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SOCIAL LINKAGES TO BIOLOGICAL MARKERS OF HEALTH AMONG THE ELDERLY

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Summary. The social environment and exposure to life challenge affect a person's physical and emotional well-being. The present research uses a population-based study of the elderly in Taiwan to elaborate the cumulative physiological costs – as reflected in biological markers of risk factors known to have adverse consequences for health – of challenge and unfavourable position in social hierarchies and networks. Overall, biological markers of risk among the elderly are similar in Taiwan and the United States. However, male and female Taiwanese elderly are at lower risk for illness associated with indicators of DHEA-S, while women are at higher risk for illness associated with elevated blood pressure, and men at lower risk for illness associated with total/HDL cholesterol, and glycosylated haemoglobin. There are strong and statistically significant effects of position in social hierarchy (education) and challenge (recent widowhood and a perception of high demands) on an index of cumulative risk (allostatic load). Membership in social networks and participation in social activities have expected, but not statistically discernible, effects.

Introduction

Over the last two decades, social scientists and medical researchers alike have found a rich source of insight into understanding health and illness in the examination of social status and connection. Similarly, links between health and the experience of stress have been elaborated.

Conditions or events that individuals react to as being stressful abound. Illness, relocation, work-related events, and familial demands are all examples of environmental challenge. The effects of challenge may be immediate or may be reflected as a cumulative response to repeated challenge over the course of a lifetime. Aging is associated with losses of many kinds, and more generally, the elderly are particularly vulnerable to challenges that are ordinarily perceived as unusually stressful. The loss of a spouse, relatives or friends through death, the deterioration of physical or cognitive function, involuntary migration or change of residence, retirement and the loss of life-defining work are all changes that are commonly associated with aging.

To date, most research has focused on either the social or the biological correlates of health; few studies have been able to link data from social surveys with data on physiological response. Over the past 5 years the authors have worked on a project that allows new biological and health examination data to be brought to the task of explicating and interpreting how these factors interact. As a first step towards realizing plans for a larger initiative, a pilot study was fielded in Taiwan that collected both self-reported and physiological data from about 100 participants who resided in a single geographic area in Taiwan that included both an urban and a rural setting. The pilot data have been grafted onto survey data that were collected from the same respondents over the previous 10-year period. Jointly, they allow the exploration of multiple dimensions of the social environment–health-challenge nexus.

The focus of this paper is on the cumulative physiological costs of exposure to challenge and unfavourable position in social hierarchies and networks. Using an index of 'allostatic load' as a measure of those costs, the level of the components of allostatic load in the pilot population is documented, these components are compared with their levels in a US sample from the MacArthur Study of Successful Aging, and the links between allostatic load and the social environment and challenge are examined.

Theoretical background

Social environment

A large literature documents the importance of social connection for a variety of health outcomes, including survival, disability and chronic illness (e.g. Bowling, 1991; Broadhead, Kaplan & James, 1983; House, Landis & Umberson, 1988; Lynch *et al.*, 2000; Rogers, Hummer & Nam, 2000). Early research in this area (dating as far back as the mid-1800s) focused largely on marital status, but more recent efforts have broadened their scope to examine the extent to which different aspects of social connection are linked to health status. Virtually all studies have found large differences in health outcomes (i.e. mortality, functional disability and illness) by marital status, with married individuals faring better than their unmarried counterparts (Hu & Goldman, 1990), and most studies have found important differences in health outcomes as a function of various aspects of social connection such as social integration, perceived emotional support, and the presence of an intimate relationship (Bassuk, Glass & Berkman, 1999; Fratiglioni *et al.*, 2000; Seeman & Crimmins, 2001; Thoits, 1995).

In spite of extensive research, understanding of the underlying pathways linking these factors to health outcomes remains poor. One reason is that many earlier studies are plagued by methodological problems and data limitations (Korenman, Goldman

& Fu, 1997). Many data sets that have been used to investigate the association between social environment and health are cross-sectional and lack detailed data on social environment and health status; they do not allow controls for changes in social environment and health status over time or distinguish between distinct components of the social environment (e.g. social networks vs social support).

Promising research focusing on social connection and health has come from a group of prospective community studies, designed primarily to examine the role of social networks and social support on adult mortality (House, Robbins & Metzner, 1982; Blazer, 1982; Schoenbach *et al.*, 1986; Berkman & Breslow, 1983; Welin *et al.*, 1985; Zuckerman, Kasl & Ostfeld, 1984). Although results have not always been consistent across studies, the evidence suggests that persons with little social integration are at greater risk of dying, even in the presence of controls for initial health status (see House *et al.*, 1988).

Social support may be especially important during old age when individuals face the greatest risk of illness, disruption in their sources of support, and experience more serious and chronic forms of life events (Sherbourne *et al.*, 1992). Recent studies of the elderly (e.g. Goldman, Korenman & Weinstein, 1995; Shye *et al.*, 1995; Beckett *et al.*, 2002) confirm the importance of the social environment on the health of elderly men and women.

