compensatory mechanism or resilience. In other words, although physiological change or functional deterioration is closely associated with increasing age, psychological and social aspects of aging may not have positive relationships with physiological changes across the life span [52]. Therefore, certain psychological or social mechanisms such as happiness, positive affect, and social ties may compensate for physiological decline and allow some older adults to age successfully [52]. Thus, this alternative aspect of the successful aging model may contribute to the multidimensional successful aging construct and help older adults achieve successful aging even under conditions of physical health limitations and disabilities.

Even though this study provides an innovative perspective on successful aging, it is important for researchers to pay attention to a couple of limitations. First, the sample of this study was from only one geographic area of the United States. Other oldest-old adults in different regions might present different patterns of successful aging. In addition, there were some discrepancies between the proportions of sex and race in this study and national statistics. The 2010 census data, for instance, indicated that there were 36.3% male and 63.7% female people among the population of 80 years old and older [53], whereas our data included 79.4% of women and 20.6% men. Homogeneity may have limited the interpretation and application of these results to larger populations of oldest-old adults across the country. Second, we should consider different time points to assess whether oldest-old adults are successful agers or not. In other words, we need to consider survivorship effects when interpreting the results. Baltes and Smith [54] suggested that studies focusing on very old age pay attention to survival and mortality [55, 56]. For example, we can assume that survivors into very late life at some point in their lives had better scores in some domains such as health, intelligence, education, and psychological aspects than their counterparts who died prematurely or were close to death when being assessed [54]. Therefore, even though none of the centenarians satisfied the criteria of the successful aging model compared to 15.1% of octogenarians, centenarians might have at some point in their lives been functioning better on the three criteria of successful aging than those who had died earlier. Thus, we should differentiate age differences from selective survivorship in terms of considering longevity and successful aging. Finally, it is noted that the original successful aging model used objective measures, but alternative criteria of this study were not objective measures. A number of studies have shown discrepancies between self-rated-successful-agers and successful-agers-based Rowe and Kahn's criteria (e.g., [8, 57]). However, as Kahn [9] suggested, the purpose of this study was to contribute diverse aspects to a successful aging model among oldest-old adults rather than comparing two equivalent models.

Despite these limitations, this study revealed interesting insight into the successful aging model of oldest-old adults. This information has numerous implications for gerontologists and practitioners. In particular, this investigation suggests that the successful aging model may not apply to oldest-old adults. Researchers and practitioners should consider many different factors for successful aging. Future research on oldest-old adults should use sequential designs when assessing successful aging. For example, investigators may want to apply the successful aging model to different cohort groups for several years. Based on this sequential design, the investigators may be able to explore the simultaneous examination of time and age effects for successful aging.

It may be difficult to achieve successful aging in extremely late life. There is still no agreement on the definition of successful aging, and future work needs to expand the criteria for successful aging. In addition, more work needs to be done to examine predictors of successful aging as parts of developmental processes. Future work will contribute to the study of successful aging and help older adults achieve successful aging for as long as possible with a systematic approach to consider the past and present life and with a holistic view to understand age-related changes and challenges.

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Research Article

Successful Aging: A Psychosocial Resources Model for Very Old Adults

G. Kevin Randall,[1] Peter Martin,[2] Mary Ann Johnson,[3] and Leonard W. Poon[4]

[1] *CC Wheeler Institute, Bradley University, 05 Bradley Hall, 1501 W. Bradley Avenue, Peoria, IL 61625, USA*
[2] *Gerontology Program, Iowa State University, 1096 LeBaron Hall, Ames, IA 50011-1120, USA*
[3] *Department of Foods & Nutrition, The University of Georgia, 143 Barrow Hall, 115 DW Brooks Dr, Athens, GA 30602, USA*
[4] *Institute of Gerontology, College of Public Health, The University of Georgia, 255 E. Hancock Avenue, Athens, GA 30602-5775, USA*

Correspondence should be addressed to G. Kevin Randall, krandall@bradley.edu

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Objectives. Using data from the first two phases of the Georgia Centenarian Study, we proposed a latent factor structure for the Duke OARS domains: Economic Resources, Mental Health, Activities of Daily Living, Physical Health, and Social Resources. *Methods*. Exploratory and confirmatory factor analyses were conducted on two waves of the Georgia Centenarian Study to test a latent variable measurement model of the five resources; nested model testing was employed to assess the final measurement model for equivalency of factor structure over time. *Results*. The specified measurement model fit the data well at Time 1. However, at Time 2, Social Resources only had one indicator load significantly and substantively. Supplemental analyses demonstrated that a model without Social Resources adequately fit the data. Factorial invariance over time was confirmed for the remaining four latent variables. *Discussion*. This study's findings allow researchers and clinicians to reduce the number of OARS questions asked of participants. This has practical implications because increased difficulties with hearing, vision, and fatigue in older adults may require extended time or multiple interviewer sessions to complete the battery of OARS questions.

1. Introduction

Aging is often conceptualized as a developmental challenge to maintain balance between the gains and losses of resources necessary for adaptation to age-related change, with losses increasing over the lifespan [1, 2]. Yet, Von Faber and colleagues [3] reminded us that, "Successful aging as an optimal state implicates more than physical well-being and fits the World Health Organization's definition of health as a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity." These resources-material, social, or personal characteristics essential for successful aging-hold a prominent position in studies of older adults [4–6]. Consequently, the need for a valid, reliable, and efficient resource measure, designed for use in clinical and community settings with older adults, arose. In response, Fillenbaum [7] and associates developed the *Multidimensional Functional Assessment of Older Adults: The Duke Older Americans Resources and Services Procedures* (OARS hereafter). Since development of the OARS, advances in statistical methodology, computer technology, and software programs have made factor analytic procedures commonplace, enabling researchers to suggest less complex and shorter versions of measurement scales and to model measurement error in empirical studies. To date, we know of no studies that investigated the underlying, latent factor structure of the five OARS resources with data from older adults—the purpose of the present study.

Studies on multiple resources and successful aging among older adults have grown tremendously [8–11], spawning psychometric concerns regarding how and what to assess [12]. Researchers have demonstrated the need to expand investigations of multidimensional resources in older populations [13, 14]. This body of work was motivated not only by the increased prevalence of older adults but also by a growing concern among those assessing and caring for frail older adults. The OARS was developed by a multidisciplinary team who recognized that older adults' personal well-being encompasses many aspects or multiple functions [7]. Because older adults often present with chronic disabilities or ailments [15, 16], the developers of the OARS designed an assessment tool that focused primarily on adaptation and the maintenance of personal well-being in five resources: Social Resources, Economic Resources, Mental Health, Physical Health, and self-care capacity or functional health (including both instrumental activities of daily living (IADL) and activities of daily living (ADLs)). This instrument has received widespread use by a diverse group of geriatric practitioners, researchers, and service group providers such as epidemiologists characterizing particular populations, clinicians assessing patient status, resource allocators providing services, and program evaluators investigating the impacts of interventions [12, 17–19].

In addition, because clinical work and empirical research may be tiring and confusing for older participants, a reduced version of the five OARS resources as modeled by five latent variables would prove helpful in reducing the time required to assess older adults' resources. However, few studies have specified the OARS resources as latent variables [20–22]. Further, to date, no study was found that developed a measurement model for all five OARS resources.

The purpose of this study was to specify and test the latent factor structure of the five OARS resources administered to participants in their 60s, 80s, and 100s. We hypothesized that (a) the resource model proposed by Fillenbaum [7] can be obtained using data from old and very old individuals and (b) a reduced short version of the OARS will yield a satisfactory latent variable solution.

2. Methods

2.1. Procedure and Participants. Participants were selected through the assistance of the University of Georgia Survey Research Center, the Office of the Governor of Georgia, the media, and local older adult service organizations [23–25]. Selection criteria for the final sample of community-dwelling individuals included a score of 23 or higher on the Mini-Mental Status Examination (MMSE; [26]) or a score of 2 or lower on the Global Deterioration Scale [27].

The data collection at phase one included 321 older adults (217 women, 104 men), classified as sexagenarians ($n = 91$), octogenarians ($n = 93$), and centenarians ($n = 137$). At time two, 201 participants provided data for this longitudinal study: 70 sexagenarians, 63 octogenarians, and 68 centenarians. Those in their 60s and 80s were followed up within 60 months; due to mortality attrition, centenarians were followed up within 20 months. Almost one-third of the sample was African American (27.7% and 30.8% at Time 1 and Time 2, resp.). The majority of the sample was female (67.6%), well-educated (at least graduated from high school), and rated their health as excellent or good (Table 1).

Table 1: Sample demographic characteristics.