Socioeconomic status mediates both the exposure to, and impact of, life changes in the form of life events, chronic strains and daily hassles (Cohen, 1988; House *et al.*, 1994; McLeod & Kessler, 1990). Both life events and chronic difficulties have been shown to be associated with physical morbidity, mortality and psychiatric disorders (Thoits, 1995). Considerable evidence suggests that chronic strains are more prevalent among lower socioeconomic strata than among those who are well off (House *et al.*, 1994; Theorell, 1982; Thoits, 1983, 1995; Pearlin *et al.*, 1981).

Financial assets can cushion the impact of challenges that do arise, and education may provide knowledge of and access to resources that reduce their impact. And, while the exact mechanisms are not well understood, there is substantial evidence that social contact not only reduces the negative effects of life events and strains, but also affects the perception and interpretation of events (Cohen & Wills, 1985; House *et al.*, 1994; McLeod & Kessler, 1990; Denenberg & Zarrow, 1971; Levine *et al.*, 1967; Meaney *et al.*, 1988, 1989).

Social factors and physiological expression

Less attention has been given to the effects of social factors on the expression of biological or physiological parameters (Seeman & McEwen, 1996) than to health and longevity (but see Diez-Roux *et al.*, 1999, 2000; Kawachi & Kennedy, 1999; Seeman & Crimmins, 2001); however, only this information can help to identify the pathways through which social circumstances influence health outcomes. In a review of 81 studies linking social support to physiological function, Uchino, Cacioppo & Kiecolt-Glaser (1996) conclude that there is strong evidence relating social support to aspects of the cardiovascular, endocrine and immune systems.

Positive aspects of social interaction have been found to predict lower physiological arousal while negative interactions are associated with increased cardiovascular and neuroendocrine activity; relative social status and quality of social relationships emerge as especially important variables (Seeman & McEwen, 1996; Uchino *et al.*, 1996). For example, children exposed to more negative social environments (e.g. less nurturance and greater conflict) are more likely to exhibit dysregulated cortisol activity and show greater cardiovascular and sympathetic nervous system reactivity to challenge (Seeman *et al.*, 1993; Repetti, Taylor & Seeman, 2002). Among adults, progression of atherosclerosis has been linked to psychosocial factors such as job demands and low socioeconomic status (Lynch *et al.*, 1998; Everson *et al.*, 1997).

Results from the MacArthur Study of Successful Aging (e.g. Seeman *et al.*, 1994) confirm that positive levels of support lead to reduced neuroendocrine activity. The findings show large sex-related differences in neuroendocrine response, consistent with results from many sociological and epidemiological studies that have identified stronger and more consistent associations between social relationships and health for men.

Having a supportive friend is related to lower cardiovascular reactivity to challenge (Kamarck, Manuck & Jennings, 1990; Kirschbaum *et al.*, 1995), while marital conflict is associated with physiological arousal including high blood pressure and elevated levels of pituitary and adrenal hormones (Ewart *et al.*, 1991; Levenson, Carstensen & Gottman, 1994; Malarkey *et al.*, 1994; Orth-Gomer *et al.*, 2000; Ryff & Singer, 2000).

Allostatic load

The association between exposure to stressors (both negative events and chronic strains) and physical and mental disorder has been well documented. Stress has been shown to be linked to the development of type II diabetes (McEwen & Stellar, 1993), cardiovascular disease (Brosschot *et al.*, 1994), immune function (Evans *et al.*, 1995; Birmaher *et al.*, 1994; Easterling *et al.*, 1994; Cohen, Tyrrell & Smith, 1991) and the symptoms, expression and seriousness of chronic illness (Bedell *et al.*, 1977; Wyler, Masuda & Holmes, 1971; Weiner, 1992).

Stressful experiences cause a chain of physiological reactions, 'interrupting' normal homeostatic processes, and readjusting them for response to the stressor. These include alterations in the release of hormones and neurotransmitters that interact in complex ways with intricately interrelated systems to produce normal function.

Allostasis refers to the balance among physiological systems fluctuating to meet demand from external forces (McEwen & Stellar, 1993; McEwen & Seeman, 1999; McEwen, 2000). 'Allostatic load' refers to the cost of chronic exposure to fluctuating or heightened neural or endocrine response resulting from continual environmental challenges. Involved in allostatic load are elevated levels of neuroendocrine, immunological and sympathetic nervous system reactivity and the accompanying strain on multiple organs and tissues resulting from repeated fluctuations in physiological response. The accrual over long periods of high allostatic load can lead to organ-system breakdown, impaired immune response, elevated cortisol and insulin secretion, and ultimately, a range of chronic disease outcomes including coronary heart disease, diabetes, depression and musculo-skeletal problems. The advantage of the allostatic load approach is that it provides a summary measure of risk, encompassing risks accumulated across systems – e.g. cardiovascular, hypothalamic–pituitary–adrenal axis, sympathetic nervous system – each contributing to risk for various types of pathology. Higher levels of allostatic load have themselves been linked to previous life experiences of relatively greater socioeconomic or psychosocial deprivation (Kubzansky, Kawachi & Sparrow, 1999; Seeman *et al.*, 2002; Singer & Ryff, 1999).

Hypotheses

In Taiwan, as in other locations, education, occupation and income are important determinants of position in social hierarchy. Education, in particular, is a critical determinant of social status and upward mobility on the island and has held a central role in Chinese culture dating back at least as far as the Han dynasty (206 BC; Mote, 1971). This traditional value placed on education in Chinese culture has, if anything, increased in Taiwan since the end of the Japanese colonial period in 1945 and the influx, in 1949, of Chinese from the mainland (Egan, 1994; Lin, 1947; Waley, 1949; Smith, 1981; Fricke, Chang & Yang, 1994). Higher position in social hierarchies, particularly education, are expected to be inversely related to allostatic load.

Taiwanese society has traditionally been highly stratified by sex. The lower autonomy and position of women in Taiwan are expected to result in higher levels of allostatic load for women than for men.

Familial ties are central in Taiwanese culture (Fricke *et al.*, 1994). Interactions with family members – particularly with spouse and children – and the potential strains that arise from them, are expected to have important effects on health. Specifically, more frequent contact with non-resident children is expected to be associated with a lower level of allostatic load. The relation between allostatic load and having one or more co-resident children is less clear. Traditionally, elderly Taiwanese have expressed preferences for living with their adult sons, but preferences, expectations and actual experience over the last two decades suggest that this pattern is undergoing transformation (Weinstein *et al.*, 1990, 1994). Given these changes, the relation between co-residence and allostatic load may well depend upon whether the elderly parent's preferences are being realized. Therefore, in the aggregate, the authors have no prior expectation about the direction of the relationship.

Other measures of the respondent's social network – chronically low levels of association with friends and participation in social activities – are expected to be associated with higher levels of allostatic load.

Finally, exposure to stressful experience is expected to be directly associated with this measure: people who experience a greater number of stressful events will have higher levels of allostatic load.

Data and methods

Pilot study protocol and data

Between December 1997 and January 1998 the authors conducted a pilot study that was designed to test the feasibility of collecting biological and medical data that included a 12-hour urine specimen from a population-based sample of the elderly. The study was conducted in Taichung, Taiwan, a township that includes both rural and urban settings. The goal was to obtain a sample size of approximately 100 elderly Taiwanese who had participated in early rounds of the Study of Health and Living Status of the Elderly in Taiwan (Chang & Hermalin, 1989).

The pilot data collection initiative included: (1) self-reported information on demographic and background variables; (2) a non-invasive health examination by a physician; and (3) markers of biological function and genetic endowment based on assays of blood and urine specimens. In this paper, ten measures are used for which there are comparable data for the elderly in the United States from the MacArthur Study of Successful Aging.

Prospective participants were first contacted by letter from the Director of the Taiwan Provincial Institute of Family Planning (TPIFP), which in 2001 was reconstituted as the Center for Population and Health Survey Research, Bureau of Health Promotion, Ministry of Health. The letter was followed by a visit from the local public health nurse who explained the study to the prospective participant, conducted a brief demographic and health interview, and scheduled a physical examination for the participant in the local hospital. The night before the hospital appointment, a member of the TPIFP staff visited the participant, explained the 12-hour urine collection procedure, answered questions, and obtained formal agreement to participate. On the morning of the hospital exam, a TPIFP staff member went to the respondent's home, collected the urine specimen, accompanied the study participant to the hospital (where she continued to conduct the participant through the hospital protocol), and administered a questionnaire regarding the blood and urine specimens. At the hospital, the participant was examined by a physician and provided blood and spot urine specimens. The participants were provided with breakfast at the hospital, were given a small gift of appreciation, and were accompanied back to their homes by a member of the TPIFP staff.

The biological measures used in the subsequent analysis are based on the overnight urine collections, blood specimens and physical assessments. As of the evening prior to the hospital examination, participants collected all urine voided over a 12-hour period (7 pm to 7 am) in a cold-storage container provided by a staff member and refrained from eating between midnight and the completion of their physical examination the following morning. The urine specimens provided integrated estimates of cortisol, adrenaline and noradrenaline; results for these measures were calibrated to creatinine levels in order to adjust for differences in absolute levels of the urine parameters that are related to differences in body size. Creatinine is excreted at a steady rate that is proportional to total muscle mass so the adjustment by grams of creatinine in the total urine sample provides standardization for differences related to the concentration of the hormones in the urine specimen as well as any missing portions of the 12-hour urine collection. Blood samples provided estimates of dehydroepiandrosterone sulphate (DHEA-S), high-density lipoprotein (HDL) and total cholesterol, tricylcerides, glycosylated haemoglobin, a full blood work-up (including red and white blood counts, haemoglobin, haematocrit, platelets and measures of liver and renal function), and Apoliprotein-E (APOE) genotype. The Union Clinical Laboratory (UCL) in Taipei, Taiwan, performed all blood and urine