Variables	Time 1		Time 2		χ^2
	n	%	n	%	
Sex					1.59
Male	104	32.4	60	29.9	
Female	217	67.6	141	70.1	
Race					2.61
Black	89	27.7	62	30.8	
White	232	72.3	139	69.2	
Age group					18.86***
60s	91	28.3	70	34.8	
80s	93	29.0	63	31.3	
100s	137	42.7	68	33.8	
Education					6.19
0-8 years	90	28.2	55	28.8	
High school	84	26.3	42	22.0	
Business/trade school	23	7.2	14	7.3	
College	75	23.6	44	23.0	
Graduate school	47	14.7	36	18.8	
Self-rated health					4.7
Excellent	67	21.1	39	20.2	
Good	159	50.2	93	48.2	
Fair	79	24.9	52	26.9	
Poor	12	3.8	9	4.7	

Because of rounding, percentages may not add to 100.
$^{***}P < .001$.

As noted earlier, in this sample of old and very old adults, mortality attrition resulted in a reduction of participants, particularly among the centenarians, from 321 at time 1 to 201 at time 2. Table 2 examines the differences for the OARS manifest variables and two measures of cognitive status. Overall, the sample at time 2 showed significantly higher scores relative to time 1.

2.2. Measures. Because the purpose of this study was to develop a latent variable model for the five OARS resources, in this section we provide a brief overview of the measures based upon Fillenbaum's [7] work. Details of our final latent variables and corresponding indicators are presented in Section 3. In addition, the appendix lists each resource and its indicators and associated questions, based on our final results.

2.2.1. Economic Resources. Six questions were asked; examples included "How well does the amount of money you have take care of your needs—very well, fairly well, or poorly?" and "Please tell me how well you think you are now doing financially as compared to other people your age—better, about the same, or worse?" These items were scaled from 0: poorly or worse to 2: very well or better.

2.2.2. Mental Health. Satisfaction (six items), sleep disturbance (two items), lethargy (6 items), and paranoid (three

Table 2: Differences between participants at Time 1 and participants at Time 1 and Time 2.

Variables	Time 1 Only		Time 1 and Time 2		t
	M	SD	M	SD	
Mini-Mental (MMSE)	25.30	2.72	26.31	3.01	-3.03^{**}
Short Portable (SPMSQ)	8.63	1.58	9.04	1.38	-2.41^{*}
Economic Resources	4.73	1.48	4.82	1.47	.48
Mental Health	5.12	1.33	5.27	1.24	.97
IADLs	4.81	1.30	5.25	1.19	3.02^{**}
Physical Health	3.73	1.70	4.24	1.58	2.73^{**}
Social Resources	4.49	1.55	4.57	1.47	.42

$^{*}P < .05$. $^{**}P < .01$.

items) comprised the four dimensions of Mental Health [7]. Examples of questions included (a) satisfaction: "In general, do you find life exciting, pretty routine, or dull?" scaled so that 0: dull, 1: pretty routine, and 2: exciting; (b) sleep disturbance: "Do you wake up fresh and rested most mornings?" scaled so that 0: no, 1: yes; (c) lethargy: "Have you had periods of days, weeks, or months when you couldn't take care of things because you couldn't "get going?" scaled so that 0: no, 1: yes; (d) paranoid: "Does it seem that no one understands you?" scaled so that 0: no, 1: yes.

2.2.3. ADLs. Two commonly used dimensions, instrumental activities of daily living (IADL; seven items) and physical activities of daily living (PADLs; six items), comprised the self-care capacity assessment. An example of an IADL question included "Can you do your housework?" scaled so that 2: without help (can clean floors, etc.); 1: with some help (can prepare some things but unable to cook full meals yourself) or 0: are you completely unable to prepare any meals? A PADL question was "Can you dress and undress yourself" scaled so that 2: without help (able to pick out clothes, dress and undress yourself) 1: with some help, or 0: are you completely unable to dress and undress yourself?

2.2.4. Physical Health. Three questions assessing subjective self-rated health were included. For example, participants responded to "How would you rate your overall health at the present time—excellent, good, fair, or poor?" scaled so that 0: poor and 3: excellent.

2.2.5. Social Resources. Social Resources were measured using seven questions. An example of a question focusing on the interaction aspect of social support was "How many people do you know well enough to visit with in their homes?" Participants chose from a scale of 0: none to 3: five or more. An assessment of dependability of social support included two questions. These questions were answered 1: yes and 0: no. For example, one question was "Do you have someone you can trust and confide in?" A third assessment of the affective domain of social support also included two questions, scaled 1: yes and 0: no. For example, one question was "Do you see your relatives and friends as often as you want to or not?"

2.3. Data Analysis. The analyses conducted to confirm a measurement model included the following steps for each resource: (a) specifying and testing Fillenbaum's subscales; (b) adapting Fillenbaum's recommendations when modeling difficulties were encountered; (c) employing exploratory factor analyses (i.e., principal axis factoring retaining three factors with oblique rotation) to assess relationships within the data and to posit possible indicators for latent constructs; (d) testing the measurement model by confirmatory factor analyses. We developed at least three indicators for each resource and then tested the latent variable measurement model via confirmatory factor analysis. Table 3 provides assessment of measurement model fit, standardized loadings, and the uniqueness or R^2 for each indicator. All variables were scaled so that higher scores indicated higher levels of the resource. In the appendix, we provide a nontechnical summary of our results, listing the recommended questions for each indicator of the five OARS resources.

We used full-information maximum likelihood (FIML) to estimate our models [28, 29]. For our latent variable analyses we used *M*plus 6.11 [30] and employed FIML with the estimator MLR (maximum likelihood parameter estimates with standard errors and a mean-adjusted chi-square test statistic that are robust to nonnormality).

Exploratory factor analyses were conducted using SPSS 18.0, whereas confirmatory factor analyses and structural equation modeling were conducted with *M*plus [30]. Overall model fit was assessed by employing the Satorra-Bentler chi-square test statistic. This type of chi-square test statistic provided maximum likelihood parameter estimates with standard errors and a mean-adjusted chisquare test statistic that is robust to nonnormality of measures. Because the chisquare goodness of fit test and its corresponding probability value are sensitive to sample size, often making it difficult to accurately assess model fit when limited to this single statistic [31, 32], other measures of model fit were reported including the Comparative Fit Index (CFI) [33], the Tucker-Lewis coefficient (also called the NNFI) (TLI) [34], Browne and Cudeck's [35] root mean squared error of approximation (RMSEA), and the standardized root mean squared residual (SRMR). It has been suggested that values close to .95 for TLI and CFI, .08 for SRMR, and .06 for RMSEA are necessary before concluding that a relatively good fit between the observed data and the hypothesized model exists [36, 37].

TABLE 3: OARS resources latent variable measurement model results.

Construct/indicators	Loadings (λ)[a]	Uniqueness (R^2)	Loadings (λ)[a]	Uniqueness (R^2)
	T1*		T2**	
Economic Resources				
Sufficient Income	.81[b]	.66	.96[b]	.93
Overall Income	.70	.49	.61	.37
Meet Payments	.63	.40	.30	.09
Mental Health				
Exciting	.60[b]	.36	.53[b]	.28
Overall Mental Health	.53	.29	.49	.24
Life Satisfaction	.50	.25	.69	.47
IADLS				
Getting Out	.89[b]	.80	.94[b]	.88
Housework	.88	.78	.94	.88
Medicine	.65	.42	.77	.59
Physical Health				
Low Troubles	.70[b]	.49	.86[b]	.73
Overall Physical Health	.66	.44	.49	.24
Comparative Health	.46	.21	.48	.23
Social Resources				
Phone Talk	.64[b]	.41	.94[b]	.89
Visit Network Number	.47	.22	.08	.01
Visits With Others	.42	.17	.29	.08

[a]Parameter estimates are from the standardized solution. [b]These indicator loadings were fixed to 1.0 (unstandardized) for model identification; all estimated loadings $P < .01$; except Time 2 Social Resources.
*T1 Fit Indices: MLR χ^2 ($N = 321$; df = 80) = 144; CFI = .94; TLI = .92; RMSEA = .05; SRMR = .05.
**T2 Fit Indices: MLR χ^2 ($N = 201$; df = 80) = 136; CFI = .93; TLI = .90; RMSEA = .06; SRMR = .07.

3. Results

Economic Resources included six items. We conducted an exploratory factor analysis (principal axis factoring) with an oblique rotation and extracted three factors, accounting for 76 percent of the variance. Based upon these results, we constructed three indicators. First, we summed the three dichotomous items tapping the sufficiency of the respondent's economic resources to meet emergencies and provide extras currently and in the future (Cronbach's alpha = .81). This indicator, *Sufficient Income*, was recorded so that the scores ranged from 0 to 2. (Because we summed these indicators to create a manifest variable in other analyses, we recorded the indicators for equal weighting.) Second, two items loaded on a second factor, both asking the respondents how well they were doing financially. These two items were then averaged to create a second indicator, *Overall Income*, and assessed how well the respondents felt they were doing relative to their overall financial well-being (Cronbach's alpha = .59). Finally, the last item, *Meet Payments*, assessed the participant's expenses, was recorded to 0–2, and used as a third indicator. This item tapped the respondents, ability to meet payments. The three indicators loaded significantly and substantively on the latent variable, Economic Resources, at Time 1 and Time 2 (Table 3).

Inspection of the *Mental Health* assessment revealed that five items had 90% or more respondents scoring alike, five had 80% or more of respondents scoring alike, and three had 70% or more of respondents scoring alike. Thus, we did not use these items and specified a latent variable with three single-item indicators: (a) "In general, do you find life exciting, pretty routine, or dull?" (b) "How would you rate your mental or emotional health at the present time?" and (c) "Taking everything into consideration how would you describe your satisfaction with life in general at the present time?" These three indicators, *Exciting*, *Overall Mental Health*, and *Life Satisfaction*, loaded significantly and substantively on the latent variable Mental Health at Time 1 and Time 2 (Table 3).

Activities of Daily Living (IADL) consisted of instrumental activities of daily living (seven items) and physical activities of daily living (six items). Because descriptive statistics demonstrated that for those in their 60s and 80s few difficulties with physical activities of daily living were encountered, we did not include this subscale but created three indicators for IADL based upon an exploratory factor analysis of the seven items of IADL. The first indicator, labeled *Getting Out*, included items assessing (a) "Can you use the phone?" (b) "Can you get to places out of walking distance?" and (c) "Can you go shopping for groceries or clothes?" Cronbach's alpha for these three items was .76. The second indicator, *Housework*, was comprised of three items (Cronbach's alpha = .88) assessing: (a) "Can you prepare your own meals?" (b) "Can you do your own housework?" and (c) "Can you handle your own money?" The third indicator, *Medicine*, was a single item, "Can you take your own medicine?" The three indicators loaded significantly and substantively on the latent variable IADL at Time 1 and Time 2 (Table 3).

Physical Health consisted of three single-item indicators assessing subjective health perceptions. First, for the indicator *Low Troubles*, respondents were asked, "How much do your health troubles stand in the way of your doing the things you want to do?" Second, the question for the indicator *Overall Health* asked "How would you rate your overall health at the present time?" A third question for the indicator *Comparative Health* asked, "Is your health now better, about the same, or worse than it was five years ago?" These three indicators loaded significantly and substantively on the latent variable Physical Health at Time 1 and Time 2 (Table 3).

Social Resources included seven items. Because three dichotomous items did not provide much variance (over 90% of respondents scored "yes"), we did not use them. We then conducted an exploratory factor analysis on the remaining questions. Four items were used in our initial latent variable: (a) "How many times did you talk to friends, relatives, or others on the phone in the past week?" (b) "How many people do you know well enough to visit in their homes?" (c) "How many times in the past week did you spend some time with someone who does not live with you?" and (d) "Do you find yourself feeling lonely?" (recorded so that high scores reflected low loneliness). Thus, a latent variable was specified with *Phone Talk* as the first indicator, with *Visit Network Number* as a second indicator, *Visits With Others* as a third indicator, and *Loneliness* as a fourth.

Based on the previous exploratory factor analyses, we specified and tested a measurement model using confirmatory factor analysis and comprised of the five factors and their respective indicators as previously discussed. However, in the first test of the measurement model, loneliness did not significantly load on the latent variable for Social Resources at Time 1 ($t = 1.62$); this item was dropped and not used as an indicator in further analyses. Next, we conducted a similar analysis and these indicators loaded on the latent factor, Social Resources, significantly and substantively at Time 1 (see Table 3 for the results). However, at Time 2 the second and third indicators did not load significantly or substantively, although the overall measurement model fit to the data was adequate. This indicates that the construct might have changed over time, and the results for Time 2 Social Resources need to be stated with caution (Table 3).

The five latent variables were significantly correlated with one another at each measurement occasion with a few exceptions at Time 2 (Table 4). For example, at Time 2 Social Resources was only significantly associated with IADL; also, Physical Health was not significantly associated with either Mental Health or Social Resources at Time 2. Also, power issues may have influenced the results as the sample size was $N = 321$ at time 1 and $N = 201$ at Time 2, resulting in a lack of findings that may have existed. For example, consider the correlation between Social Resources and Mental Health at Time 2: $r = .25$, $P > .05$. However, at Time 1, with the larger sample size, two correlations close to the same magnitude as that between Social Resources and Mental Health at Time 2—the correlation between Economic Resources and IADL ($r = .25$, $P \leq .01$) and the correlations between Economic Resources and Social Resources ($r = .27$, $P \leq .01$)—are significant, indicating a likely reduction in power at Time 2. Table 5 presents the final correlations and descriptive statistics for all indicators of the OARS measurement model.

Table 4: Correlation Matrix of OARS Resources Latent Variables (Time1 below the diagonal; Time 2 above the diagonal).

	1	2	3	4	5
1. Economic Resources	—	.26**	.43**	.27**	.08
2. Physical Health	.46**	—	.15	.58**	.14
3. Mental Health	.60**	.83**	—	.38**	.25
4. IADLS	.21**	.56**	.42**	—	.45**
5. Social Resources	.27**	.34**	.35**	.50**	—

** $P < .01$.

Finally, we attempted a nested model test for factorial invariance over time by constraining the loadings of each indicator at Time 1 equal to the same indicator at Time 2. Also, the residual for each indicator at Time 1 was correlated with its counterpart at Time 2. This constrained or nested model did not fit the data well: MLR χ^2 (354, $N = 201$) $=$ 527.03, $P = .001$, CFI = .91, TLI = .89, RMSEA = .05, and SRMR = .07. However, despite increasing the number of iterations and specifying starting values, we were not able to get the unconstrained or base model to converge. This measurement model included the Social Resources latent construct at Time 2 that did not have significant loadings for its estimated indicators. Thus, the overall poor model fit may be due to a poor measurement model for Social Resources.

As a follow-up, we decided to fit a measurement model without the Social Resources latent variable. The unconstrained or base model, including the four latent variable resource constructs (without Social Resources at Time 1 and Time 2), specified with correlated residuals across time, fit the data well: MLR χ^2 (211, $N = 201$) $= 289.09$, $P = .001$, CFI = .95, TLI = .94, RMSEA = .04, and SRMR = .06. Next, we added across time constraints to the factor loadings for each corresponding indicator and ran the model. This constrained or nested model with eight more degrees of freedom fit the data well also: MLR χ^2 (219, $N = 201$) $= 300.18$, $P =$ .001, CFI = .95, TLI = .94, RMSEA = .04, and SRMR = .07. Finally, we performed a nested model chi-square difference test following the specifications provided by B. Muthén and L. Muthén [30] for the MLR chi-square. In this case, the chi-square difference was 11.06 with eight degrees of freedom, $P = .20$. Thus, no significant difference was found between these two models and it is reasonable to assume factorial invariance over time.

4. Discussion

The focus of this study was a widely used integral part of the *Multidimensional Functional Assessment of Older Adults: The Duke Older Americans Resources and Services Procedures* [7]. To date, few studies have specified one or more of the five OARS resources as latent variables [20–22] and we found no studies with older adults, especially centenarians, specifying

Table 5: Correlation matrix of indicators for OARS measurement model (Time 1 below the diagonal; Time 2 above the diagonal).