Table 1. Outcome of pilot study recruitment efforts

Township	Target sample size	Blood and urine collected	Urine only collected	Died (since 1996)	Non-response or refusal	Response rate (%)*
Taichung City						
Total	69	43	4	3	19	65
Area 1	30	20	3	1	6	69
Area 2	39	23	1	2	13	62
Taichung County						
Total	100	67	3	13	17	77
Area 3	37	27	2	4	4	82
Area 4	63	40	1	9	13	74
Total Township	169	110	7	16	36	72

*Calculated as: respondents who provided urine and blood specimens divided by the number of respondents alive at the time of the study.

specimen assays that are reported in this paper. In addition to the routine standardization and calibration tests performed by the laboratory, duplicate samples of a subset of the specimens were sent to UCL and to Quest Diagnostics in order to assess both the reliability and the validity of the assays.

The physical assessments included blood pressure readings (based on an average of two seated readings taken with a mercury sphygmomanometer, with the respondents in a seated position) and measurements such as waist and hip circumference, and height and weight. In addition, an abdominal ultrasound provided information on measures of liver and renal function.

As shown in Table 1 co-operation was high: in the urban area (Taichung City), complete participation was obtained from 65% of the target sample who were still alive at the time of the interview; in rural Taichung, an even higher percentage (77%) participated.

About 10% of the target sample had died in the year and a half between the previous interview and the pilot study. Elderly residents of Taiwan are eligible for a yearly health examination under the National Health Program. Not surprisingly, as shown in Table 2, the single most common reason that respondents gave for refusing to participate (in part or altogether) was that they had only recently had a physical examination.

The participants in the Taiwan study ranged in age from 67 to 94 years; the mean age of the men was 72·4 years, and that for women was 72·8 years. As shown in Table 3, most participants were aged between 70 and 74 years.

Prior survey data from Taiwan

In addition to the pilot data, this study exploits longitudinal data that incorporate a rich range of historical and current information on demographic, social, economic

Table 2. Reasons for non-response, refusal or incomplete specimen collection

Reason	Number
Problems locating respondent	
Temporarily out of the country	4
Out of Taichung	2
Other	3
'Medical' reasons	
Hospitalized or institutionalized	2
Too 'old' or not well enough to participate	4
Too well to need physical examination	2
Just had physical examination	10
Afraid of having blood drawn	2
Afraid of worrying about test results	1
Other	
Too busy	2
Respondent or family refused, no reason given	3
Agreed to participate, but did not do so	6
Not specified	2

and health-related characteristics and experiences. This study, the Survey of Health and Living Status of the Elderly in Taiwan, was originally fielded in 1989 (Chang & Hermalin, 1989). Interviews with 4049 persons aged 60 and above were completed, representing a response rate of 91·8%. Unlike most data on the elderly, the full population, not just the non-institutionalized, is included in the study. Re-interviews of the original cohort of elderly people have been done at intervals of approximately 3 years; in 1996 an additional 'near-elderly' cohort of persons aged 50–66 was interviewed.

These data are richer than most other demographic and health surveys of the elderly in several respects. The data include detailed information on all household members and potentially important social ties (e.g. all children, parents, other relatives and friends and neighbours not living in the household). They include the type and frequency of contacts and the nature of instrumental and financial exchanges in which the respondent is the provider or recipient. An important aspect of these data, typically neglected in other surveys, is the potentially *negative* interactions resulting from these social ties, such as heavy demands being placed upon the respondent. The survey data also include information on life challenges, both acute life events that are likely to have relatively long-term effects, and chronic adverse social and economic circumstances.

MacArthur data

The MacArthur Study of Successful Aging was a longitudinal cohort study focusing on high-functioning men and women and designed to identify factors

Table 3. Age distributions of the samples by sex, Taiwan and US data*

			MacArthur Study of Successful Aging					
	Taiwan		High functional status		Medium functional status		Low functional status	
Age (years)	Males n (%)	Females n (%)	Males n (%)	Females n (%)	Males n (%)	Females n (%)	Males n (%)	Females n (%)
65–69	15 (27·8)	12 (25·5)						
70–74	28 (51·9)	21 (44·7)	210 (58·7)	211 (56·9)	10 (43·5)	15 (45·5)	10 (45·5)	9 (45·0)
75–79	6 (11·1)	10 (21·3)	140 (39·1)	152 (41·0)	13 (56·5)	18 (54·6)	12 (54·6)	11 (55·0)
80+	6 (9·2)	4 (8·5)	8 (2·2)	8 (2·2)				
Total	54 (100·0)	47 (100·0)	358 (100·0)	371 (100·0)	23 (100·0)	33 (100·0)	22 (100·0)	20 (100·0)
Mean (SD)**	72·4 (5·5)	72·8 (5·1)	74·0 (2·7)	74·2 (2·8)	75·2 (3·0)	74·5 (2·7)	74·9 (2·5)	75·2 (2·1)

*Column percentages may not sum to 100 because of rounding.
**Overall mean (SD) for the MacArthur Study of Successful Aging: males (N=403), 74·1 (2·7); females (N=424), 74·3 (2·7).

associated with successful aging. Subjects were selected in 1988 from the East Boston, MA, Durham, NC, and New Haven, CT, sites of the Established Populations for the Epidemiologic Study of the Elderly (EPESE) based on criteria designed to identify those in the top third of those aged 70–79 years with respect to physical and cognitive function. In addition to this sample of high-functioning individuals, data were also collected for two comparison groups of 70–79-year-olds: 80 medium- and 82 low-functioning individuals. Additional details of the data collection are described in Berkman *et al.* (1993) and Seeman *et al.* (1997). Age was restricted to reduce the impact of age differences in health and functioning and permit evaluation of other factors, including behavioural, social and psychological factors. Participants were asked to complete a 90-minute face-to-face interview that included detailed assessments of physical and cognitive functioning and performance as well as biomedical and health status measurements; they also provided blood specimens and a 12-hour, overnight urine sample (Berkman *et al.*, 1993; Seeman *et al.*, 1997). The age distribution for this sample is shown in Table 3. The mean age of the men in the study was 74·1 years and that for women was 74·3 years.

Variable construction

Allostatic load. The realization of allostatic load is based on prior research that suggests that the measure is a good predictor for (subsequent) cardiovascular disease, cognitive function and physical performance based on measures of balance, gait, chair stands, foot taps and manual ability (Seeman *et al.*, 1997) and that it reflects prior psychosocial experience (Singer & Ryff, 1999; Seeman *et al.*, 2002). Based on data from various domains of physiological regulation, including the cardiovascular, hypothalamic–pituitary–adrenal and sympathetic nervous systems, measures were selected to represent either direct or indirect markers of regulatory activities that contribute to 'wear and tear'. Parameters included are: (1) systolic and diastolic blood pressure (measures of cardiovascular activity); (2) the waist/hip ratio (indexing metabolism and adipose tissue deposition); (3) urinary cortisol (hypothalamic–pituitary–adrenal axis activity); (4) urinary adrenaline and noradrenaline levels (sympathetic nervous system); (5) blood plasma levels of glycosylated haemoglobin (glucose metabolism); (6) serum DHEA-S (hypothalamic–pituitary–adrenal axis and cardiovascular risk); and (7) serum HDL and HDL/total cholesterol ratios (long-term atherosclerotic risk). In this study, as in the MacArthur study, allostatic load is calculated as the sum of the number of parameters for which individuals fell into the highest-risk quartile over each of the components. The highest-risk quartile is the highest quartile for all parameters except HDL cholesterol and DHEA-S levels; in these two cases the lowest quartile is associated with the highest risk of chronic disease (see also Seeman *et al.*, 1997, 2001).

Position in social hierarchies. Indicators of position in social hierarchies comprise the respondent's sex, education, average income between 1989 and 1996, and the occupation of the respondent (or her husband if the respondent was female). Education was based on data collected in 1989 in response to the question, 'What is the highest level of school you attended?' Five persons who reported that they could read, but who did not report a grade level, were treated as having completed primary school. Average income was based on three questions. In 1989, respondents were asked, 'At present, what is the total money income you and your spouse receive in a month?' In 1993, the question was, 'Approximately what is your total money income per month?' In 1996, respondents were asked, 'How much total income did you and your spouse receive last year?' Responses for 1989 and 1993 were recorded in categories. In 1996 an exact amount was used for those who provided it; for the remainder, income was reported in categories. The 1996 responses were recoded to correspond to the 1989 and 1993 categories. Average income is based on the maximum number of non-missing responses. Occupational status is based on the respondent's 1989 response to the question, 'What is/was your major occupation?' for male respondents; husband's occupational status was used for female respondents in the sample. The score uses Tsai & Chiu's (1991) socioeconomic index for Taiwanese occupations; higher scores reflect higher occupational status.

Position in social networks and social connection. The choice of indicators for characterizing the respondent's position in social networks is guided by previous work on the Taiwan Study survey data (Beckett *et al.*, 2002). Three measures are used: (1) the extent to which the respondent's participation in social activities is chronically poor; (2) the extent to which the number of friends or neighbours that the respondent sees or talks with at least weekly is persistently low; and (3) the respondent's contact with his/her children. The extent to which the respondent's participation in social activities is chronically poor is operationalized by summing the number of survey dates at which s/he reports engaging in fewer than the median number of activities reported by the sample as a whole. An analogous construct based on the number of friends or neighbours that the respondent sees or talks with at least weekly is used to measure the degree to which the respondent has a chronically low level of social contact. Two separate dimensions of contact with children are used: first, the number of survey dates at which the respondent reported visiting weekly or more often with at least one non-resident child; and second, the number of survey dates at which the respondent reported that s/he co-resided with a child.