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
(1) Age Group	—	−.18**	.02	−.08	−.22**	−.23**	−.13	−.72**	−.71**	−.47**	−.27**	−.10	−.09	−.40**	−.18**	−.03		
(2) Sufficient Income	−.05	—	.58**	.28**	.17**	.18**	.32**	.27**	.25**	.12	.19**	.30**	.04	.14	−.02	.16		
(3) Overall Income	.07	.56**	—	.22**	.07	.14	.21*	.02	.04	−.01	.02	.16*	.04	.08	.10	.09		
(4) Meet Payments	−.04	.55**	.41**	—	.09	.06	.14	.12	.10	.06	.21**	.10	.13	−.02	−.06	−.01		
(5) Exciting	−.24**	.22**	.27**	.20**	—	.29**	.35**	.23**	.17	.22**	.05	.13	−.09	.14*	.06	.20**		
(6) Overall Mental Health	−.08	.28**	.31**	.16**	.27**	—	.33**	.16**	.21**	.07	.00	.33**	.01	.07	.13*	.03		
(7) Life Satisfaction	−.10	.22**	.24**	.24**	.38**	.23**	—	.19*	.26**	.20*	.09	.18**	−.02	.16**	.04	.17**		
(8) Getting Out	−.69**	.17**	.11	.18**	.33**	.13**	.20**	—	.88**	.73**	.46**	.32**	.17*	.40**	.13	.02		
(9) House Work	−.63**	.04	.07	.16**	.29**	.11	.14**	.79**	—	.72**	.48**	.27**	.16*	.40**	.07	.07		
(10) Medicine	−.38**	.19**	.00	.02	.21**	.03	.07	.55**	.61**	—	.38**	.27**	.14	.31**	.07	.05		
(11) Low Troubles	−.26**	.19**	.25**	.21**	.32**	.26**	.28**	.41**	.35**	.30**	—	.40**	.41**	.09	−.14*	.00		
(12) Overall Physical Health	−.16**	.30**	.29**	.22**	.33**	.48**	.20**	.28**	.24**	.17**	.45**	—	.33**	.16*	.03	.08		
(13) Comparative Health	−.28**	.08	.12	.11	.25**	.17**	.13**	.29**	.27**	.19**	.35**	.28**	—	.10	−.13	−.03		
(14) Phone Talk	.23**	.04	.18**	.03	.16**	.08	.11	.35**	.30**	.20**	.15*	.20**	.01	—	.07	.27**		
(15) Visit Network Number	−.21**	.03	.07	.09	.11**	.05	.04	.32**	.21**	.19	.10	.13	.09	.24**	—	.19		
(16) Visits With Others	−.03	.14**	.05	−.01	.10	.09	.11	.10	.00	.08	.11	.09	−.01	.31**	.25**	—		
Means	Time 1	$N = 321$	1.14	1.52	1.44	1.78	1.41	2.06	1.75	1.63	1.58	1.83	1.29	1.89	.86	2.41	2.86	2.16
	Time 2	$N = 201$	.99	1.52	1.42	1.72	1.42	1.97	1.77	1.55	1.47	1.77	1.17	1.83	.78	2.41	2.87	2.08
SD	Time 1	$N = 321$	.78	.78	.52	.50	.57	.70	.47	.46	.59	.40	.76	.77	.62	.85	.49	.77
	Time 2	$N = 201$	.83	.78	.77	.58	.57	.72	.49	.55	.67	.51	.78	.80	.61	.89	.48	.88

$^{*}P \leq .05$. $^{**}P \leq .01$.

all five OARS resources as latent variables. Thus, empirical and clinical attention to multidimensional assessments of older adults and their successful aging, especially those in their 80s and 100s, and the continued popularity of the OARS instrument as a standardized scale motivated this study development of a measurement model of psychosocial resources essential to successful aging for very old adults.

Five latent variables with three indicators each, corresponding to the five OARS resources, were specified; the combined measurement model fit the data adequately using a sample of older adults in their 60s, 80s, and 100s. Three results from the measurement analyses are noteworthy. First, because of advances in SEM programs and techniques allowing specification of measurement error and latent factor modeling, a comprehensive measurement model of the five OARS resources would prove useful to researchers and those assessing and caring for older adults. With the exception of Social Resources at Time 2, researchers employing the OARS may confidently specify the measurement model tested in this study. The measurement model tested in this study fit the data well at Time 1 and Time 2. Factor loadings (except those of Social Resources at Time 2) were significant and substantive, providing adequate evidence of an acceptable latent variable measurement model for the five OARS resources.

Second, supplementary analyses of factorial invariance over time, conducted without Social Resources at Time 2, revealed that in this sample, the four latent variables (i.e., Economic Resources, IADL, Physical Health, and Mental Health) fit the data well and did not change significantly over time. It is noted that for the younger participants (i.e., those in their 60s and 80s), five years elapsed between measurement occasions, whereas, for the centenarians, 20 months. Researchers interested in developmental questions of change over time are encouraged to employ the measurement model verified by this study and to extend this work by carefully considering the time intervals necessary for proximal and distal influences to unfold among older adults.

Third, Social Resources tended to have the lowest loadings per indicator. In this sample, relative to the other indicators, talking on the phone is the main indicator tapping the respondent's Social Resources. Burholt and colleagues [38] investigated OARS Social Resources in a population-based study of older adults living independently in six Western European countries and argued that the items demonstrated a breadth of conceptual assessment. It is our contention that such is the case with the three single-item indicators for the latent variable Social Resources. These indicators may assess a breadth of structure and at times the items may not be related. These three items may better serve as a checklist of social resources structure. Expecting relatively high factor loadings for such a construct may be unfounded (see [39], for a discussion regarding why checklist assessments often exhibit low internal consistency). Thus, other valid and reliable assessments of social support might be examined to augment or supplant the items included in the OARS assessment. Finally, empirical work investigating the relationship between measures of social support and loneliness has demonstrated discriminant validity; despite the strong association these measures tap different constructs [40, 41]. This is consistent with the finding of this study; the loneliness item did not load significantly on the Social Resources latent variable and was not included in the final measurement model.

4.1. Limitations and Direction for Future Research. Several limitations, however, exist that affect the generalization of this study's results. First, the participants were Southeastern older adults in reasonably good health, mentally competent, and community-dwelling. Second, the younger age groups (those in their 60s and those in their 80s) were randomly selected by race and gender to approximate older adults in Georgia. However, in contrast, centenarians were selected using convenience sampling through state and local agencies. Also, the sexagenarians and octogenarians were assessed in testing locations; centenarians completed their assessments at home. In addition, for the two younger age groups, measurement occasions were five years apart, but for the centenarians the measurement occasions were approximately 20 months apart. With only two waves of data, longitudinal results are to be interpreted with caution. Future research will want to employ other valid assessments of similar assessments of the five resources for comparison, particularly with larger, more homogeneous samples. This would provide opportunity to compare the relationships between the revised OARS latent resources based on our results and other known measures. Also, using a more homogenous sample of older adults might mitigate some of the methodological difficulties inherent in our heterogeneous sample that includes three age groups of old (60s and 80s) and very old adults (100s).

Finally, the items used for Social Resources in this study could be improved in future research. All the latent variables except Social Resources were fairly consistent across measurement occasions. In fact, for the models tested without the Social Resources latent variable, the overall measurement model fit the data well and factorial invariance of the latent variables over time was substantiated. Future research is encouraged to consider other measures of Social Resources (see [42], for 12 different measures assessing social support).

This study employed data from the Georgia Centenarian Study and used the popular Duke OARS [7] to develop a measurement model consisting of latent variables for Economic Resources, Instrumental Activities of Daily Living, Physical Health, Mental Health, and Social Resources. The model was specified and affirmed using longitudinal (two waves) data from a sample of sexagenarians, octogenarians, and centenarians, further substantiating the robustness of these latent variables in research with older adults. The results of this study allow reduction of the numerous items used in assessing the five OARS resources. This has valuable and practical implications because increased difficulties with hearing, vision, and fatigue in older adults may require extended time or multiple interviewer sessions to complete the extensive battery of questions in the OARS. Thus, researchers conducting etiological investigations, health professionals conducting intake and out-patient assessments, and other practitioners wishing to employ the OARS with older populations and the resources essential to successful aging will benefit from using this reduced version.

Appendices

A. OARS Economic Resources

A.1. Sufficient Income

Are your assets and financial resources sufficient to meet emergencies?

1 Yes

0 No

Do you usually have enough to buy those little "extras," that is, those small luxuries?

1 Yes

0 No

At the present time do you feel that you will have enough for your needs in the future?

1 Yes

0 No

A.2. Overall Income

Please tell me how well you think you are now doing financially as compared to other people your age—better, about the same, or worse?

3 Better

2 About the same

1 Worse

How well does the amount of money you have take care of your needs—very well, fairly well, or poorly?

3 Very well

2 Fairly well

1 Poorly

A.3. Meet Payments

Are your expenses so heavy that you cannot meet the payments, or can you barely meet the payments, or are your payments no problem to you?

0 Subject cannot meet payments

1 Subject can barely meet payments

2 Payments are no problem

B. OARS Mental Health

B.1. Exciting

In general, do you find life exciting, pretty routine, or dull?

2 Exciting

1 Pretty routine

0 Dull

B.2. Overall Mental Health

How would you rate your mental or emotional health at the present time—excellent, good, fair, or poor?