Exposure to challenge. Five measures are used to characterize each respondent's exposure to challenge: (1) whether the respondent was widowed between 1989 and 1997 (information on whether the spouse was still living was collected at the time of the pilot study as well as in 1989, 1993 and 1996); (2) whether the respondent had a child who died between 1989 and 1996; (3) the extent to which people placed demands on the respondent; (4) whether the respondent experienced financial difficulties; and (5) whether the respondent reported having a spouse in poor health.

The measure of the extent of demands placed on the respondent is based on the sum of three questions in 1989 and one question in 1993. In 1989, respondents were asked, 'How much do you feel your spouse/children/friends, neighbours or relatives make too many demands on you?' In 1993, respondents were asked, 'Do you feel that the people close to you make too many demands on you (e.g. daily life demands, material or financial demands, or demands for taking care of the household)?' Each instance in which the respondent reported that demands were made on him contributed to the sum.

At each of the survey dates, the respondent was asked whether he/she was satisfied with his/her financial situation or whether he/she was experiencing difficulties attributable to his/her financial situation. Chronic financial problems are defined as dissatisfaction or difficulty with finances at two or more surveys.

The final measure of challenge is based on the respondent's report of the health of his/her spouse. In 1993, a respondent who reported that his/her spouse was in 'excellent, very good, or good' health was treated as having a spouse in good health; otherwise, he/she was characterized as having a spouse in poor health. In 1996, a respondent who reported that his/her spouse's health was 'not so good' or 'poor' was treated as having a spouse in poor health. The summary variable classifies respondents as having a spouse in poor health based on such a report in either year.

Methods

The analyses consist of two parts. The first section compares mean levels for each of the biomarkers in Taiwan and the United States. The second part examines the associations among social factors, challenge and allostatic load. Bivariate correlations between allostatic load and each of the social factors and challenges are presented along with a regression analysis. However, owing to the small sample size, which constrains the power of the regression analysis, and to high correlations among some of the factors, the number of explanatory variables used in the multivariate model is limited.

Results

Mean values of the biomarkers: Taiwan/US comparisons

Data are presented for 101 Taiwanese respondents who had valid measures for all of the ten components of allostatic load, and for a total of 827 participants in the MacArthur study. The MacArthur data are shown categorized by functional status (although sample sizes are small for the low and medium functional categories). Because of the small pilot sample size, the Taiwan data have not been disaggregated by functional status.

Table 4 presents 95% confidence intervals for each of the parameters of the index of allostatic load by sex for theTaiwan data and for data from the MacArthur Studies of Successful Aging (Seeman *et al.*, 1997).

Overall, average levels of these biomarkers are similar across the two populations, but there are a few notable differences. DHEA-S measures for both men and women in Taiwan appear to be higher on average than for their US counterparts. For women, blood pressure is higher in Taiwan than in the US, while for men, the total cholesterol/HDL ratio, glycosylated haemoglobin and noradrenaline are lower in Taiwan than among US men in the MacArthur sample. On the whole, however, controlling for sex, average values for these biomarkers are similar in the US and Taiwan studies.

Table 4. Components of allostatic load: means and 95% confidence intervals by sex, Taiwan and US data

Sex and allostatic load parameter	Taiwan data	MacArthur high functional status	MacArthur medium functional status	MacArthur low functional status
Males	*n*=54	*n*=358	*n*=23	*n*=22
Systolic BP	141·4 (135·4, 147·4)	137·6 (135·6, 139·5)	143·3 (135·2, 151·5)	139·5 (127·5, 151·3)
Diastolic BP	81·4 (78·6, 84·2)	77·2 (76·1, 78·3)	83·1 (77·6, 88·7)	82·3 (76·1, 88·5)
Waist–hip ratio	0·91 (0·89, 0·93)	0·94 (0·93, 0·95)	0·96 (0·93, 0·99)	0·94 (0·91, 0·97)
Total cholesterol/HDL ratio	4·2 (3·9, 4·5)	5·3 (5·1, 5·5)	5·2 (4·5, 5·9)	5·3 (4·4, 6·3)
Total glycosylated haemoglobin	5·9 (5·7, 6·1)	6·9 (6·7, 7·1)	6·9 (6·1, 7·8)	7·7 (6·8, 8·6)
Cortisol*	21·1 (17·8, 24·4)	19·9 (18·2, 21·6)	13·6 (10·8, 16·5)	21·2 (9·8, 32·6)
Noradrenaline*	29·4 (25·2, 33·6)	40·1 (35·7, 44·6)	60·0 (2·6, 117·5)	33·0 (25·8, 40·2)
Adrenaline*	3·4 (2·9, 3·9)	3·5 (3·3, 3·7)	3·6 (2·8, 4·5)	3·8 (2·9, 4·7)
DHEA-S	108·0 (90·6, 125·4)	82·3 (76·5, 88·0)	66·5 (39·7, 93·4)	54·9 (41·4, 68·5)
HDL cholesterol	46·8 (43·4, 50·2)	42·5 (41·2, 43·9)	44·5 (36·9, 52·0)	39·9 (35·1, 44·6)
Females	*n*=47	*n*=371	*n*=33	*n*=20
Systolic BP	146·6 (141·3, 152·0)	137·9 (136·0, 139·9)	138·1 (131·3, 144·9)	135·7 (125·1, 146·4)
Diastolic BP	83·1 (80·0, 86·3)	76·4 (75·4, 77·4)	78·2 (74·0, 82·3)	75·7 (70·5, 81·0)
Waist–hip ratio	0·87 (0·85, 0·89)	0·84 (0·83, 0·85)	0·85 (0·82, 0·88)	0·87 (0·84, 0·90)
Total cholesterol/HDL ratio	4·5 (4·2, 4·8)	4·8 (4·7, 5·0)	4·8 (4·3, 5·4)	4·7 (4·0, 5·4)
Total glycosylated haemoglobin	6·5 (6·1, 6·9)	6·8 (6·6, 7·0)	7·5 (6·6, 8·3)	6·9 (6·4, 7·5)
Cortisol*	25·9 (21·6, 30·2)	23·1 (21·5, 24·8)	29·9 (11·6, 48·3)	22·9 (14·9, 30·9)
Noradrenaline*	35·7 (28·9, 42·5)	42·4 (40·4, 44·4)	37·4 (31·2, 43·7)	45·2 (35·3, 55·1)
Adrenaline*	4·0 (3·4, 4·6)	4·4 (4·2, 4·7)	4·4 (3·5, 5·4)	4·9 (3·6, 6·2)
DHEA-S	69·8 (54·3, 85·3)	56·4 (52·7, 60·0)	47·3 (32·5, 62·0)	24·1 (14·7, 33·4)
HDL cholesterol	49·5 (46·4, 52·6)	52·2 (50·6, 53·8)	49·9 (43·3, 56·6)	51·0 (44·0, 58·0)