3 Excellent

2 Good

1 Fair

0 Poor

B.3. Life Satisfaction

Taking everything into consideration how would you describe your satisfaction with life in general at the present time—good, fair, or poor?

2 Good

1 Fair

0 Poor

C. OARS IADL

C.1. Getting Out

Can you use the telephone. . .

2 without help, including looking up numbers and dialing?

1 with some help (can answer phone or dial operator in an emergency, but need a special phone or help in getting the number or dialing)?

0 are you completely unable to use the telephone?

Can you get to places out of walking distance. . .

2 without help (drive your own car, or travel alone on buses, or taxis)?

1 with some help (need someone to help you or go with you when traveling)?

0 are you unable to travel unless emergency arrangements are made for a specialized vehicle like an ambulance?

Can you go shopping for groceries or clothes (assuming subject has trans). . .

2 without help (taking care of all shopping needs yourself, assuming you had transportation)?

1 with some help (need someone to go with you on all shopping trips)?

0 are you completely unable to do any shopping?

C.2. Housework

Can you prepare your own meals. . .

2 without help (plan and cook full meals yourself)?

1 with some help (can prepare some things but unable to cook full meals yourself)?

0 are you completely unable to prepare any meals?

Can you do housework. . .

2 without help (can clean floors, etc.)?

1 with some help (can do light housework but need help with heavy work)?

0 are you completely unable to do any housework?

Can you handle your own money. . .

2 without help (write checks, pay bills, etc.)?

1 with some help (manage day-to-day buying but need help with managing your checkbook and paying your bills)?

0 are you completely unable to handle money?

C.3. Medicine

Can you take your own medicine. . .

2 without help (in the right dose at the right time)?

1 with some help (able to take medicine if someone prepares it for you and/or reminds you to take it)?

0 are you completely unable to take your medicines?

D. OARS Physical Health

D.1. Low Troubles

How much do your health troubles stand in the way of your doing the things you want to do—not at all, a little (some), or a great deal?

2 Not at all

1 A little (some)

0 A great deal

D.2. Overall Health

How would you rate your overall health at the present time—excellent, good, fair, or poor?

3 Excellent

2 Good

1 Fair

0 Poor

D.3. Comparative Health

Is your health now better, about the same, or worse than it was five years ago?

2 Better

1 About the same

0 Worse

E. OARS Social Resources

E.1. Visit Network Number

How many people do you know well enough to visit with in their homes?

3 Five or more

2 Three to four

1 One or two

0 None

E.2. Phone Talk

About how many times did you talk to someone—friends, relatives, or others—on the telephone in the past week (either you called them or they called you?) (if subject has no phone, question still applies).

3 Once a day or more

2 2–6 times

1 Once

0 Not at all

E.3. Visits with Others

How many times during the past week did you spend some time with someone who does not live with you, that is, you went to see them or they came to visit you, or you went out to do things together?

3 Once a day or more

2 2–6 times

1 Once

0 Not at all

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Research Article

Response to Acute Psychophysical Stress and 24-Hour Glycemic Control in Healthy Older People

Loretta DiPietro,[1,2,3] Catherine W. Yeckel,[1,2] and Andrei Gribok[4]

[1] *The John B. Pierce Laboratory, Yale School of Medicine, New Haven, CT 06519, USA*
[2] *Department of Epidemiology and Public Health, Yale School of Medicine, New Haven, CT 06519, USA*
[3] *The Department of Exercise Science, School of Public Health and Health Services, The George Washington University, 817 23rd Street, NW, Washington, DC 20052, USA*
[4] *Beltsville Human Nutrition Research Center, The United States Department of Agriculture, Beltsville, MD 20705, USA*

Correspondence should be addressed to Loretta DiPietro, ldp1@gwu.edu

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We examined the relation between stress reactivity and 24 h glycemic control in 17 inactive, healthy older people (≥60 years) under both a novel psychophysical stress and a seated control condition. Plasma cortisol was measured over the course of the stress and recovery periods. Glycemic control was determined over the subsequent 3 h from an oral glucose tolerance test (OGTT) and over 24 h *via* continuous glucose monitoring (CGM). We observed significant ($P < 0.05$) elevations in perceived stress, cardiovascular activity, and peak cortisol response at 30 min (10.6 ± 3.1 versus $8.6 \pm 2.6\,\mu\text{g}\cdot\text{dL}^{-1}$, resp.) during the stress compared with the control condition; however, 3 h OGTT glucose and insulin responses were similar between conditions. The CGM data suggested a 30–40 min postchallenge delay in peak glucose response and attenuated glucose clearance over the 6 h following the stress condition, but these alterations were not statistically significant. Healthy older people may demonstrate minimal disruption in metabolic resiliency following everyday psychological stress.

1. Introduction

"Stress" is a common and adaptive component of our interaction with the environment [1], and *allostasis* refers to the body's ability to reestablish stability (i.e., homeostasis) when confronted by various environmental challenges through the activation of neural, neuroendocrine, and neuroendocrine-immune responses [2]. There is some evidence from animal models that aging *per se* alters allostatic ability, although the data in humans are inconclusive [3]. Nonetheless, older age is characterized by diminished physical capabilities (e.g., vision, strength, and reaction time), which may make normal everyday experiences and challenges (like driving an automobile or crossing the street) more stressful [4]. Thus, older people may have more frequent exposures to stressful situations, along with a compromised ability to respond appropriately to them. There are significant individual differences in how individuals cope with environmental challenges, however, and this may be due to the interaction of heredity, development, education, and life experiences [5, 6]. Furthermore, there is substantial heterogeneity with regard to patterns of aging [7] such that some older people appear more resilient than others to the physiological consequences of various environmental challenges. Resiliency to psychophysical stress therefore may be considered an important indicator of successful aging.

To date, much of the experimental study of stress reactivity and health has focused on cardiovascular function. Despite the epidemiologic data describing the association between adverse psychosocial factors and poor diabetes control [6], the harmful effect of acute psychological stress on metabolic control is often difficult to demonstrate experimentally [8, 9]. Moreover, the studies that have investigated the role of stress response in glycemic control have included primarily younger people [8, 10], or those with already established type 1 or type 2 diabetes [9], have used specific tasks or responses to natural disasters [11] that are not usually encountered on a daily basis by older people, and have only considered glycemic responses over 2-3 hours. The purpose of this study was to examine the relation between stress reactivity and glycemic control over 24 h in healthy older people, using a common "everyday life" stress challenge. We hypothesized that (1) older subjects would demonstrate elevated cardiovascular and hormonal responses to this challenge compared with a control condition and (2) an exaggerated stress response would result in significantly disrupted glycemic control in the short term (i.e., 3 h) but not over 24 hours. Due to the robust health status of this study sample, we proposed that alterations in metabolic control in the short term would be normalized over the remainder of the day. To our knowledge, these hypotheses have not been tested before in healthy people of any age using continuous glucose monitoring.

2. Methods

2.1. Study Subjects. Older (≥60 years) volunteers ($N = 6$ men and 11 women) were recruited by advertisement from community senior centers throughout the greater New Haven County. Eligible subjects were nonsmoking, and not taking beta-blockers, glucose-lowering medication, antidepressants, or reporting an alcohol intake >2 drinks/day. To eliminate the confounding influence of cardiovascular fitness on stress reactivity and on glycemic control, all subjects were reported to be inactive (<2 days/week of moderate-intensity physical activity lasting more than 10 min duration). Interested subjects first were administered a cognitive function screening using the nine-item Short Portable Mental Status Questionnaire [12]. All persons achieving a score of 5 or fewer correct answers on the SPMSQ were excluded from further study. Interested subjects meeting the cognitive function criterion then were given a screening oral glucose tolerance test (OGTT (75 g load)) to rule out undiagnosed type 2 diabetes. Those with a fasting plasma glucose concentration $\geq 110\,\text{mg}\cdot\text{dL}^{-1}$, a 2 h postchallenge measurement $\geq 140\,\text{mg}\cdot\text{dL}^{-1}$ or at least one other postchallenge $\geq 180\,\text{mg}\cdot\text{dL}^{-1}$ were excluded from further study. Eligible volunteers had all details of the study explained to them and signed a form indicating their informed consent. All protocols were approved by the Human Investigations Committee of the Yale School of Medicine.

2.2. Study Protocol. Each study subject underwent two separate study conditions: (1) the actual psychophysical stress challenge and (2) a seated control condition. The two conditions were randomly ordered and spaced approximately 2–4 weeks apart. Because depression may influence the relation between stress response and insulin sensitivity, subjects were administered the Center for Epidemiologic Studies-Depression (CES-D) [13] scale (a 20-item measure of the frequency of depressive symptoms over the past week) one week prior to their first study. The Perceived Stress Scale (PSS) [14] (a 10-item measure of perceived psychological stress over the previous month) was also administered at this time.

On the day of testing, subjects arrived at the Hospital Research Unit (HRU) of the Yale Center for Clinical Investigation (YCCI) at 8:00 AM in the fasted state. We chose to apply the stress stimulus in the fasted (rather than postprandial) state to avoid an anticipated wide range of postmeal glucose excursions in these older people, which could potentially mask any stress-related effects on glycemic control. Subjects were weighed and the abdominal circumference [15] was measured. Subjects then sat in a semirecumbent position for the placement of a catheter in an antecubital vein. A blood sample was drawn (15 cc) for the determination of basal glucose, insulin, and cortisol. At approximately 8:30 AM, the probe of the continuous glucose monitoring system (CGM) (MiniMed, Sylmar, CA, USA) was inserted subcutaneously in the abdominal wall and the CGM was calibrated while subjects sat quietly in the recumbent position for a 60 min equilibration period. Following the equilibration period, a baseline blood sample was drawn for the study substrates and stress hormones of interest. At about 9:30 AM, subjects then either sat quietly for 30 min reading or listening to music (seated control) or were given instructions about the tasks involved in the psychophysical challenge. Following the 30 min psychophysical challenge (or seated control condition), subjects sat quietly for another 30 min recovery period. Blood samples were taken every 15 min over the experimental (or control) and the recovery periods, and heart rate and blood pressure were measured continuously *via* an automated device (Colin Medical Instruments, Komaki, Japan), with recordings every 5 min. Interstitial glucose concentrations were also measured continuously during this time using CGM. Following the recovery period (∼10:30 AM), subjects were allowed to void and were moved from the testing chair to an adjacent bed in order to perform the 3 h OGTT. Following the OGTT (∼1:30 PM), subjects were fed a standardized lunch (60% carbohydrate; 20% protein; $\sim 32\,\text{kcal}\cdot\text{kg body weight}^{-1}/\text{day}$), instructed on the home use of CGM and provided with a standardized evening meal before being released from the HRU. Subjects were instructed to rest quietly for the remainder of the afternoon and evening, to eat their evening meal at ∼6:00 PM, and to retire by 10:00 PM. On the following morning, subjects were visited at home in order to obtain fasting blood samples of glucose and cortisol, as well as to remove the glucose sensor probe.

2.3. Psychophysical Stress Challenge. The automated psychophysical test (APT) (National Public Services Research Center, 1996) [16, 17] is a computerized series of *timed performance measures* such as simple reaction time, choice reaction, visual tracking, static and dynamic acuity, and information processing. The APT contains a battery of items that tests specific automobile driving-related perceptual and cognitive abilities developed by the National Public Services Research Institute. As we employed these driving-related tasks solely to elicit a stress response, we did not actually score their performance. Subjects were told, however, that we were testing their driving performance as part of a study on psychophysical abilities in older age and diabetes risk. To enhance the social evaluation component of the psychophysical challenge, performance was "monitored" with a shame video camera. Immediately after the challenge (or control), subjects rated their *level of perceived threat* using 8 visual analog (100 mm) scales.

2.4. Oral Glucose Tolerance Test. To measure transient disruptions in glycemic control following the stress challenge, a 75 g OGTT was performed according to the American Diabetes Association guidelines [18]. Blood samples (5 cc each) were collected before (−15, 0 min) and following (5, 10, 20, 30, 45, 60, 90, 120, 150, and 180 min) glucose ingestion for the determination of glucose and insulin concentrations. The OGTT was terminated when the glucose value for a given subject returned to be within $10\,\mathrm{mg\cdot dL^{-1}}$ of baseline; otherwise subjects were monitored over 3 hours.

2.5. Continuous Glucose Monitoring. Whole-day interstitial glucose profiles were collected over 24 hours using the CGMS. The device provided glucose pattern and trend data up to 288 times per day over 24 h [19, 20] by measuring interstitial glucose and converting it at a glucose oxidase interface to hydrogen peroxide, which was then oxidized to produce an amperometric signal [19]. This signal is proportional to the interstitial glucose concentration and is stored in the monitor. The stored amperometric data then were transferred and converted to glucose concentrations after data collection was completed using an infrared link to a personal computer and the data analyzed using the CGM systems solution software (version 3.0B). Four to six actual blood glucose values (obtained *via* glucometer (Medtronics, Sylmar, CA, USA)) were entered into the monitor in order to calibrate the interstitial readings. In addition to continuous readings, a number of summary data over a 24 h period were generated by CGM: (1) averaged premeal; (2) averaged 2 h postprandial; (3) 24 h averaged glucose concentrations.

2.6. Ratings of Perceived Stress and Threat. Upon completion of the psychophysical challenge, subjects rated their level of perceived stress and threat to social self using 8 visual analog (100 mm) scales [3]. These scales assessed: (1) how difficult the challenge was; (2) how confident they were in their performance; (3) how much they were personally involved in the challenge; (4) how controllable the situation was; (5) how threatening the situation was; (6) how much stress they were experiencing due to failure; (7) how much stress they were feeling due to time constraints; (8) how content they were with their performance. At one end of the scale was the rating of "not at all" (0 mm) and at the other (100 mm), the rating "extremely."

2.7. Stress Hormone and Substrate Analysis. All blood samples were analyzed in the core laboratory of the YCCI. Plasma *cortisol* concentrations were determined by radioimmunoassay (Diagnostic Products Corporation, Los Angeles, CA, USA). Plasma *glucose* was analyzed by the glucose oxidase method (YSI 2300, Yellow Springs Instruments, Yellow Springs, OH, USA). Plasma immunoreactive *insulin* concentrations were determined with a double antibody radioimmunoassay (Diagnostic, Webster, TX, USA).

2.8. Statistical Analysis. Univariate statistics ($\chi \pm$ SD) were first generated on all study variables for descriptive purposes. Total area and incremental area under the cortisol, as well as under the OGTT glucose and insulin curves (AUC), were determined by the trapezoidal method. In addition, we considered peak cortisol response, as well as the basal cortisol concentrations taken in the morning before and the morning after the psychological challenge to use in combination with the cortisol response curve as an additional indicator of integrated stress response. Mean differences in the physiological response variables between the two conditions were tested using paired t-tests. The relation between stress response and disrupted glycemic control (AUC and CGM summary variables) was determined using analysis of variance (ANOVA) for repeated measures. The original CGM data then were transferred into StatLab and were smoothed using cubic splines with an empirically selected smoothing parameter. Individual and pooled CGM data curves were examined by study condition to determine the degree of variability of response between the two conditions. Statistical significance was set at an alpha level of 0.05.

3. Results

The age of the study sample was 72 ± 9 years, with a range from 60 to 88 years. On average, subjects were overweight ($27 \pm 4\,\mathrm{kg\cdot m^{-2}}$), but were normotensive (127 ± 10/73 ± 10 mmHg) and had normal glucose tolerance based on 2 h postchallenge blood glucose concentrations from the screening OGTT ($130 \pm 22\,\mathrm{mg\cdot dL^{-1}}$). In addition, scores of depressive symptoms (9 ± 4) and perceived stress (12 ± 6) were within normative values for that age group (12,13). Not surprisingly, subject perception of the difficulty (56.8 ± 18.6 versus 3.7 ± 4.2 mm), threat (34.3 ± 30.3 versus 4.8 ± 5.7 mm), time stress (61.8 ± 39.4 versus 16.4 ± 28.0 mm), and failure stress (61.7 ± 34.3 versus 5.0 ± 5.8 mm) were significantly greater following the psychophysical challenge, compared with the control condition ($P < 0.01$). These perceptual data were corroborated by significant differences in cardiovascular responses in both systolic and diastolic blood pressure and heart rate between the two conditions ($P < 0.01$; Figure 1).

Average cortisol AUC response over the experimental and recovery period was not significantly higher during the stress relative to the control condition, with the exception of peak response at 30 min (10.6 ± 3.1 versus $8.6 \pm 2.6\,\mu\mathrm{g\cdot dL^{-1}}$, resp.; $P < 0.05$). When the data were stratified by median age, however, peak cortisol response from the stress condition was significantly amplified in subjects <70 years ($n = 9$) but reversed in those ≥70 years ($n = 8$) (Figure 2). For example, during the stress condition, 30 min cortisol concentrations increased from baseline by 22% ($P < 0.05$) in the younger subjects, but *decreased* by 7% in those aged 70 years and older. This variation in cortisol response was attributable to a significantly higher basal level in those ≥70 years, compared with their younger counterparts ($P < 0.05$).