*Measured as μg/g creatinine from urine specimens.

Bivariate and multivariate associations among allostatic load, position in social hierarchies, extent of social network and challenge

The next section examines the relationship between allostatic load – the summary index of these biomarkers – and its association with social factors and exposure to challenging experience in Taiwan. Correlation coefficients among the variables are shown in Table 5. The relationship between allostatic load and position in social hierarchy is clear: the higher one's standing, the lower one's allostatic load. Of the four dimensions examined, education is the most highly correlated ($r = -0{\cdot}22$, $p = 0{\cdot}02$). Measures of the extent of the respondent's social activities are less correlated with allostatic load. Those who report chronically low levels of social interaction – who see friends less often than the median frequency or who engage in few social activites – have higher levels of allostatic load, but these correlations are not significant. The two dimensions of interaction with children – frequency of visits and co-residence – behave in different ways. There is a correlation of 0·15 ($p = 0{\cdot}13$) between allostatic load and co-residence with a child, but only a small and statistically indiscernible association between allostatic load and frequency of visits with non-co-resident children.

Exposure to challenge is clearly associated with allostatic load. The correlations show that for each measure, a higher level of exposure is associated with a higher level of allostatic load. Three of the measures (the extent of demands on the respondent, financial difficulties and whether the respondent was widowed between 1989 and 1997) are significantly correlated (at the 0·05 level) with allostatic load. However, because of the high correlation between financial difficulties and the demands placed on the respondent, only one of those two measures (and widowhood) is used in the regression analysis.

Ordinary least squares regression is used to assess the joint effects of education, the extent of demands placed on the respondent, and widowhood on allostatic load. The results are shown in Table 6. Overall the model accounts for just over 12% of the variation in allostatic load in the Taiwan sample. All three factors that have significant (bivariate) correlations are significant in the multivariate model. For the respondents in the sample, being widowed since the start of the study and having high demands placed on them are associated with higher levels of allostatic load, while higher education is associated with lower allostatic load.

Discussion

These analyses show that overall, average levels of the components of allostatic load – a measure of risk that captures cumulative wear-and-tear on physiological systems – are similar for elderly samples in both the United States and Taiwan. Allostatic load is related in expected ways to position in social hierarchies, to the extent of one's social network, and to exposure to challenge. The results show that position in the social hierarchy, measured along four dimensions (income, education, sex and occupational status), was inversely correlated with allostatic load: the higher one's position, the lower the allostatic load. The extent of one's social connections (visits with friends and children and engagement in social activities) was inversely

Table 5. Bivariate associations among allostatic load and measures of social hierarchy, connection and challenge: Pearson correlation coefficients (significance level shown in parentheses)