The OGTT-derived glucose and insulin response curves following the stress and control conditions are shown in Figure 3. Although clearly elevated and indicative of

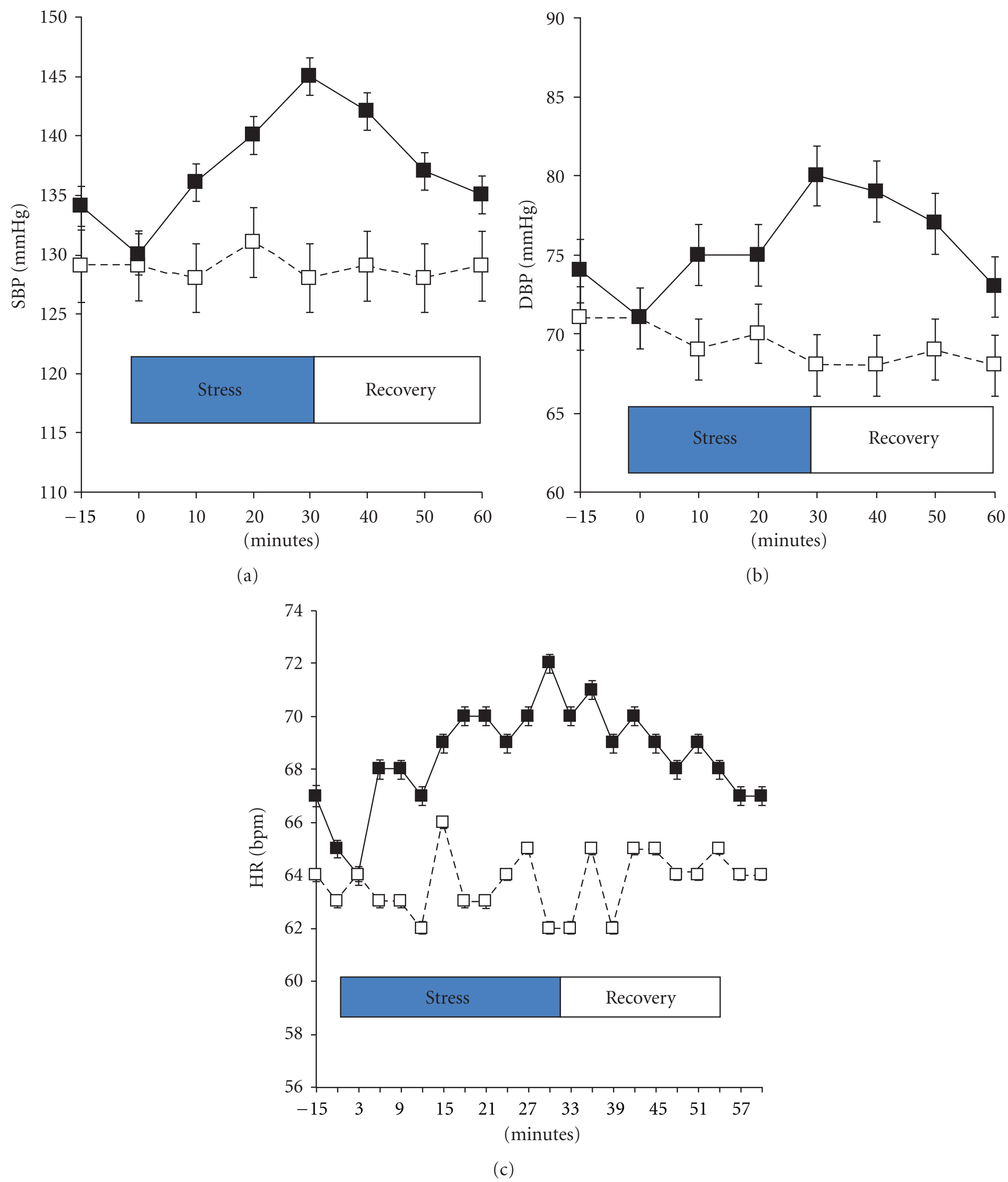

Figure 1: Differences in (a) systolic and (b) diastolic blood pressure and (c) heart rate response during the stress challenge (solid line) and control (broken line) condition. Data are mean ± se; $N = 17$.

impaired glycemic control, the curves are quite similar for the two conditions, with the exception of the peak glucose response shifting from 60 to 90 min and the peak insulin response shifting from 90 to 120 min following the stress condition. These findings were unaltered after stratifying the data by age group (<70/≥70 yrs). Of note in this figure, however, is the average 2 h glucose concentration from the screening OGTT, which is significantly lower (130 ± 22 $\text{mg}\cdot\text{dL}^{-1}$; $P < 0.05$) than 2 h values following either the stress (182 ± 43 $\text{mg}\cdot\text{dL}^{-1}$) or control (174 ± 60 $\text{mg}\cdot\text{dL}^{-1}$) conditions. Glucose curves obtained *via* CGM over 24 h are displayed for each condition in Figure 4 and suggest a rightward shift and a 30–40 min delay in peak postchallenge glucose response following the stress condition, with glucose levels elevated relative to the control condition for as long as 6 hours afterward. We observed no difference, however, in averaged 24 h glucose concentrations (111.7 ± 12.3 versus 114.0 ± 24.0 $\text{mg}\cdot\text{dL}^{-1}$), or averaged prelunch concentrations (130.7 ± 43.9 versus 129.7 ± 47.0 $\text{mg}\cdot\text{dL}^{-1}$) between the two conditions, although averaged 2 h postlunch glucose concentrations (measured at approximately 4 PM) were slightly higher following the stress compared with the control

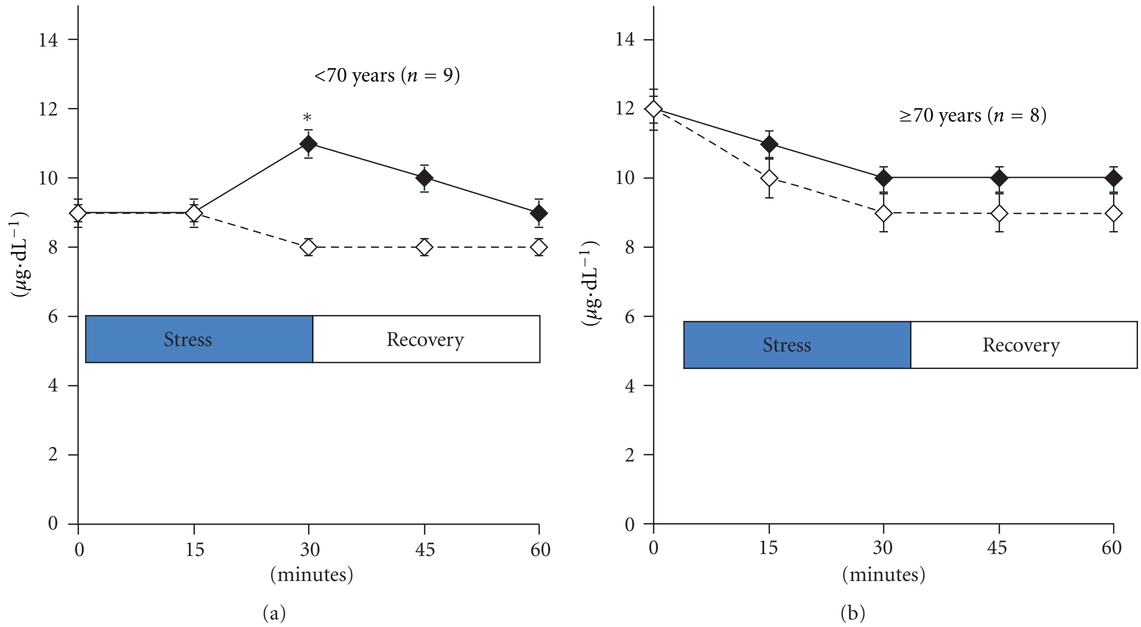

FIGURE 2: Cortisol responses between the stress condition (solid line) and the control (broken line) condition by age group. Age groups are based on the median cut point of the distribution. Data are mean ± se; $N = 17$; $^{*}P < 0.05$.