Variable		Measures of position in social hierarchies				Measures of social connection				Measures of challenge			
	Allostatic load	Income	Educ.	Occup.	Female	See friends	Visit child	Co-resident child	Social activities	Poor health	Demands	Finance	Widowed 1989–97
Income	−0·12* (0·25)												
Education	−0·22* (0·02)	0·49 (0·00)											
Occupation	−0·25* (0·01)	0·41 (0·00)	0·62 (0·00)										
Female	0·10† (0·34)	−0·33 (0·00)	−0·42 (0·00)	−0·33 (0·00)									
See friends	0·09† (0·36)	−0·20 (0·05)	−0·07 (0·47)	−0·04 (0·70)	−0·06 (0·54)								
Visit child	−0·04* (0·66)	−0·03 (0·80)	−0·18 (0·07)	−0·23 (0·02)	0·16 (0·11)	0·00 (1·00)							
Co-resident child	0·15? (0·13)	−0·07 (0·49)	−0·23 (0·02)	−0·17 (0·08)	−0·02 (0·87)	0·05 (0·60)	−0·01 (0·91)						
Social activities	0·15† (0·14)	−0·25 (0·01)	−0·36 (0·00)	−0·30 (0·00)	0·16 (0·11)	0·14 (0·17)	−0·04 (0·68)	0·04 (0·71)					
Poor health of spouse	0·16† (0·10)	−0·26 (0·01)	−0·17 (0·09)	−0·05 (0·60)	0·05 (0·65)	0·25 (0·01)	−0·04 (0·70)	0·07 (0·48)	0·18 (0·07)				
Demands	0·21† (0·04)	0·09 (0·39)	−0·11 (0·26)	0·00 (0·94)	−0·08 (0·45)	0·21 (0·04)	−0·20 (0·05)	0·05 (0·61)	−0·01 (0·90)	0·09 (0·38)			
Finance	0·21† (0·05)	−0·33 (0·00)	−0·24 (0·02)	−0·18 (0·09)	0·03 (0·77)	0·32 (0·00)	−0·10 (0·35)	0·17 (0·09)	0·19 (0·07)	0·30 (0·00)	0·22 (0·03)		
Widowed 1989–97	0·24† (0·02)	−0·15 (0·14)	−0·12 (0·24)	−0·08 (0·46)	0·03 (0·78)	0·02 (0·81)	−0·12 (0·23)	0·02 (0·85)	−0·02 (0·85)	0·13 (0·20)	0·09 (0·40)	0·03 (0·76)	
Child died 1989–96	0·04† (0·68)	−0·06 (0·53)	−0·20 (0·04)	−0·22 (0·03)	0·14 (0·18)	−0·01 (0·94)	0·17 (0·09)	0·14 (0·16)	0·11 (0·29)	0·05 (0·65)	−0·09 (0·37)	0·13 (0·22)	0·09 (0·37)

*Expected direction of relationship with allostatic load is negative.
†Expected direction of relationship with allostatic load is positive.
?No hypothesized direction for the relationship with allostatic load.

Table 6. Estimated coefficients and standard errors from ordinary least squares regression of allostatic load on indicators of position in social hierarchies and challenge

Characteristic	*B* (SEM)	*p**
Education	− 0·061 (0·034)	0·04
Demands placed on respondent	0·601 (0·338)	0·04
Respondent widowed 1989–97	0·866 (0·421)	0·02
(Constant)	2·775	

R^2=0·12; N=98; $F_{3,94}$=4·35 (p<0·01); σ(estimated)=1·44.
**p*-values based on a one-tailed test.

associated with allostatic load: the greater the extent of the respondent's connections and activities, the lower the allostatic load. Co-residence with children, on the other hand, was positively associated with allostatic load, suggesting that tensions between the respondents and their adult children might be a factor, or alternatively, that parents with health problems are more likely to co-reside with children. Exposure to stressful life events and chronic stressors was also associated with increased allostatic load in the Taiwan sample. Having a spouse in poor health, having high demands placed on oneself, having chronic financial difficulties, and being widowed were all positively related to higher allostatic load.

These findings are consistent with an earlier study (Beckett *et al.*, 2002), which explored factors that explain declines in health (or death) between 1993 and 1996 in the Taiwanese population from which the pilot study was drawn. In particular, that analysis (1) found a graded negative relationship between position in the social hierarchy and the probability of health decline, and (2) confirmed the importance of life events, such as losses of important social ties, and chronic strains for health deterioration. The findings in this paper are consistent with data from two studies of populations in the United States: The Wisconsin Longitudinal Study (Singer & Ryff, 1999), as well as recently reported findings from the MacArthur Studies of Successful Aging (Seeman *et al.*, 2002).

The analyses provide some insight into the intermediate biological pathways through which social factors and exposure operate to affect health outcomes. They provide strong and statistically significant evidence of links between position in social hierarchies (education) and exposure to challenge (being widowed in the previous 8 years and high levels of perceived demands) with risk factors known to be associated with adverse health consequences. Although none of the measures of the respondent's social network that were examined had a statistically discernible effect on the index of risk factors, all were associated in predictable ways.

Because of the small sample size, and because many of the explanatory factors are interrelated, the power of the analyses is constrained. For example, it is not possible to examine interactions with sex, or examine whether position in the social hierarchy mediates the consequences of poor social support or high exposure to challenge. Data from the larger study, which was fielded in 2000–2001, will provide the power to address these questions with greater precision in the future.

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