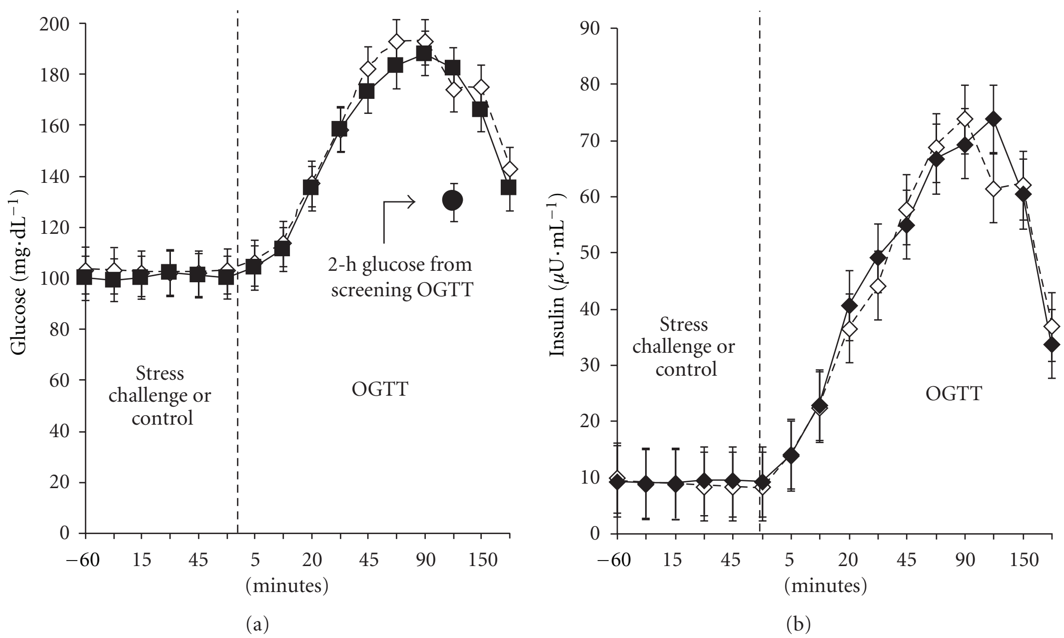

FIGURE 3: Glucose and insulin responses over the experimental period and the OGTT between the stress (solid line) and control (broken line) conditions. Data are mean ± se; $N = 17$. To convert to the International System of Units (mmol), multiply glucose values by 0.055.

condition (106.6 ± 22.3 versus 96.9 ± 12.3 mg·dL^{-1}, resp.; $P < 0.07$). Variability of glycemic response appeared greater following the stress, compared with the control condition; however, differences in the estimates of mean skewness (0.70 ± 0.51 versus 0.57 ± 0.56, resp.) and kurtosis (3.38 ± 0.91 versus 3.04 ± 1.22, resp.) were not statistically significant.

4. Discussion

Adaptation to stress frequently involves the activation of the hypothalamic pituitary adrenal (HPA) axis in order to mobilize energy stores. Although the anti-insulin and glu-coneogenetic actions of cortisol appear consistent with this

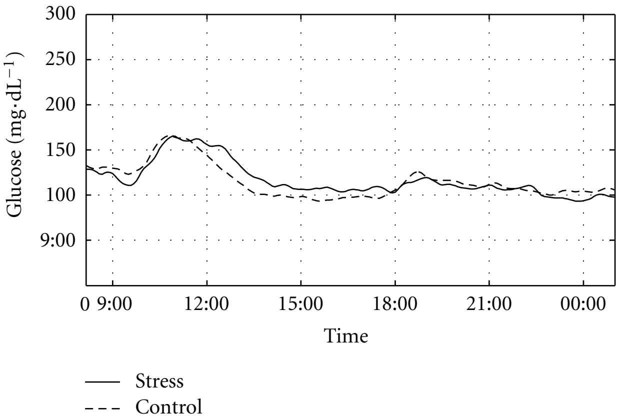

Figure 4: Glucose response curves obtained over 24 h *via* CGMS following the stress (solid line) or control (broken line) conditions. Data are mean values; Time = time of day; $N = 17$. To convert to the International System of Units (mmol), multiply glucose values by 0.055.

notion, there is limited experimental evidence to support this idea [8]. We observed significant evidence of perceived stress and cardiovascular engagement to a 30 min psychophysical stressor among healthy older people, although HPA response appeared somewhat blunted relative to responses observed in other studies of older people [21, 22]. We did observe that our oldest study subjects (i.e., ≥70 years) had significantly greater basal cortisol concentrations compared with younger (<70 years) subjects, which is consistent with what has been proposed by Seeman and Robbins [23] and perhaps reflects the allostatic burden of aging, as the perceived stress scores were significantly higher in the oldest subjects compared with the younger subjects (14.4 ± 5.2 versus 9.5 ± 5.8; $P < 0.05$). Contrary to what we hypothesized, 3 h post-OGTT glucose and insulin concentrations were elevated equally under both conditions, suggesting little effect of the stress challenge *per se* on short-term glycemic control in those both older and younger than 70 years. Moreover, the CGM data provided evidence that tight glucose homeostasis may be only minimally altered following a stressful episode in healthy older people. Any subtle differences in glycemic control apparent up to 6 h after challenge had completely dissipated by 24 h, and CGMS data averaged over 24 h indicated no differences in overall response following the stress and control conditions. Whether these findings are indicative of heightened resiliency in successful (relative to normal) aging, of normal aging-specific homeostatic control, or of methodological differences between our study and others is not clear.

In general, studies that applied stressors during the fasted state observed significantly blunted cortisol and negligible glycemic responses [8, 9] compared with stress applied in the postprandial state [8, 9, 24], suggesting that ready access to energy is necessary for the permissive effects of HPA reactivity on glycemic control. We applied the psychophysical stress in the fasted state (thinking that prevailing glucose stores would be ample in this older population and wishing to avoid large postmeal glucose excursions), which more than likely explains the blunted cortisol response and minimal stress effects on 3 h postchallenge metabolic control.

Interestingly, 2 h postchallenge glycemic responses to the OGTT (measured at ~12:30 PM) were markedly elevated in both the stress and control conditions, compared with the early morning screening OGTT (182 ± 43 versus 174 ± 60 versus $130 \pm 22\,\mathrm{mg\cdot dL^{-1}}$, resp., for the stress, control, and screening conditions). These previously reported late-morning exaggerated glycemic excursions [25] may be attributed to the diurnal drop in insulin secretion reported in older people at this time of day [26] and more than likely prevented any further stress-related disruption. However, there is also other evidence that a stress challenge does not increase overall glycemic response, but rather shifts the peak response to the right, suggesting a stress-related *delay* in glucose absorption by the gut [23]. Our postchallenge glucose and CGM response curves are consistent with this delayed absorption phenomenon, as are the prevailing insulin concentrations from the OGTT, as the peak insulin response shifted from 90 min to 120 min. Nonetheless, if we consider the OGTT as the trigger for setting the stress-induced allostatic control response in motion, we observed only slight alterations with this control following the stress compared with the control condition—evidenced by the small lag in peak glucose response at 30–40 min after challenge, the slower rate of glucose clearance over the subsequent 6 hours (but not beyond), and the slightly greater individual variability in glycemic control. Consistent with HPA reactivity studies performed in the postprandial state [8, 9, 24], greater fuel availability 2 h following refeeding may have contributed to greater averaged postlunch glucose concentrations following the stress relative to the control condition, despite the fact that prelunch values were similar. These subtle differences would not have been detected without the use of CGM over 24 h.

The issue of selective survival is an important consideration when performing challenge studies in people who are in their 8th and 9th decades of life. Indeed, one hallmark of successful aging is a greater physiological resiliency to various environmental perturbations compared with people who have not survived to that age or who could not meet inclusion criteria for the study. Thus, although we used a stressor that mimics challenges often encountered daily in real life, it may not have been of sufficient intensity or duration for such a robust older population. This issue of an insufficient stimulus may be particularly problematic given the degree of inter- and intraindividual variability in physiological response to stress that was evident in our data and those of others [21, 27]. Also, the stress challenge was applied in the morning, when glucose concentrations were at their lowest. Had we performed the stress challenge in the later afternoon, when cortisol concentrations reach their daily nadir, we likely would have observed a greater relative increase in HPA response as others have [21, 22]. However, due to a possible diurnal drop in insulin secretion in the late afternoon, glucose responses under both conditions would have been exaggerated even more than we observed, thereby further masking any stress-induced effects.

In conclusion, the true nature of the relationship between stress and glucose homeostasis remains elusive and may be influenced by a number of individual, environmental, or temporal conditions. Our use of CGM allowed us to unmask some subtle short-term stress-related disruptions, but these alterations dissipated over 24 h in this healthy sample. On the other hand, given the number of environmental (e.g., driving, shopping) and psychological stressors encountered daily among the general population of older people, these findings may have greater relevance for less robust people with already-existing impairments in glucose control or with diabetes.

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